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Enhancing Paper Cup Manufacturing Quality Using Six Sigma's DMAIC Methodology

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After its emergence, Six Sigma found wide application across the world. Later on, a few companies began to implement only the DMAIC phases of the Six Sigma programme. Despite its application in various industries, paper cup manufacturing companies have yet to adopt DMAIC. The absence of research activity involving the application of DMAIC in paper cup manufacturing companies is concerning to researchers, engineers, and managers, given the increasing use of paper cups. The research described in this paper has overcome this deficient situation. In this research report, we applied the DMAIC phases to the production of paper cups, aiming to prevent productivity loss and quality issues caused by leaks in the manufacturing process. While conducting this research, four factors have to be changed to get maximum results involving the best combination of factors and level. While carrying out the analysis phase, experiments were conducted by adopting Taguchi's Design of Experiment methodology. Subsequently, the best combination of factors and levels was determined. On the whole, the implementation of the DMAIC phases aided to improve the sigma value from 3.17 to 4.01 by overcoming the leakage problem in the manufacturing of paper cups. The smooth implementation of the research reported in this paper has favoured the implementation of DMAIC phases in many paper cup manufacturing machines. Such kind of efforts will enable the companies to export paper cups that would meet the requirements of world-class quality requirements.

Keywords: Six Sigma, DMAIC, Paper cups, Manufacturing, Design of experiments.

1. Introduction

As soon as the world began to experience the invasion of Japanese products during the 1970s, the need for improving quality in the manufacturing of products was intensively realized. It is due to the fact that Japanese products were of high quality but were available for a low price. These features attracted customers worldwide, and hence, Japanese products began to be sold in most parts of the world. As a result of this development, manufacturers developed the impression that manufacturing products with a high degree of quality would enable the companies to face the onslaught of the high intensity of competition in the world markets. In consequence of this realization, the concept of achieving continuous quality improvement in the manufacturing of products emerged. Furthermore, the contributions of quality gurus like Juran, Feigenbaum, Crosby, and Ishikawa were publicized and adopted in many parts of the world. At one point in time, all these continuous quality improvement approaches were addressed and adopted under the umbrella named Total Quality Management (TQM). Till the 1980s, many approaches and principles under TQM were implemented in organizations across the world. Most of these organizations witnessed the inculcation of a continuous quality improvement culture. Yet, at one point in time, manufacturers began to realize that the TQM principles are not supportive of achieving business prosperity. For example, it was reported that although TQM facilitated the continuous quality improvement of manufacturing processes, it failed to ensure that the profit was generated due to the implementation of such endeavors. In order to overcome this deficient situation, the Six Sigma concept was developed by the practitioners at Motorola in the United States of America.

The Six Sigma concept is encompassed with two pillars. According to the first pillar, a project is to be chosen and executed through five phases, namely Define, Measure, Analyze, Improve, and Control (DMAIC). The second pillar is the imparting of training and education to the team members to successfully implement Six Sigma projects. While imparting such training and education, the trainers are given the designations under the titles champion, master black belt, black belt, green belt, and white belt. During the beginning days, which happened during the 1970s, these two pillars of Six Sigma were implemented in the world's leading companies like General Electric and Asia Bravery by spending huge amounts of money and time. As a result of implementing Six Sigma, these companies reported to have gained substantial financial benefits. On observing these business benefits, Six Sigma was adopted by major companies across the world. Later on, medium- and small-sized manufacturing companies also began to implement Six Sigma. While Six Sigma was implemented in medium- and small-sized manufacturing companies, the difficulty in spending huge amounts of money was realized. Particularly, companies with low financial strength found it difficult and uneconomical to spend a huge amount of money on implementing the training pillar of the Six Sigma concept. As a result, many researchers and practitioners began to explore the outcome of implementing only the DMAIC phases of the Six Sigma concept.

During recent times, many researchers have reported cases in which only DMAIC phases of the Six Sigma concept were implemented (Srinivasan et al. 2016). These researchers have published papers reporting such cases in the literature arena. In most of the cases, it has been reported that the implementation of only the DMAIC phases has resulted in generating substantial financial benefits. This observation is a highly promising proposition for improving the quality of products manufactured in small and medium-sized companies that are financially weak. A careful study in the literature arena has indicated that DMAIC phases have been applied in companies belonging to manufacturing and service industries. The impact of DMAIC is yet to be explored in certain manufacturing companies.

The manufacturing companies producing paper cups are yet to witness the implementation of DMAIC phases. This is a concerning situation as paper cup manufacturing is fast becoming a dominant entity in the manufacturing industry. This is due to the reason that the use of paper cups is being given increasing thrust to overcome ecological problems that arise due to the use of plastic cups. In order to overcome this gap, the research reported in this paper cup was carried out. While pursuing this research, the literature arena was searched to find out the reporting of applying the DMAIC phases in the paper cup manufacturing industry. Then, the processes adopted for manufacturing paper cups in a company located in India were studied. The result of this study revealed that leaking of liquid contained in the paper cups is a major ‘critical to quality’ criterion. In order to overcome this leakage problem, DMAIC phases were applied. The results of applying DMAIC phases were obtained in the form of optimum pressure that needs to be applied in the paper cup manufacturing machine so as to avoid the leakage of liquid contained in the paper cups. The details of these research activities have been presented in the following sections of this paper.

2. Literature review

After choosing to implement the DMAIC stages to enhance the quality of paper cup production, a thorough search of the literature was conducted to identify any relevant studies conducted worldwide. The survey was conducted in two distinct domains. The researchers reviewed the application scope of DMAIC phases in the first domain. The second subject of study involved a comprehensive examination of studies conducted in the field of paper cup manufacture. The specific facts and expertise obtained from reviewing the research papers in these two areas are concisely outlined in the subsequent sections. From the 1990s, many companies began to implement only the DMAIC phases for achieving six-sigma level quality. Time and again, the researchers have also reported such applications in the literature arena. While carrying out the literature survey being reported here, as many as 18 papers containing DMAIC in their titles were downloaded from the world's leading databases like Science Direct and IEEE and the databases maintained by the publishers like Emerald Insight, Taylor & Francis, and Springer Link. These papers and the areas in which the DMAIC applications reported in them are enumerated in Table 1.

Table 1. DMAIC application areas

S. No.	Paper	Area of application of DMAIC phases
1	Sin et. al. 2015	Knowledge
2	Mast and Lakkerbol. 2012	Problem solving
3	Fan et al. 2015	Life testing
4	He et al. 2015	Voluntary turnover of employee
5	Prasad and Vivek. 2006	Bacterial level of water filter
6	Yeh et al. 2006	Supply chain management
7	Qureshi et al. 2013	Higher education
	Yu and Ueng. 2012	
8	Chen et.al. 2013	Health care
	Mayer. 2014	
9	Li et.al. 2010	Service
10	Kaushik and Khaundija. 2009	Power plant
11	Ferreira et al. 2013	Logistics in manufacturing
12	Tong et al. 2004	Manufacturing
	Kumaravadivel and Natarajan. 2013	
	T Sharma and Rao. 2014	
	Barbosa et al. 2014	
	Ghosh maiti. 2012	

As shown in Table 1, the applications of Six Sigma's DMAIC phases have been reported in as many as 12 areas. The purpose of applying DMAIC phases varied from reducing the voluntary turnover of employees for improving the quality in foundries. In all these researches, the DMAIC phases are applied with very little variations. In the define phase, goals of the project are defined. Further, the activities involving suppliers and customers are mapped. During the measure phase, the current performance of the process or system under consideration is measured by using any one of the appropriate measures like sigma level, process capability index and cost of poor quality. The measured values will indicate the gap to be filled by making appropriate efforts to achieve six sigma level qualities. During analysis phase, the causes of the gap between the six sigma level quality and the current performance level are analyzed. During the improve phase, solutions are evolved to fill the gap existing between the six sigma level quality and current performance level. In this phase, the solutions are also implemented. In the control phase, the sustenance of the solutions implemented during improve phase is ensured. Further study of the researches reported in the papers presented in Table 1 indicated that despite the wide application of Six Sigma's DMAIC phases in industries of different types, the implementation of the same is to be reported in the case of manufacturing of paper cups. In the context of this observation, the researches reported in the domain of paper cups manufacturing were studied. The information and knowledge gathered by carrying out this study were presented in the next subsection. While searching the literature arena, five papers reporting research on manufacturing paper cups were encountered. The information and knowledge gained by reviewing these papers are presented in this subsection.

Hocking (1991) has compared the merits of polystyrene foam and paper cups from the point of view of using them for handling hot drinks. It is mentioned that the raw material used for manufacturing paper cups is wood. In order to manufacture one paper cup of a certain weight, double the weight of wood is required to be processed. The usage of abundant wood for making paper cups depletes the trees available in several countries. Thus, the usage of paper cups leads to environmental degradation. This problem is overcome when polystyrene foam cups are manufactured. In the case of manufacturing polystyrene foam cups, the raw material used is polystyrene, which is an a petroleum product. Both paper and polystyrene cups have approximately equal stiffness. However, in the case of paper cups, the stiffness value reduces when pouring hot drinks in them. Further, recycling of paper cups is more difficult than recycling of polystyrene foam cups. The weight of the polystyrene foam cup with a certain dimension is less compared to the paper cup of the same dimension. Altogether, it is suggested to use a polystyrene foam cup in place of a paper cup. While significant data are provided to compare the merits of using polystyrene foam cups over paper cups, research reporting the application of modern tools and techniques for achieving favourable values of parameters that would overcome quality problems is absent in this paper.

Hockings (1994) has compared the merits and demerits of using reusable and disposal cups. In this paper, the characteristics of cups made of five materials, namely ceramics, re-usable plastics, glass, paper, and polystyrene, are compared. The data required to exercise this comparison were derived from America and Canada. A key finding of this comparison is that the energy required to manufacture ceramic cups is highest, whereas that is least in the case of manufacturing polystyrene foam cups. In the case of manufacturing paper cups, the energy requirement is slightly higher than that is required to manufacture the polystyrene foam cups. Further, the energy required to wash the reusable cups was compared. In the case of ceramic and polystyrene foam cups, the number of servings required to break even is 1006. On the other hand, in the case of cups made of glass and paper, the number of servings required to break even is 15. These observations favour the usage of paper cups in place of cups made of other materials. However, distinct results cannot be derived as the rate of return on using the cups to make any type of material depending on the nature of the usage of the cups. For example, in the case of a restaurant, where the number of servings is high, the usage of ceramic cups can also be preferred, even though the energy required to manufacture them is very high. Besides comparing the energy required to manufacture and wash the cups, which is often having an impact on the price, the customers attached importance to aesthetics and convenience (ergonomics) in choosing the material of the cups to be used for containing hot and cold drinks.

Kim and Park (2012) have reported research in which the values of three parameters of a paper cup-forming machine were optimized to increase the productivity of producing paper cups. It is pointed out that as the paper cups are convenient to use and are environmentally friendly, the demand for the same is increasing. In order to cope with this increased demand, the productivity of the paper cup-forming machine should be increased by choosing appropriate parameters and their values. Increasing productivity without choosing optimum values of parameters will result in vibration and produce defective cups in the paper cup-forming machines. In the context of this observation, the values of the parameters concerned with the part called the barrel cam of the paper cup-forming machine were optimized. The roll rests on the barrel cam to regulate the turret for making paper cups. Increased usage of the barrel cam results in wear and tear, which in turn can create vibration. The optimization of the values of appropriate parameters will reduce the wear and tear of the barrel cam and increase the productivity of the paper cup-forming machine. While pursuing this research, it was found that nine parameters play roles in determining the wear and tear of barrel cams. Out of them, three parameters, namely ‘radius of index’, ‘height of rollers', and ‘radius of rollers', were chosen for achieving optimization. After determining the levels of these parameters, the response surface analysis was carried out to obtain a regression model. This model relates the proportions of the above-mentioned three parameters with the contact force between the barrel cam and rollers. The objective was to reduce the peak value of contact force between the barrel cam and rollers. Using the above regression model, the optimized values of these parameters were determined. Subsequently, a dynamic model was created to analyse the impact of the optimized values of chosen parameters of the contact force between the barrel cam and rollers. Finally, a prototype of the barrel cam was fabricated by using the optimized values. Using this prototype, an experiment was conducted five times. The results of this experiment indicated that the average acceleration was reduced by 17%. This reduction in acceleration validated the optimality of the values of the three chosen parameters.

Mitchel et al. (2014) have reported research in which the recycling of disposable cups used for handling beverages like tea and coffee was dealt with. It is reported that several tonnes of disposable cups need to be recycled in restaurants serving beverages like tea and coffee. The recycling of those disposable cups is difficult as the bond between cellular's fibre and the polyethylene coating presented in them prevents their effective recycling. In order to overcome the difficulty, the usage of composites for manufacturing paper cups is being investigated by the researchers. In this direction, many studies involving the production of composites for manufacturing disposable cups have been reported. However, the strength of these composites has been insufficient to make pellets. In order to overcome this deficiency, a composite with coupling agent was developed. While carrying out this research, disposable cups were obtained from a major UK supplier by name Solo Cup. Subsequently, the disposable cups were shredded and coupling agent was added. The extraction and injection processes were applied to produce few composites. Subsequently, mechanical property tests were conducted. These results indicated that the addition of a coupling agent has given rise to the increased tensile strength of the composite used for manufacturing the disposable cups.

Jenkovic (2014) has reported research in which the recycling of disposable coffee cups by using a process called “pyrolysis” was dealt with. It is claimed that 14.4 million disposable cups are used in the USA while consuming coffee. Hence, it becomes a necessity to recycle those disposable cups. However, recycling those disposable cups is difficult because these cups are impregnated with plastic and stuck with grease. In order to apply pyrolysis for recycling disposable cups, the kinetics of the particles needs to be studied. In order to carry out this study, an experiment was conducted. The results of this experiment were analyzed. Several findings were derived by conducting this analysis. For example, the moister content in the disposable cup does not have any impact on its recyclability. On the other hand, the heat generated in the pyrolysis process favours the faster recyclability of disposable coffee cups.

The above information and knowledge indicate that from the year 1990, researchers have begun to show interest in carrying out research in the domain of manufacturing disposable cups. After leaving a little gap from the 2000s, researchers began to study the energy requirement for manufacturing disposable cups. In recent years, researchers have begun to study the challenges of recycling disposal cups. Amidst these developments, it is prudent to observe the research reported in Kim and Park (2012). In this paper, it is reported that, in recent years, the need for using paper cups is amazingly increasing. This is due to the fact that the paper cups are convenient to use and are environmentally friendly. Hence, the need of the hour is to focus on increasing the productivity of paper cup-producing machines by improving the quality of operating the same. In this direction of research, so far no researcher has attempted to apply Six Sigma's DMAIC phases for improving the quality of the paper cup-producing machines. The research reported in the subsequent sections has facilities to fill this research gap.

3. Manufacturing of paper cup

The research being reported here was carried out in a company by name Rajaseker Paper-Cup Works (hereafter referred to as RPW) RPW which is situated in Kanyakumari district of Tamilnadu state of India. RPW was started in the year 2009. The raw material used in RPW to manufacture the paper cups is Low Density Poly Ethylene (LDPE) coated triplex paper board. The LDPE coating prevents the paper cups from getting soaked by liquid food. This coating is also used to seal the folding area of paper cups by applying heat and pressure. The paper board adds strength to the paper cup. The paper cup is made up of two pieces of paper board. One piece is used to manufacture bottom part. This part is known as cup bottom and other piece of paper board is used to manufacture the wall part. This part is called as cup cone. The paper board used for making cup bottom is known as bottom paper and the paper board used to manufacture cup cone area is known as wall paper. As mentioned earlier, the research being reported here was begun by observing the stages followed in RPW to manufacturing cups. The manufacturing stages thus observed are shown in Figure 1.

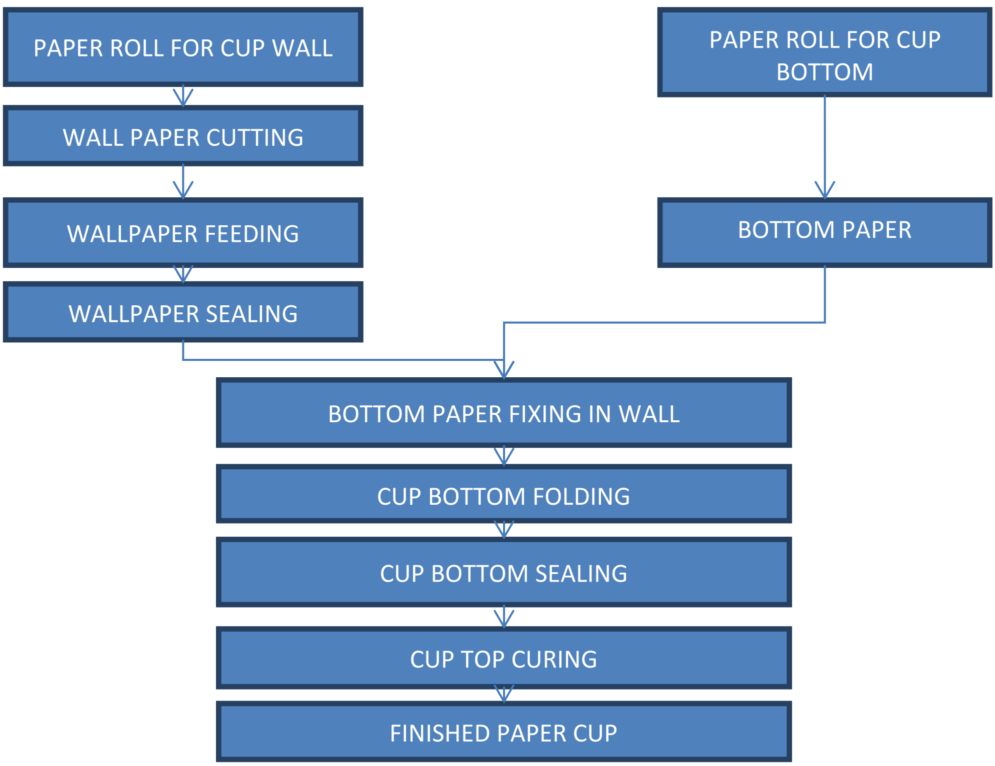

Figure 1. Steps followed at RPW for manufacturing paper cups

As shown, in RPW, the steps begin by the procurement of LDPE coated paper rolls from paper mills. While carrying out this procurement, two types of paper rolls are procured. One type of paper rolls are used for manufacturing paper cup wall. Other type of the paper rolls are used for manufacturing cup bottom. The manufacturing of cup wall and cup bottom is carried out in parallel. In order to manufacture cup wall, the paper rolls are cut in the shape of paper wall and it is fed into the paper cup forming machine. By using this machine, the paper cup wall is sealed. In parallel to the execution of these steps, the paper rolls purchased for manufacturing cup bottom is punched. After the cup wall and cup bottom are manufactured, the cup bottom is fixed in the cup wall. Subsequently, the cup bottom is folded. Then the cup bottom is sealed by applying heat. Next the heated area is knurled by using heated knurling wheel. On knurling, the strength of the bottom portion of the cup is increased. In order to provide the griping facility, the tip of the wall portion is curled. On completion of these steps, the finished paper cup is taken out of the paper cup forming machine.

4. Application of DMAIC methodology

As mentioned earlier, in the research being reported here, DMAIC phases were applied in RPW to overcome liquid leaking problem in paper cups. The steps carried out under each phase of DMAIC methodology are briefly reported in the following subsections.

4.1 Define

In this phase, the leaking on filling the liquid in paper cup was defined as the problem. In order to study the significance of this problem, the data on the rejection of paper cups due to the liquid leaking problem for 10 days were gathered in RPW. The quantity of paper cups manufactured per day in RPW in a paper cup forming machine is 52000. As this quantity is very high, it has been impossible to carry out to 100% inspection for checking the liquid leaking problem in the paper cups manufactured in RPW. Hence, the goal of the research being reported here was set to determine the factors and levels of operating the chosen paper cup forming machine, so as to prevent the manufacturing of paper cup with leaking problem. Here, the factors refer to the operating parameters of the paper cup forming machine.

4.2 Measure

While beginning the measure phase it was observed that in RPW, the liquid leaking problem in paper cups was inspected by following a qualitative method. According to this method, a sample of three paper cups were chosen from a lot of size 100. In these chosen paper cups, the quantity of the water to be contained in them was stored for approximately from 30 to 60 seconds. During this period, the water leakage was visually inspected. The paper cups from which water leaked were rejected. While pursuing this research being reported here, the need for replacing this qualitative approach with a quantitative approach was realized. Such quantitative approach was found to be essential for gathering the necessary statistical data, analyzing them and evolving solution to prevent the occurrence of liquid leaking problem in paper cups. In order to carry out this approach, a pressure testing equipment shown in Figure 2 was designed and fabricated. As shown, a pressure gauge is fit in the middle of pipe. At the end of this pipe, the paper cup is fixed. From the front end of this pipe, compressed air is supplied. The paper cup which is required to withstand the pressure developed by liquid contained in it was tested. For example, a paper cup which has to contain 100 ml of liquid has to withstand with the pressure of 157 millibar. In order to carry out this test, the cups manufactured by using paper cup forming machine being used in RPW were collected. As the sample out of 12 paper cup forming machine used in RPW, one among them was chosen to determine the optimum operating parameter and levels which will prevent the manufacturing of paper cups with liquid leaking problem.

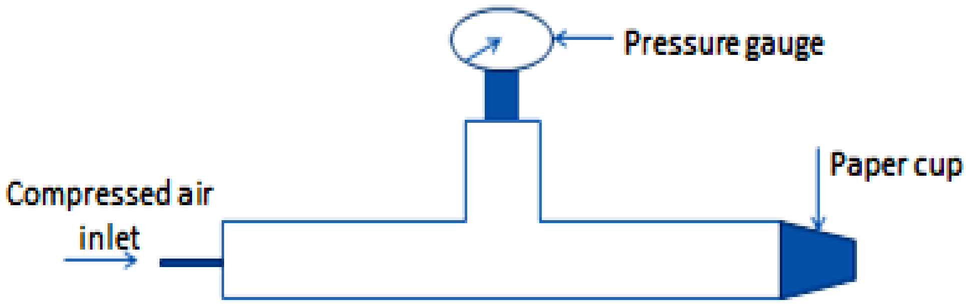

Figure 2. Pressure testing equipment

4.3 Analyse

As the goal of the research being reported here is to identify the factors and levels thus should be applied in paper cup forming machine, so as to prevent the occurrence of leaking problem in the paper cups, it was decided to conduct experiments by following Taguchi's design of experiment methodology. The factors that could be varied in the chosen paper cup forming machine were identified. It was identified that the wall paper sealing temperature, cup bottom curling temperature, cup bottom knurling temperature and speed of production could be changed in this chosen paper cup forming machine in specified levels. These factors and levels are presented in Table 2.

Table 2. Factors and their levels that can be varied in the paper cup forming machine

Factors	Level	
	Maximum	Minimum
Wall paper sealing temperature	115^0 C	125^0 C
Cup bottom curling temperature	235^0 C	245^0 C
Cup bottom knurling temperature	235^0 C	245^0 C
Speed of production	40 cups per minute	50 cups per minute

By equally spreading the values in the specified ranges, the levels to be set for designing experiments against the four factors were chosen. Those levels and corresponding factors are shown in Table 3.

Table 3. Factors and levels involved in the manufacturing of paper cups

Factor	Level 1	Level 2	Level 3
Wall paper sealing temperature	115^0 C	120^0 C	125^0 C
Cup bottom curling temperature	235^0 C	240^0 C	245^0 C

Cup bottom knurling temperature	235^0 C	240^0 C	245^0 C
Speed of production	40 cup/min	45 cup/min	50cup/min

Subsequently the experiments were designed by choosing L9 orthogonal array. The experiments thus was designed are shown in Table 4.

Table 4. Design of Experiments

Experiment number	Factors			
	Wall paper sealing temperature	Cup bottom curling temperature	Cup bottom knurling temperature	Speed of production
1	115^0 C	235^0 C	235^0 C	40 cup/min
2	115^0 C	240^0 C	240^0 C	45 cup/min
3	115^0 C	245^0 C	245^0 C	50cup/min
4	120^0 C	235^0 C	240^0 C	50cup/min
5	120^0 C	240^0 C	245^0 C	40 cup/min
6	120^0 C	245^0 C	235^0 C	45 cup/min
7	125^0 C	235^0 C	245^0 C	45 cup/min
8	125^0 C	240^0 C	235^0 C	50cup/min
9	125^0 C	245^0 C	240^0 C	40 cup/min

After designing, the experiments were conducted. While conducting each experiment, 50 paper cups were manufactured. The pressure withstanding capacity of each paper cup was measured by using the pressure testing equipment. Then the average value of the pressure withstanding capacity of cups on conducting each experiment was calculated. These values are shown in Table 5.

Table 5. Experimental results on the mean pressure withstanding capacity of paper cups

Experiment Number	Mean pressure withstanding capacity in millibars
1	314.4
2	320.4
3	310.4
4	299
5	325.4
6	307.6
7	304.8
8	297.4
9	319.8

As shown in Table 5, on conducting the experiment number 5 of the 50 cups produced exhibited highest mean pressure capacity with the value of 325.4 millibar. Hence it was inferred that the factors and levels chosen to conduct experiment number 5 were yielding best results. Those factors and levels are shown in Table 6.

Table 6. Factors and levels for obtaining paper cups with high pressure withstanding capacity

Factors			
Wall paper sealing temperature	Cup bottom curling temperature	Cup bottom knurling temperature	Speed of production
120^0 C	240^0 C	245^0 C	40 cup/min

4.4 Improve

After determining of best combination of factors and levels, the confirmation experiment was conducted. The results of this confirmation experiment are shown in table 7.

Table 7: Results of confirmation experiments

Factors				Mean pressure withstanding capacity in millibars
Wall Paper Sealing Temperature	Cup Bottom curling Temperature	Cup Bottom Knurling Temperature	Speed of Production	
120^0 C	240^0 C	245^0 C	40 cup/min	328.2

As shown, the average withstanding pressure found by conducting confirmation experiment is 328.2 millibar which is falling within 10% tolerance values obtained during the conduct of experiment number 5. After confirming the best combination of factors and levels, the S/N ratio's of nine number of experiments were calculated. As this experiment belongs to "Larger the Better" type category, the formula given below was used to calculate the S/N ratio.

S/N ratio = $-10 * \log(\Sigma(1/Y^2)/n)$

The S/N ratios calculated by using the above formula are presented in table 8.

Table 8. S/N ratio

Experiment Number	Mean pressure withstanding capacity in millibar	S/N Ratio
1	314.4	49.94965
2	320.4	50.11385
3	310.4	49.83843
4	299	49.51342
5	325.4	50.24835
6	307.6	49.75973
7	304.8	49.6803
8	297.4	49.46682
9	319.8	50.09757

By referring to the values, the main effect of the factors was calculated against the S/N ratio. Those values are shown in table 9.

Table 9: Main effect of the factors

Factors	Level 1	Level 2	Level 3	Max-Min	Rank
Wall paper sealing temperature	49.96731	49.8405	49.74823	0.219082	III
Cup bottom curling temperature	49.71446	49.94301	49.89858	0.228549	II
Cup bottom knurling temperature	49.7254	49.90828	49.92236	0.196963	IV
Speed of production	50.09852	49.85129	49.60623	0.492298	I

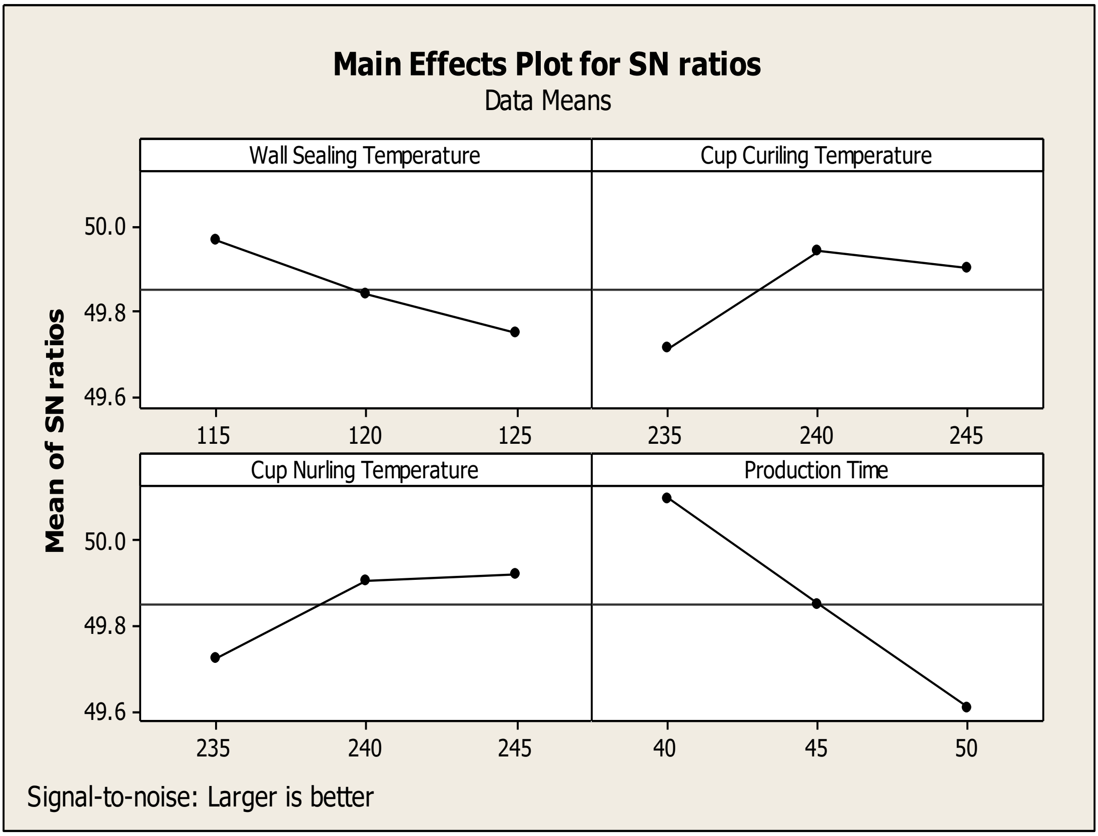

Figure 3. Main effect of the factors versus SN ratio

The main effects were also plotted in two dimensional graphs using mini tab software. These graphs are shown in Figure 3. As shown in Table 9 and Figure 3, the speed of production plays significant role in manufacturing paper cups. Subsequently the ANOVA was carried out. The results of conducting ANOVA are shown in Table 10.

Table 10. ANOVA

Parameter	DOF	Sum of square	Mean square	F Ratio	P Value	% Contribution
Wall paper sealing temperature	2	0.09679	0.048395	2.919859	0.092632	11.67944
Cup bottom curling temperature	2	0.117478	0.058739	3.543961	0.061736	14.17584
Cup bottom knurling temperature	2	0.096585	0.048292	2.913673	0.093018	11.65469
Speed of production	2	0.484718	0.242359	14.62251	0.000607	58.49003
Error	12	0.198892	0.016574			4
Total	20	0.994462	0.414359			100

These values confirmed that the contribution of speed of production is highest in manufacturing leak free paper cups. Thus, in total, improvement in the quality of manufacturing paper cups through the prevention of producing paper cup with leaking problem could be achieved by determining the best combination parameters and levels in the chosen paper cup forming machine. .

4.5 Control

In order to ensure the best combination of factors and levels are applied in practice, these results were pasted in front of the chosen paper cup forming machine in RPW. Further the supervisor was advised to check whether the operators apply only the best combination of factors and level while manufacturing paper cups by visiting the work place once in an hour.

5. Results and Discussions

The benefits of implementing DMAIC methodology will be sensed effectively only when the sigma value increases. In order to check this aspect, the sigma value before and after the implementation of the best combination of the factors and levels were computed. The detailed of this computation are presented below

5.1 Sigma value before the implementation of the combination of factors and levels.

i. number of paper cup inspected = 1000

ii. number of paper cup found to be rejected due to leaking problem = 47

iii Defects per unit = 0.047

iv. number of opportunities = 1

v. defects per unit opportunity = 0.047

vi. defects per million opportunity = 47000

vii. Process six sigma level = 3.17

5.2 Sigma value after the implementation of the combination of factors and levels.

i. number of paper cup inspected = 1000

ii. number of paper cup found to be rejected due to leaking problem = 6

iii Defects per unit = 0.006

iv. number of opportunities = 1

v. defects per unit opportunity = 0.006

vi. defects per million opportunity = 6000

vii. Process six sigma = 4.01

As shown at the end of two subsection 4.1 and 4.2 the sigma value increased from 3.17 to 4.01 on achieving continuous quality improvement by preventing the production of paper cup leaking problem through the application of DMAIC phases described in the previous sub sections. This increase in the sigma value revealed that the application of DMAIC in the other paper cup forming machines will enable RPW to progress towards performing at Six Sigma level quality

6. Conclusion

Although paper cups are used largely for supplying liquid beverages, the focus on improving the quality of their manufacturing has not been significant in the research field. In practical scenario also, not much efforts have been made by the engineers and managers for enabling the improvement of quality in the manufacturing of paper cups. In consequence to this observation, effects were made in the research reported in this paper to improve the performance of paper cup forming machine to prevent the production of paper cup with liquid leaking problem. Research reported this paper has opened the avenues for carrying out practice oriented researches for improving quality in the manufacturing of paper cups through the application of DMAIC phases. While carrying out this practice oriented research, the activities could be conducted without any hassles. Only in the case of measurement, the approximate method of inspection was replaced with the accurate method of inspecting the leaking of fluids in the paper cup manufacture in RPW. The best results were obtained and the smooth conduct of the research reported this paper have favored to extend the application of DMAIC phases in other machine employed in RPW to manufacturing paper cups. Furthermore, it is desirable to find out the optimum results which will be encapsulated with optimum combination of factors and levels. These optimized factors and level, can be determined by applying a suitable optimization technique. The article is concluded by mentioning that the research reported here is novel in nature and has opened avenue for transferring the knowledge and skills of managers, engineers and researchers for improving the quality in the case of manufacturing paper cups.

Conflict of interest

There is no conflict of interest in the submission of this work, and has been agreed by all the authors for the publication of the manuscript.

Credit Author Statement

Harikrishna Bommala - Investigation

Abullais Nehal Ahmed - Validation and Analysis

M Shunmugasundaram - Data Curation and Compilation

S. Ajit - Formal Analysis.

N.Sivakumar - Writing - review & editing.

Madhava Rao Chunduru - Writing - review & editing

P. Jayaseelan - Writing - review & editing

G. Nagarajan - Methodology, Conceptualization, Original drafting (corresponding author)

Declaration of 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.

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