Journal of King Saud University – Engineering Sciences xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original article

Implementation and analysis of the clustering process in the enhancement of manufacturing productivity

Satbir Singh *, Sandeep Singhal

Mechanical Engineering Department, NIT Kurukshetra, Haryana, India

ARTICLE INFO

Article history:
Received 3 August 2019
Accepted 13 June 2020
Available online xxxx

Keywords:
Clustering
Productivity improvement
Cycle time
Manufacturing cost
Statistical analysis

ABSTRACT

The instant paper offers the features, analysis, and comparisons of industrial productivity. The work done is the pioneering endeavor to review the factors needed for the improvement of productivity in the typical Indian manufacturing sector. The proposed approach finds an alternative way-out to engage the material and workforce sources accessible in the plant, to contribute to the improvement of production and, subsequently, the productivity of the manufactory. The authors recommended the execution of the clustering technique with sequenced tooling to cultivate higher productivity. The proposed study put together the managers to examine materials and methods for applying the available resources efficaciously for productivity perfection. The suggested approach turns into implemented through raising the monthly production and reducing part manufacturing cost via decreasing production cycle time by way of targeting the unproductive setting as well as tool changing time. The executed research superbly added to the betterment of production and consequent productivity. The experimentation revealed a comparable gain in total productivity of above 13%.

1. Introduction

Productivity implies replication of overall survey cultivating the transition of the resources viz. material & labor pool into needful services, moreover intended goods in an establishment or company. Accelerated production could firmly manage economic growth with tremendous productiveness in the Indian manufacturing sector (IMS). Productivity has emerged globally as the phrase described above as everyone recognizes its meaning. The confusion seldom arises regarding the sense as productivity has both professional and managerial concepts. Humans prefer productivity in the tone of production measures, scales of turnover, as a measure of customer conciliation, workflow, and in the form of intangibles reflected as morale, commitment, and work complacency. Productivity gains whenever the same production is conceded with smaller efforts, i.e., getting better this time than previously done. The overall productivity represents the fraction of the total output to whole resource input (ILO). Productivity incessantly reconciles economic and social life to changing circumstances and requirements (EPC). Productivity keeps essential equilibrium among the independent aspects of production activity, which concludes in a final output with the least effort (Peter Drucker).

The vital goal of the current research is to implement an analysis-based approach to authenticate how instantly product quality, and productivity, maybe improved through alleviating waste, in the production of essential parts if helpful resources in the plant are engaged accurately and elegantly. While developing a problem for prevailing practice, the primary step to being taken care of is to understand the current manufacturing process thoroughly. Executing the required operational activities on multiple machines to produce the crucial parts by way of implementing the traditional manufacturing strategies uses added time and needs excess labor charges. Such production tactics require

Abbreviations: IMS, Indian manufacturing sector; ILO, International labor organization; EPC, European productivity council; TFP, Total factor productivity; GHG, Green house gas; HMC, Horizontal machining center; VMC, Vertical machining center; WIP, Work in process; UCLP, Upper limit of control for p-chart; LCLP, Lower limit of control for p-chart; CL, Centerline; SD, Standard deviation; HSS, High speed steel; TCT, Tool changing time.

* Corresponding author.
E-mail addresses: satbirsingh2k12@gmail.com (S. Singh), Sandeep_singhal_reck@rediffmail.com (S. Singhal).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.jksues.2020.06.005
1018-3639/

Please cite this article as: S. Singh and S. Singhal, Implementation and analysis of the clustering process in the enhancement of manufacturing productivity, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2020.06.005

enormous space, additional expenses for handling the materials, abundant freighting plus delivery cost, and massive tooling expenditures. Resultantly, while the cost of production enormously increases, productivity goes extensively declined. The global business inclination nowadays speedily changing with the fast technological modifications. In the contemporary scenario, the firm's benefit is growing marginal while the competition is becoming rigorous. Production industries need not only to come out of such a severe condition rather have to achieve a rapid pace of development. The primary aim of manufacturing today is to control component manufacture cost by reducing cycle time for contributing to productivity enrichment.

Manufacturing worldwide needs to be revamped by applying new production tactics such as **clustering**, i.e., executing a group of production operations in a standard working plane on the machine table using a single developed setup, to explore a reduction in setting time. Tool changing time requires being curbed through employing **sequenced tooling** that is adequate to carry out more operations without changing the setting of the workpiece & cutting tool, hence offering a considerable reduction in cycle time. Such carbide combination/sequenced tools sustain extreme temperature and maintain their cutting points for an analogously prolonged duration without any need of grinding, by dint of excellent properties of red hardness, and wear-resistance.

The present research practice was carried out as a case study at the automobile components production unit with a target to produce quality auto parts with intricate shapes as well as critical geometrical tolerances.

2. Literature review

Appraisal and improvement of productivity received valuable awareness in the present scenario. However, the restricted quantum of research converged so far towards productivity optimization. To prepare productivity plans assumed to be a strenuous exercise because of constraints imposed via extraordinary production heterogeneity. Several investigators centered their studies on improvement and analysis of productivity. Still, extensive analysis needs to be done to update the relevant sources by implementing new production techniques.

The principal obstacle for instant research was to conclude an initializing point of inspection, consuming comparatively less flow time. Consequently, the analysis reviewed and explored viable alternatives intended to achieve the goal by applying motion and time study tools (Al-Saleh, 2011). Findings show that conventional economic standards cannot decide enterprise progress. The outcomes suggested a significant collection of key performance indicators in cultivating a nationwide benchmarking method to improve the construction industry's effectiveness in the Saudi Arabia dynasty (Ali et al., 2013). Findings settled cost management, scheduling, layout designing, originality check, and human resources development as of vital purposes consistently predicted for ages as determinants for cultivating productiveness (Arditi and Mochtar, 2000). A higher rate of industrial turnover could contribute to the betterment of productivity by way of exchanging resources from a skilled to a semi-skilled producer (Aw et al., 2001). The proposed study of 46 manufacturing units confirmed that the union formulates an adverse impression on crucial determinants, like productivity & labor/management relationships, by reducing the effectiveness of managerial practices carried out to amplify productivity (Bemmels, 1987). Cell production facilitates tactics to cultivate manufacturing productivity (Cheng et al., 1995). An authentic sampling of Indian production enterprises from1999 to 2006 appraised the consequences of stimulus reimbursement strategies on productivity. Assigning higher reward to officials and mechanics vitally affect the productivity corresponding to the evaluation performed for the production industries in India (Chun and Lee, 2015). Productivity has improved through perpetually optimizing processing variables. Cycle time reduction resulted in adequate improvements (Dangayach and Guglani, 2015). The implemented research assessed TFP growth for the production units of different states in India (Dash et al., 2010). The article outlines the prevailing condition of the market and production methods, including the selection of advanced manufacturing technologies to be adopted in Saudi production industries (El-Tamimi, 2010). Out of different criteria employed to assess the effectiveness of the system, simulation methods are accessible to examine the multiple flexible manufacturing systems (El-Tamimi et al., 2012). Countries exceedingly relying on developing technological manufacturing toward the ensuing budgetary time enjoyed exceptional productivity increase (Fagerberg, 2000). It's far hard to explain the factors holding the productivity change for different organizations and viewpoints recommending higher productivity (Fernandes, 2008).

The implemented studies revealed that labor productivity excellence alters by fixed capital assets along with the TFP. Tactics accruing expert skills are required for developing nations to rely on professional growth and grave pursuit (Filippetti and Peyrache, 2017). The analysis consistently presents inherent productivity differences for diverse industries due to differing turnover indicating the exit of less yielding enterprises, whereas continuance for contributing sectors. The firm's turnover substantially grew aggregate productivity. (Gebreeyesus, 2008). The article aims to exhibit the notion of productivity and techniques of productivity growth. Effectively practicing the expertise in production processes can substantially enhance performance and productiveness (Gidwani and Dangayach, 2017).

Studies conducted in the 1990s signified productivity improvement in Indian industries due to import liberalization adversely effected by the underuse of valuable resources (Goldar and Kumari, 2003). Plants comprising moderate export severity intensified the productiveness through material redistribution (Görg and Hanley, 2005). The auto industries are facing harsh contest and endeavoring to devise ways to curtail production cost and waste arising therein. Executing the lean production strategy within semi-processed stock decreased the stimulation of manufacturing operation; as a consequence of employing the machinery and workforce sources accurately & skillfully, productivity was raised (Hemanand et al., 2012). Extraneous enterprises conceded raised productivity as compared to domestic counterparts (Huang and Yang, 2016). The article illustrates the employment of Maynard operations sequencing technique by way of a case study for methods development to promote labor productivity at the plant producing bath accessories (Jain et al., 2016). The most fruitful and efficient alternative for increasing productivity is to promote a professional level that is viable with effective management (Kao et al., 1995). Lead time, costs incurred, output, and joint allotment of the resources employed as the criterion for continued evaluation of required enrichments in manufacturing productivity (King, 1989). The work-in-process inventory reduction expedited improvements in productivity (Lieberman and Demeester, 1999). Manufacturing productivity may be improved by eliminating wastefulness in the conversion methods by enhancing the movement of material or decreasing variability in the industry (Milind, 2018). The paper recognizes the challenge of united workers for assembly line workstations with a motive to reduce the total production time (Moussavi et al., 2017). Through implementing lean tools setting as well as downtime decreased, resulting in an appreciable reduction of overall cycle time and fulfilling the consumer needs timely (Nallusamy and Saravanan, 2016). The findings showed an improvement of 1.02 in the optimized yearly inventory turnover ratio through implementing ABC analysis (Nallusamy et al., 2017). The significant benefit of commerce and trade openness was to grow the productivity of homely segments (Nataraj, 2011). The article investigates the significance of greenhouse gas emanations towards commercial achievement for the company's management. The outcomes of production industries in Japan for 2007–08, contributed to the financial growth and productivity betterment through regulating the plant's GHG outflows (Nishitani et al., 2014). Outcomes exhibit a moderate increase in watering productivity on average basis for almost all of the states. Advanced technologies, plus input power, have been the propulsive force for the stated improvement (Njuki and Bravo-Ureta, 2019). In dry rainfed fields, supplemental irrigation (SI) is the nurturing technique that substantially raises productivity by enhancing the farming yield (Oweis and Hachum, 2006). Results of enhancing machining performance, altering requirements, and employing diverse loading strategies have provided a quantifiable gadget to factory administrators moreover engineers for growing system productivity (Park and Li, 2019). Water productivity increased by reducing water flooding and growing yield by implementing revised plans for irrigation (Playán and Mateos, 2006). Productivity enhancement is exceedingly stimulated by promoting changes in electronic attainment (Rai et al., 2006). The data-based global review of aggregate labor productivity unveils average labor productivity for agriculture. Such productivity includes a significant industrial contribution primarily involved in limited overall productivity toward underdeveloped nations (Restuccia et al., 2008). Productivity improvement is middling before the impasse and fits in post-disaster owing to improve trade achievement (Rhee and Pyo, 2010). With reduced expected cyclic-duration to manufacture the equipment and components, productivity growth expedited to identify several wastes in different manufacturing levels (Saleeshya and Bhadran, 2015). The conclusions present foreign corporations as more yielding; though, less helpful than indigenous companies. Productivity declines, but fulfillment accelerates with growing external constraints (Sari et al., 2016). Productivity may be improved via a reduction in the cyclic time and statistical control of the process (Sheth and Sisodia, 2002). Data-based empirical results from the plant floor of the food-producing industries in Colombia for the year 1982 to1998 exhibited productivity enhancement not merely due to advanced technology and facility but most suitably by dint of essential learning influence (Shee and Stefanou, 2016). The experimentation revealed that by applying suggested processes along with advanced tools, month-to-month manufacturing raised by above 16% by way of using the reduced cyclic time (Singh and Singhal, 2016).

The authors suggested implementing clustering with advanced unconventional tooling to manufacture the vital component. The proposed method accelerated productivity by fulfilling the excellent manufacturing concepts, which led to lowered monthly rejections emerging out therein, as well as reduction of cycle time (Singh and Singhal, 2018a, 2018b). The resources allocation and working out of established sources perform a vital task in an organization to enrich the quality and productivity. The research evaluates the methodology to cultivate productivity at the enterprise level (Sivakumar and Saravanan, 2011). Reduced water reserves can raise water productivity. Because of the semi-skilled workforce with almost average skill level in Singapore, the manufacturing industries partially contributed to TFP growth (Tsao, 1985). The article differentiates the manufacturing quarters in France and the UK on a working hour basis. The comprehensive study illustrated better manufacturing productivity in France compared with the UK (Van Ark, 1990). The objective of the article is to examine and enhance the productivity of a chosen enterprise regularly involved in paint production, implementing productivity enrichment strategies (Zahraee et al., 2018).

Consequent to an assessment of the existing review, productivity becomes relevant to fulfill an essential function in the manufacturing arena. Best of the analysts partially improved productivity, which reveals a research gap; however, a real necessity of time is to enhance general productiveness, i.e., umbrella productivity. As productivity straightway reshapes the production expenses, the instant article has the novelty to cultivate overall productivity, incorporating areas like machine-labor-capital and materials without agreeing on characteristics, missions, purposes, and protection. Implementing the proposed novel production technique, the available assets within the organization got optimized.

Maximum algorithmic approaches used by authors considered an only single-objective function. Researchers focused merely on issues like reducing flow distance to minimize the material managing & handling cost, and consequently part production cost, which again reflects a gap. The ongoing paper fulfills multi-objectives viz. curtailing the cost of labor, material managing plus shipping cost, cycle time, space requirement, and the machines needed to perform the required manufacturing operations, which substantially reduced component manufacturing cost.

3. Materials and methods

To work out the above-developed problem for current practice, the earliest examine conducted to comprehend the ongoing production process entirely. Company management endeavored towards employing valuable assets to improve productiveness by restricting the duration of the production cycle for essential elements. The manufacturing got stimulated by actively hiring the vital resources and guaranteeing rapid loading–unloading of the components during their manufacture by providing adequate workpiece holding devices, i.e., fixtures. Month to month production of significant components improved. At the same time, the monthly rejections decreased by the manufacturing division of the company due to the usage of developed fixtures in fulfilling the proposed process. Specially developed cutting tools used to curtail unproductive factors, such as setting and tool changing time. Resultantly component manufacturing cost reduced.

Technique used

The proposed clustering process with advanced carbide sequenced tools, employed to fulfill the new production technique. Engaging developed extendable setup for exclusively furnished HMC & VMC, some of the operations explicitly carried out in a shared plane without changing the setting of the workpiece. As the clamped part on CNC machine table has up-down, longitudinal–transverse, and rotational movement, more operations could have been executed in clustering on the same setup. Specially developed combination tooling used for sequenced operational activities like drilling-drilling, i.e., step drilling and tapping-tapping, i.e., double-tapping to convert rough casting of the vital component into the finished part. Such tools perform different activities in the same setting to reduce the downtime, i.e., setting and tool changing time. The methodology further comprises a statistical comparison of data collected for the monthly part production with the corresponding defectives arising therein at the plant floor while using the existing and proposed manufacturing process. P-Chart used as a statistical tool to observe the variations in production attributes. The elemental chart shown in Fig. 1, underlines the growing procedural steps needed to settle the earlier formulated problem, assuring a practical utility of available resources and the betterment of production and subsequent productivity.

Please cite this article as: S. Singh and S. Singhal, Implementation and analysis of the clustering process in the enhancement of manufacturing productivity, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2020.06.005

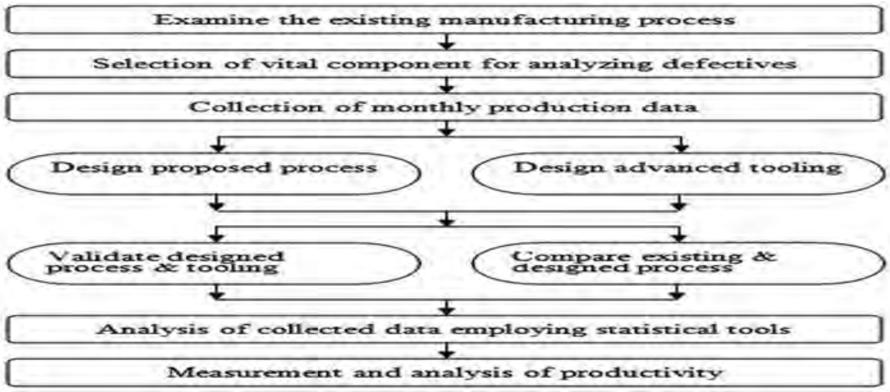

Fig. 1. Elemental chart for the recommended methodology.

3.1. Examine the existing manufacturing process

An essential element of the automotive parts manufactured by the industry, namely top cover (inner side) is exhibited in Fig. 2.

For manufacturing, the above-stated part, the existing process, time appropriated to carry-out needed actions on related machine tools, hourly machining rate, helper cost, material managing/freighting charges and component manufacture cost illustrated in the existing activities duration chart in the aspect of Table 1.

The following mandatory presumptions explored in preparing the said activities duration chart, i.e., the above table.

- Machine running costs were assessed by multiplying hourly rate with time expended on the particular machine to execute diverse activities anticipated to manufacture the stated part.
- The hour rate for separate machines listed in Table 1 comprises of machine's buying cost, the total of interest, wages accrued for operator & helper, power consumption charges, tooling costs, depreciation cost, and regulatory investments.
- Summation of entire cost elements in the above table constitutes the part manufacturing cost.
- The costs acquired for handling & transporting the material resolved as Rs1.00/-for sizable move, and Rs 0.50 set for a comparably smaller move.
- The hourly helper/attendant rate fixed at Rs 20/-.

3.2. Data collected

Monthly production data with corresponding rejections about the vital component collected from the industry's shop floor for 18 months, i.e., March 2014 to Nov. 2014, using the existing manufacturing process and Jan 2015 to Sep 2015, employing proposed production process.The monthly collected production/rejection data entered in underneath Tables 2 and 4, respectively.

The monthly prevailing partial productivity evaluated for aspects like labor-machines-capitals, materials, and overall productivity using monthly production/rejection data collected for manufacturing the significant element displayed in Table 2. The assessed productivities based on component material & selling price informed by the record division of the enterprise, as well as the prevailing manufacturing cost of the component referred from the Table 1, employing an existing manufacturing process are presented in Table 2.

Fig. 2. Top cover (inner side).

Component/part selling price (□): 500 = 00
Component/part material cost (□): 250 = 00
Component/part manufacturing cost (□): 221 = 00

3.3. Steps to calculate monthly productivity

1. Monthly revenue from production = monthly (production-rejection) × component selling price
2. Monthly material cost = monthly production × material cost per component
3. Monthly labors, capitals & machining cost = monthly production × component manufacturing cost
4. Monthly material productivity = monthly revenue/ monthly material cost
5. Monthly labors, capitals & machining productivity = monthly revenue/ monthly labors, capitals & machining cost
6. Monthly total productivity = monthly revenue/ monthly [material + (labors, capitals, and machining)] cost

3.4. Design of the recommended process and tooling

For verification of the above-suggested methodology, the following fundamental aspects are thoroughly acknowledged to reduce cycle time and month-to-month rejections in the production of the vital component and contribute to the productivity betterment and reduction of component manufacturing cost.

- Ensuring excellent rigidity by utilizing decreased quantum of set-ups on HMC and VMC results in a reduced error.
- Reliable supports, firm holding with secured clamping for the work-in-process (WIP) on the horizontal and vertical milling center, ensured by way of developing an expandable set-up.
- Reducing cycle time by carrying out part of activities using the said developed set-up by means of implementing the clustering principle.
- Curtailing tool changing time and consequently tooling cost through employing advanced tooling, viz. carbide combination/sequenced tools incorporating associated drilling-drilling-tapping-tapping tools.
- Concentricity is conveniently attained by perfectly annihilating the out of the running of the machine spindle by employing sequenced tools. Accurately drilling-drilling-tapping-tapping,

Table 1
Activities duration chart using the prevailing procedure.

Op. No.	Activity/operation description	Machines Employed	Avg. cycle time (min)	M/c Hour Rate (Rs)	Component cost (Rs)	Cost of Shipping
1	Initially inspecting the castings to trace defects i.e. visual check up and perform test for leakage in the main component	Manual	5.0	nil	3.5	7.0
2	Boss mill (4no.) and dimensions maintained as $14.50^{\pm 0.5}$	VMC	3.0	350/-	17.5	nil
3	Hole reaming (4 no.) applying taper reamer (beginning from size Ø 8.0 mm)	Manual	nil	nil	4.5	nil
4	Roughly mill 4 internal pads and upper facing with allowance 0.20 mm, mill facing to achieve size Ø16H9 &22 ± 0.05, milling sides bosses keeping size $14.3^{+0.2}$ & 66.0, Roughing bore 16H9 to 15.7 & chamfering 30° to achieve entry size Ø20, Drilling 2 holes size 6.8 to M8, 16 mm deep, top face drilling Ø9.2 four nos. Prepare three holes size $84^{\pm 0.05}$ & $94^{\pm 0.05}$; finishing bore Ø16H9 thro and four dowels Ø8H9 & 8H8 two each, Tapping two holes M8x1.25, drilling two holes dia4.5, 13 mm deep.	VMC	11.4	350/-	66.5	nil
5	Roughing dia22H9 to 21.5 through, Predrilling Ø12.5 for Ø13H9, maintain size 68.5 away dowel centre, finishing 22H9 hole, face milling hole M10 keeping $44.5^{\pm 0.1}$ from 22H9 hole centre. Predrilling Ø8.5 finish to M10x1.5, 8 mm deep, drilling 6.8hole through for 8H9, Reaming the same to 7.8, finishing to 8H9, &tapping to M10x1.5, 8 mm deep. Face milling bosses to sizes $50^{\pm 0.1}$&$47^{\pm 0.1}$ for holes M18 and M14 apart from bored hole $22H^9$, Predrilling Ø12 to tap M14x2 & Ø16.5 to tapM18x1.5.	HMC	10.0	480/-	80.0	nil
6	Applying milling cutter Ø63, spot facing holes 16H9, 5H7 & 6.11H11. Prepare bore 15out of 13H9, drilling four holes Ø9.2, through hole Ø4.0, and Ø6.11H11 & chamfering 60°, partly finishing Ø4.8 bore, ream the same to Ø5H7, 26 mm deep.	VMC	6.0	350/-	35	nil
7	Etching vendor's code on the manufactured element	Manual	2.0	nil	3.0	nil
8	Final Inspection	Manual	5.0	nil	4.0	nil

Table 2
Labor-machine-capitals, material, and overall productivity for existing process.

Months of year 2014	Monthly production	Monthly rejection	Monthly revenue from production (□) [x]	Monthly material cost (□) [y]	Monthly labours, capitals & machining cost (□), [z]	Monthly material productivity [x/y]	Monthly labour, capital and machine productivity [x/z]	Monthly total/ overall productivity [x/(y + z)]
March	1030	47	491,500	257,500	227,630	1.9087	2.1592	1.0131
April	970	43	463,500	242,500	214,370	1.9113	2.1621	1.0145
May	1050	51	499,500	262,500	232,050	1.9028	2.1525	1.0100
June	860	39	410,500	215,000	190,060	1.9093	2.1598	1.0134
July	990	46	472,000	247,500	218,790	1.9070	2.1573	1.0122
Aug	1030	48	491,000	257,500	227,630	1.9067	2.1570	1.0121
Sep	980	45	467,500	245,000	216,580	1.9081	2.1585	1.0128
Oct	1035	49	493,000	258,750	228,735	1.9053	2.1553	1.0113
Nov	850	36	407,000	212,500	187,850	1.9153	2.1666	1.0166

i.e., step drilling and double-tapping of the required holes into a solid casting using a single set up higher accuracy obtained on manufactured parts, which results in lesser defectives.

3.5. Validate the designed process and tooling

Fig. 3 shows the vital component clamped in the developed fixture mounted on the HMC table to execute some of the operational activities in clustering using proposed process.

Operations at serial number4 and six, as shown in Table 1, i.e., in activities duration chart using the prevailing procedure, are collectively executed in a single developed universal fixture on VMC. Replacing 3rd VMC from the production line has led to the economy of space. Decreased number of settings consequently promoted the reduction in cycle time and resultantly component manufacturing cost. Activity4 in underneath Table 3, i.e., in activities duration chart using the improved procedure, represents activities performed in clustering.

Fig. 3. Top cover (2-off) rigidly clamped in the developed fixture on HMC in operation.

Table 3
Activities duration chart using the improved procedure.

Op. No.	Activity/operation description	Machines Employed	Avg. cycle time (min)	M/c Hour Rate (Rs)	Component cost (Rs)	Cost of Shipping
1	Initially inspecting the castings to trace defects i.e. visual check up and perform test for leakage in the main component	Manual	5.0	nil	3.5	7.0
2	Mill 4 bosses by maintaining dimension 14.5 ± 0.5	VMC	3.0	350/-	17.5	nil
3	Ream 4 holes using taper reamer (beginning from size Ø8.0 mm)	Manual	nil	nil	4.5	nil
4	Roughly mill 4 internal pads and upper facing with allowance 0.20 mm, mill facing to achieve size Ø16H9 &22 ± 0.05, milling sides bosses keeping size $14.3^{+0.2}$ & 66.0, Roughing bore 16H9 to 15.7 & chamfering 30° to achieve entry size Ø20, Drilling 2 holes size 6.8 to M8, 16 mm deep, top face drilling Ø9.2 four nos. Prepare three holes size $84^{\pm0.05}$ & $94^{\pm0.05}$; finishing bore Ø16H9 thro and four dowels Ø8H9 & 8H8 two each, Tapping two holes M8x1.25, drilling two holes dia4.5, 13 mm deep. Applying milling cutter Ø63, spot facing holes 16H9, 5H7 & 6.11H11. Prepare bore 15 out of 13H9, drilling four holes Ø9.2, through hole Ø4.0,& Ø6.11H11 & chamfering 60°, partly finishing Ø4.8, ream the same to Ø5H7, 26 mm deep.	VMC	15.0	350/-	87.5	nil
5	Roughing dia22H9 to 21.5 through, Predrilling Ø12.5 for Ø13H9, maintain size 68.5 away dowel centre, finishing 22H9 hole, face milling hole M10 keeping $44.5^{\pm0.1}$ from 22H9 hole centre. Predrilling Ø8.5 finish to M10x1.5, 8 mm deep, drilling 6.8 hole through for 8H9, Reaming the same to 7.8, finishing to 8H9, &tapping to M10x1.5, 8 mm deep. Face milling bosses to sizes $50^{\pm0.1}$&$47^{\pm0.1}$ for holes M18 and M14 apart from bored hole $22H^{9}$, Predrilling Ø12 to tap M14x2 & Ø16.5 to tapM18x1.5.	HMC	6.0	480/-	48.0	nil
6	Etching 8285 on the prepared part as vending cryptograph and final inspection	Manual	7.0	nil	7.0	nil

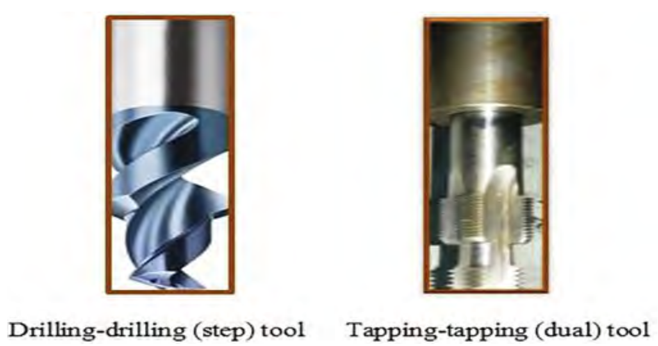

Fig. 4. Sequenced tools.

Cyclic time for producing the critical element, drastically decreased by engaging developed sequenced tooling on HMC to carry out the processing activity with serial number5, in Table 3. Necessary predrilling of the holes sizes Ø12 & Ø16.5 performed in the single setting of the cutting tool and the workpiece. Subsequently, in the following setting of the cutting tool viz. integrated dual tap and the workpiece, double-tapping of the step drilled holes to the sizes M14x2 &M18x1.5 is completed, arising equivalent gain in a month to month basis production including consequent productivity. A set of such multiple tools shown in Fig. 4.

Monthly assessment of partial productivity, in the forms like labor-machine-capitals, material, & overall productivity using monthly production/rejection data about the vital component, applying the under given reduced component manufacturing cost referred from Table 3 as an outcome of the implemented process, is exhibited in Table 4.

Component selling price (□): 500 = 00
Materials cost per component (□): 250 = 00
Component manufacturing cost (□):175 = 00

4. Statistical analysis

Monthly basis data related to production and proportionate rejections for the vital parts collected for the time exceeding a year through implementing the existing and the recommended production processes was statistically analyzed. Monthly variation in production and the defectives, viz. rejection arising out there in the manufacturing of the required components assessed. The real status of the produced parts monitored and examined by statistical techniques, i.e., exercising the acceptance sampling (inspecting each 5th part) through "GO/NO GO" indicators. As analytical methods are tremendously important among different strategies for controlling the component quality, P-CHART, engaged as the analytic gadget for statistical analysis. Holding month to month production as the statistical sample with N number of elements as the sample size to ensure higher consistency in statistical attributes, and n as the number of faulty (defective) components as exhibited in Table 5. The statistical variation of the present & revised procedure obtained by using the following relations, where:

$$\text{Month to month fractional defectives (faulty components)},\ P = n/N \quad (1)$$

$$\text{Centerline recorded as CL or } \bar{p} = \sum \frac{n}{N} \quad (2)$$

$$\text{Standard Deviation(SD) for P} - \text{chart } \sigma = \sqrt{\frac{\bar{p}(1-\bar{p})}{N}} \quad (3)$$

$$\text{Higher Limit of Control (UCLP) for P} - \text{chart} = \left\{\bar{p} + 3\sigma\right\} \quad (4)$$

$$\text{Lower Limit of Control (LCLP) for P-chart} = \left\{\bar{p} - 3\sigma\right\} \quad (5)$$

Table 5 illustrates required statistical variation in the form of analytical characteristics to prepare statistically controlled P-chart by utilizing prevailing and improved trend of production with similar rejections regarding the main part on a month-to-month basis for stipulated time, i.e., March 2014–November 2014 and from January 2015–September 2015.

For evaluation of the existing and designed methods, fractional defectives from the diverse sizes of samples were used, in the P-chart. An axis perpendicular to the ordinate of the chart, exhibiting fraction defective as 0.0460 in Fig. 5, outlines the middle axis for the map, abbreviated as CL.

The graph presented in Fig. 5 presumes that samples correspond to second, third, and ninth trilateral marks settling far off the middle line, CL, as compared to identical marks presenting fractional defectives in p-chart for the suggested process. The

Table 4
Labor-machine-capitals, material and overall productivity for improved process

Months of Year 2015	Monthly production	Monthly rejection	Monthly revenue from production (□) [x]	Monthly material cost (□), [y]	Monthly labor, capital & machining cost (□), [z]	Monthly material productivity [x/y]	Monthly labor, capital & machine productivity [x/z]	Monthly total/ overall productivity [x/(y + z)]
Jan	1180	26	577,000	295,000	206,500	1.9559	2.7942	1.1505
Feb	1120	25	547,500	280,000	196,000	1.9553	2.7933	1.1502
March	1200	26	587,000	300,000	210,000	1.9566	2.7952	1.1509
April	980	22	479,000	245,000	171,500	1.9551	2.7930	1.1500
May	1130	24	553,000	282,500	197,750	1.9575	2.7964	1.1514
June	1165	25	570,000	291,250	203,850	1.9570	2.7961	1.1512
July	1120	23	548,500	280,000	196,000	1.9589	2.7984	1.1523
Aug	1190	26	582,000	297,500	208,250	1.9563	2.7947	1.1507
Sep	960	21	469,500	240,000	168,000	1.9562	2.7946	1.1507

Table 5
Existing and improved analytical characteristics for statistically controlled chart.

Existing process						Improved process					
Month of Year 2014	Size of the Sample (N)	Defective Parts (n)	Fraction Defectives (P)	UCLP ($\bar{p}+3\sigma$)	LCLP ($\bar{p}-3\sigma$)	Months of Year 2015	Sizes of the Samples (N)	Defective Parts (n)	Fraction Defectives (P)	UCLP ($\bar{p}+3\sigma$)	LCLP ($\bar{p}-3\sigma$)
March	1030	47	0.0456	0.0655	0.0264	January	1180	26	0.0220	0.0344	0.0089
April	970	43	0.0443	0.0661	0.0258	February	1120	25	0.0223	0.0347	0.0086
May	1050	51	0.0486	0.0653	0.0266	March	1200	26	0.0216	0.0343	0.0090
June	860	39	0.0453	0.0674	0.0245	April	980	22	0.0224	0.0356	0.0077
July	990	46	0.0464	0.0659	0.0260	May	1130	24	0.0212	0.0347	0.0087
August	1030	48	0.0466	0.0655	0.0264	June	1165	25	0.0214	0.0345	0.0088
September	980	45	0.0459	0.0660	0.0259	July	1120	23	0.0205	0.0347	0.0086
October	1035	49	0.0473	0.0655	0.0264	August	1190	26	0.0218	0.0343	0.0090
November	850	36	0.0423	0.0675	0.0244	September	960	21	0.0219	0.0358	0.0075

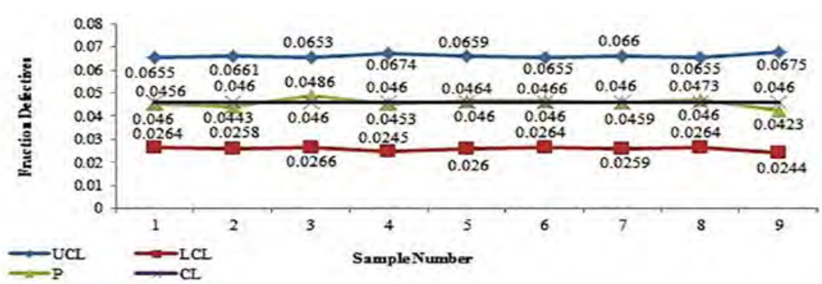

Fig. 5. P-chart using prevailing fraction defectives.

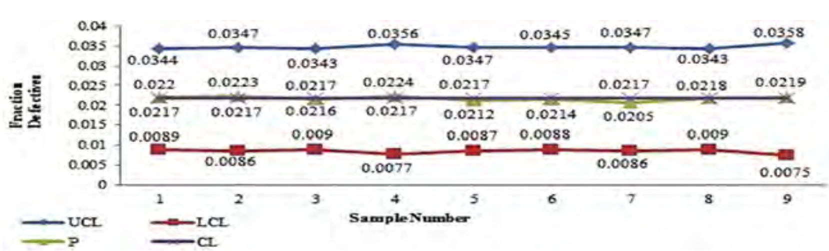

Fig. 6. P-chart using improved fraction defectives.

triangular marks for the fraction defectives in the improved control chart, i.e., in Fig. 6 tumble quite near to centerline; CL.

Analysis of charts indicates better statistical behavior for the designed manufacturing process. The illustration of graphs for the existing and enhanced methods proved a reduced variation in the month to month basis fraction defectives (faulty components) for the implemented process.

5. Results and discussion

As a consequence of the implied research and evaluation, the industry introduced post-manufacture analysis & measurement of each 10th part instead of every 5th because of achieving superior surface accuracy on completed parts. Due to the implementation of such a practice, inspection and quality control costs got

Please cite this article as: S. Singh and S. Singhal, Implementation and analysis of the clustering process in the enhancement of manufacturing productivity, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2020.06.005

considerably decreased. Employing designed clustering technique, by way of engaging the developed setup, namely, a universal fixture along with sequenced tooling, cyclic time of manufacturing the vital element now measured as 36.0 min, as illustrated in Table 3, alternatively of prior 42.4 min as in Table 1. Resultantly month to month basis production of the essential component exceedingly improved via above 15%, simultaneously component manufacturing cost exceptionally declined by over 20% due to less machining and labor cost accrued because of reduced production cycle time. Utilizing advanced tooling on the HMC and VMC, closer limits of dimensional tolerance are readily achievable.

Consequently tolerance limit of ±20 μm, incomparably smaller than the prevailing threshold of ±50 μm promptly received on produced elements, thus emerging minor defects therein, i.e., the rejection reduced down to 2%, initially which was around 4%. Interchanging carbide sequenced tools for high-speed steel (HSS) tools on the HMC and VMC, the tooling expenditure becomes curtailed by more than 12%. An improvement of 2.53% registered for the average productivity of materials. It is evident from the comparison of Tables 2 and 4, respectively, that typical productiveness for labor-capitals-machines rose through 29.48% while the aggregate productivity on the average basis was improved by13.63%.

5.1. Implications

The accomplished study has improved the overall productiveness viz. holistic productivity of the plant. However, the literature surveyed has not proclaimed such before-mentioned growth in aggregate productivity besides improving partial productivity aspects like labor, capital, material, and machine independently. The findings of the undertaken study are tremendous for global heads of manufacturing organizations. The skill and abilities released from the execution of such recommendations are meaningful and deployable within related companies. Consequently, contribution might be significant for the whole body of knowledge and learning worldwide.

6. Conclusions

Through the implementation of the recommended clustering process and sequenced tooling, the number of needed machines reduced to three of four, which promoted the facilitation of the required space and funded capitals. Savings of approximately 6 min were achieved in cyclic time as an outgrowth of the proposed technique by reducing nonproductive time viz. setting as well as tool changing time (TCT). The improved method for intended work vitally added to the corporate administration by reducing the costs of component manufacturing from Rs221 to Rs175. Greater precision attained on the manufactured parts by dint of engaging a reduced number of setups in the proposed process. Carbide tooling increases tool life by way of remarkably retaining the superior cutting ability and accomplishing an added total of actions consecutively with a singular, pointed tip, which leads to a reduced tooling cost. Company profit instantly enhanced as an outcome of improved production with the corresponding drop in defectives.

Consequently, the labor, as well as material productivity, got appreciably increased, generating substantial incentives in the form of production bonuses to staff and resultantly growing career contentment, hence promoting the retainment of an experienced team. As the statistically controlled chart for the suggested process indicates a smaller variation of statistical characteristics, thus reveals sound statistical control for the recommended method. A substantiated increase of over 13% feasibly attained for the average total productivity.

The facility layout is barely controllable to introduce in such a multi-product industry, which could have possibly restricted the cycle time reduction. The execution of drives for improving production together with productivity by reducing different aspects of the cost gets obstructed by barriers of reduced availability of adaptive controlled CNC machines in the instant industry. Although the proposed process needs increased investment in developing clustering fixtures and sequenced tooling as compared with the existing process, the incurred expenditure comfortably counterbalanced due to increased production within a minimum possible time. The executed study can be implemented for other components manufactured in the industry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ali, H.A., E.M., Al-Sulaihi, I.A., Al-Gahtani, K.S., 2013. Indicators for measuring the performance of building construction companies in the Kingdom of Saudi Arabia. J. King Saud University-Eng. Sci. 25 (2), 125–134. Doi:10.1016/j.jksues.2012.03.002.

Al-Saleh, K.S., 2011. Productivity improvement of a motor vehicle inspection station using motion and time study techniques. J. King Saud University-Eng. Sci. 23 (1), 33–41. https://doi.org/10.1016/j.jksues.2010.01.001.

Arditi, D., Mochtar, K., 2000. Trends in productivity improvement in the US construction industry. Constr. Mgt. Economics. 18 (1), 15–27. https://doi.org/10.1080/014461900370915.

Aw, B.Y., Chen, X., Roberts, M.J., 2001. Firm-level evidence on productivity differentials and turnover in Taiwanese manufacturing. J. Dev. Economics 66 (1), 51–86. https://doi.org/10.1016/S0304-3878 (01)00155-9.

Bemmels, B., 1987. How unions affect productivity in manufacturing plants. ILR Rev. 40 (2), 241–253. doi: 10.1177%2F001979398704000206.

Cheng, C.H., Kumar, A., Motwani, J., 1995. A comparative examination of selected cellular manufacturing clustering algorithms. Intl. J. Operations Prod. Manag. 15 (12), 86–97. https://doi.org/10.1108/01443579510104538.

Chun, N., Lee, S., 2015. Bonus compensation and productivity: evidence from Indian manufacturing plant-level data. J. Productivity Anal. 43 (1), 47–58. https://doi.org/10.1007/s11123-014-0421-z.

Dangayach, G.S., Guglani, L., 2015. Application of Moldflow and Taguchi technique in improving the productivity of injection moulded energy meter base. Intl. J. Process Mgt. and Benchmarking. 5 (3), 375–385. https://doi.org/10.1504/IJPMB.2015.070820.

Dash, M., Kabra, G., Singh, A., 2010. Productivity growth of manufacturing sector in india an inter-state analysis. European J. Sci. Res. 44 (3), 387–399.

El-Tamimi, A.M., 2010. Evaluation of the implementation of business practices and advanced manufacturing technology (AMT) in Saudi industry. J. King Saud Univ.-Eng. Sci. 22 (2), 139–151. https://doi.org/10.1016/S1018-3639 (18)30501-4.

El-Tamimi, A.M., Abidi, M.H., Mian, S.H., Aalam, J., 2012. Analysis of performance measures of a flexible manufacturing system. J. King Saud University-Eng. Sci. 24 (2), 115–129. Doi:10.1016/j.jksues.2011.06.005.

Fagerberg, J., 2000. Technological progress, structural change and productivity growth: a comparative study. Struct. Change Economic Dynamics. 11 (4), 393–411. https://doi.org/10.1016/S0954-349X(00)00025-4.

Fernandes, A.M., 2008. Firm productivity in Bangladesh manufacturing industries. World Dev. 10 (36), 1725–1744. https://doi.org/10.1596/1813-9450-3988.

Filippetti, A., Peyrache, A., 2017. Productivity growth and catching up: a technology gap explanation. Intl. Rev. App. Economics. 31 (3), 283–303. https://doi.org/10.1080/02692171.2016.1249831.

Gebreeyesus, M., 2008. Firm turnover and productivity differentials in Ethiopian manufacturing. J. Productivity Analysis. 29 (2), 113–129. https://doi.org/10.1007/s11123-007-0076-0.

Gidwani, B.D., Dangayach, G.S., 2017. Productivity measurement and improvement-an overview. Intl. J. Productivity Quality Mgt. 20 (3), 316–343. https://doi.org/10.1504/IJPQM.2017.082636.

Goldar, B., Kumari, A., 2003. Import liberalization and productivity growth in Indian manufacturing industries in the 1990s. Developing Economies. 41 (4), 436–460. https://doi.org/10.1111/j.1746-1049.2003.tb01010.x.

Görg, H., Hanley, A., 2005. International outsourcing and productivity: evidence from the Irish electronics industry. North American J. Economics Finance. 16 (2), 255–269. https://doi.org/10.1016/j.najef.2004.11.006.

Please cite this article as: S. Singh and S. Singhal, Implementation and analysis of the clustering process in the enhancement of manufacturing productivity, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2020.06.005

Hemanand, K., Amuthuselvan, D., Raja, S.C., Sundararaja, G., 2012. Improving productivity of manufacturing division using lean concepts and development of material gravity feeder–a case study. Intl. J. Lean Thinking. 3 (2), 117–134.

Huang, C.H., Yang, C.H., 2016. Ownership, trade, and productivity in Vietnam's manufacturing firms. Asia-Pacific J. Accounting Economics. 23 (3), 356–371. https://doi.org/10.1080/16081625.2016.1188449.

Jain, R., Gupta, S., Meena, M.L., Dangayach, G.S., 2016. Optimisation of labour productivity using work measurement techniques. Intl. J. Productivity Quality Mgt. 19 (4), 485–510.

Kao, C., Chen, L.H., Wang, T.Y., Kuo, S., Horng, S.D., 1995. Productivity improvement: efficiency approach vs effectiveness approach. Omega. 23 (2), 197–204. https://doi.org/10.1016/0305-0483(94)00058-I.

King, R.A., 1989. Manufacturing strategy for productivity improvement. J. Business Strategy. 10 (2), 62–63. https://doi.org/10.1108/eb039300.

Lieberman, M.B., Demeester, L., 1999. Inventory reduction and productivity growth: linkages in the Japanese automotive industry. Mgt. sci. 45 (4), 466–485. https://doi.org/10.1287/mnsc.45.4.466.

Milind, M.A., 2018. Understanding of industry performance from the perspective of manufacturing strategies. J. King Saud University-Eng. Sci. 3 (30), 206. doi: 10.1016%2FS1018-3639(18)30327-1.

Moussavi, S.E., Mahdjoub, M., Grunder, O., 2017. Productivity improvement through a sequencing generalised assignment in an assembly line system. Intl. J. Prod. Res. 55 (24), 7509–7523. https://doi.org/10.1080/00207543.2017.1378828.

Nallusamy, S., Balaji, R., Sundar, S., 2017. Proposed model for inventory review policy through ABC analysis in an automotive manufacturing industry. Intl. J. Eng. Res. Africa. 29, 165–174. Trans Tech Publications. Doi: 10.4028/www.scientific.net/JERA.29.165.

Nallusamy, S., Saravanan, V., 2016. Lean tools execution in a small scale manufacturing industry for productivity improvement-a case study. Indian J. Sci. Technol. 9 (35), 01–07.

Nataraj, S., 2011. The impact of trade liberalization on productivity: evidence from India's formal and informal manufacturing sectors. J. Intl. Economics. 85 (2), 292–301. https://doi.org/10.1016/j.jinteco.2011.07.003.

Nishitani, K., Kaneko, S., Komatsu, S., Fujii, H., 2014. How does a firm's management of greenhouse gas emissions influence its economic performance? Analyzing effects through demand and productivity in Japanese manufacturing firms. J. Productivity Analysis. 42 (3), 355–366. https://doi.org/10.1007/s11123-015-0432-4.

Njuki, E., Bravo-Ureta, B.E., 2019. Examining irrigation productivity in US agriculture using a single-factor approach. J. Productivity Analysis. 51 (2–3), 125–136. https://doi.org/10.1007/s11123-019-00552-x.

Oweis, T., Hachum, A., 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. Agricultural Water Mgt. 80 (1–3), 57–73.

Park, K., Li, J., 2019. Improving productivity of a multi-product machining line at a motorcycle manufacturing plant. Intl. J. Prod. Res. 57 (2), 470–487. https://doi.org/10.1080/00207543.2018.1448129.

Playán, E., Mateos, L., 2006. Modernization and optimization of irrigation systems to increase water productivity. Agricultural Water Mgt. 80 (1–3), 100–116. https://doi.org/10.1016/j.agwat.2005.07.007.

Rai, A., Tang, X., Brown, P., Keil, M., 2006. Assimilation patterns in the use of electronic procurement innovations: a cluster analysis. Information Mgt. 43 (3), 336–349. https://doi.org/10.1016/j.im.2005.08.005.

Restuccia, D., Yang, D.T., Zhu, X., 2008. Agriculture and aggregate productivity: a quantitative cross-country analysis. J. Monetary Economics. 55 (2), 234–250. https://doi.org/10.1016/j.jmoneco.2007.11.006.

Rhee, K.H., Pyo, H.K., 2010. Financial crisis and relative productivity dynamics in Korea: evidence from firm-level data (1992–2003). J. Productivity Analysis. 34 (2), 111–131. https://doi.org/10.1007/s11123-010-0177-z.

Saleeshya, P.G., Bhadran, A., 2015. Productivity improvement through lean initiative in a surgical equipment manufacturing company: a case study. Intl. J. Business and Systems Res. 9 (4), 297–314.

Sari, D.W., Khalifah, N.A., Suyanto, S., 2016. The spillover effects of foreign direct investment on the firms' productivity performances. J. Productivity Analysis. 46 (2–3), 199–233. https://doi.org/10.1007/s11123-016-0484-0.

Shee, A., Stefanou, S.E., 2016. Bounded learning-by-doing and sources of firm-level productivity growth in Colombian food manufacturing industry. J. Productivity Analysis. 46 (2–3), 185–197. https://doi.org/10.1007/s11123-016-0481-3.

Sheth, J.N., Sisodia, R.S., 2002. Marketing productivity: issues and analysis. J. Business res. 55 (5), 349–362. https://doi.org/10.1016/S0148-2963 (00)00164-8.

Singh, S., Singhal, S., 2016. Productivity improvement: Implementation and analysis of clustering technique in manufacturing of timing gearbox cover. Mgt. Sci. Lett. 6 (4), 315–324. https://doi.org/10.5267/j.msl.2016.1.009.

Singh, S., Singhal, S., 2018a. Productivity betterment: implementation of clustering with improved tooling in manufacturing. Intl. J. Productivity Mgt. Assessment Technol. 6 (2), 1–18. https://doi.org/10.4018/IJPMAT.2018070101.

Singh, S., Singhal, S., 2018b. Productivity perfection and analysis in manufacturing top cover: implementing clustering approach with combination tooling. J. Eng. Technol. 6, 339–353.

Sivakumar, A., Saravanan, K., 2011. A simulation-based analysis for improvement of productivity in sick chemical dyeing factory: a research article. Intl. J. Electron. Transport. 1 (1), 96–110. https://doi.org/10.1504/IJET.2011.043112.

Tsao, Y., 1985. Growth without productivity: Singapore manufacturing in the 1970s. J. Dev. Economics. 19 (1–2), 25–38. https://doi.org/10.1016/0304-3878 (85)90037-9.

Van Ark, B., 1990. Manufacturing productivity levels in France and the United Kingdom. National Institute Economic Rev. 133 (1), 62–77. doi: 10.1177%2F002795019013300105.

Zahraee, S.M., Rohani, J.M., Wong, K.Y., 2018. Application of computer simulation experiment and response surface methodology for productivity improvement in a continuous production line: a case study. J. King Saud University-Eng. Sci. 30 (3), 207–217. https://doi.org/10.1016/j.jksues.2018.04.003.

Satbir Singh as a Research Scholar, Ph.D. (Part-time) at NIT, Kurukshetra, India has submitted his PhD Thesis. He did his BE (Mech) from NIT, Kurukshetra and ME (Manufacturing) from NITTTR, Chandigarh. His research interest includes Industrial Manufacturing and Productivity Management. He has above 20 years of teaching and industrial experience. He is ex-member, Board of Studies for Kurukshetra University Kurukshetra. He is presently working as Sr. faculty member at Ambala College of Engineering & Applied Research, Haryana. Many times he has been conferred Letter of Appreciation for excellent teaching. He authored 4 books and published 07 research papers in reputed Journals/Conferences.

Sandeep Singhal is presently working as Associate Professor in Department of Mechanical Engineering, National Institute of Technology (NIT), Kurukshetra, Haryana, India, an institution of national importance. At present he is the Chairman of ISTE, Haryana Chapter. He is a PhD from NIT, Kurukshetra. He has more than 27 years of teaching, research and professional experience and has authored more than 70 research papers in reputed national & international peer reviewed journals and conferences. He has authored a book on ''Entrepreneurship''. His areas of interest are SCM, ERP, TQM, Entrepreneurship, Facility Management, etc. He has worked with AICTE and NBA the apex regulatory body for technical education in various capacities for 7 years and was closely associated with Washington Accord. He has guided / guiding research scholars at MTech and PhD levels.

Please cite this article as: S. Singh and S. Singhal, Implementation and analysis of the clustering process in the enhancement of manufacturing productivity, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2020.06.005