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A case study on Simulation and Design optimization to improve Productivity in cooling tower manufacturing industry

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Abstract. Cooling towers are the heat transfer devices commonly found in industries which are used to extract the high temperature from the coolants and make it reusable in various plants. Basically, the cooling towers has Fills made of PVC sheets stacked together to increase the surface area exposure of the cooling liquid flowing through it. This paper focuses on the study in such a manufacturing plant where fills are being manufactured. The productivity using the current manufacturing method was only 6 to 8 fills per day, where the ideal capacity was of 14 fills per day. In this plant manual labor was employed in the manufacturing process. A change in the process modification designed and implemented will help the industry to increase the productivity to 14. In this paper, initially the simulation study was done using ARENA the simulation package and later the new design was done using CAD Package and validated using Ansys Mechanical APDL. It's found that, by the implementation of the safe design the productivity can be increased to 196 Units.

Keywords:
Fill manufacturing optimization; manufacturing system simulation; Arena model; productivity enhancement;

1. **Introduction**

The goal of any industry is to deliver the products maximally with the minimal consumption of resources and energy. These resources include electricity, labor etc. These resources were available in abundant during the last few decades. Due to the development of industrial sector, the resources that are available have decreased over the time. Cooling towers are heat transfer devices which are prevalent in industries helps in dissipating the heat energy gained by the coolant produced during cooling process. The cooling towers consist of tank like structure with a lot of stacked materials called fills fitted inside huge tanks. These Fills are made up of PVC material. The main function of the fills is to provide a cascading effect to the flowing water which increases the surface area exposure of the water to the air thus increases the rate of heat transfer. The fills are not independently used in the cooling tower instead they are stuck together to form stacks. The fills are stuck in such a way that there is a small amount of space for the water to fall and flow between two layers of fills.

Fig 1 Stacked Fills and Cooling tower. [1]

The behaviour of a system can be studied in general by two methods, one is experimentation with actual system and the other is by creating a model of the system. Experimenting with the actual system is always expensive and time-consuming whereas model analysis is a much more feasible method. The model can be any three types namely analytical modeling, scientific modeling and mathematical modeling. The solution to the mathematical modeling can be done analytically or using simulation. Simulation means mimicking the real-time system which can result in the efficiency of the system easily. Simulation models can be built to study the effectiveness of different forms of materials handling equipment by considering their detailed parameters such as speed, process paths and control logic as stated by Wilson R. Nyembaa and Charles Mbohwab [2]. With the swift development of computer technology, computer simulation theory and virtual reality technology make it possible great achievements was discussed by Maria Pia Fanti et.al. [3]. With even more complex decision structures, demand variation and the need for evaluating alternatives within this frame, simulation and simulation-optimization have been identified as key decision-making tools commented by James Bekker and Sylvain Guittet-Remaud [4]. Choong-Yeun Liong et.al. presented in his work that Time, quality and cost are therefore basic, but important measures against the price [5].

Rockwell ARENA is a simulation and automation software from Rockwell Automation Inc. It uses SIMAN as its simulation language and the current version is version 15.0 (Arena Simulation 2009; Arena Wiki 2009). In ARENA simulation, a model can be built by putting together predefined modules, which represent various processes and logic. Connector lines are used to connect modules define the flow or order of the processes. Various important data such as Statistical, cycle time and waiting time are recorded and stored automatically as reports for every cycle and for a particular time interval in ARENA. ARENA has been widely used in simulating business processes and various kinds of discrete event operations. Some of the large firms that use ARENA include GM, UPS, IBM, Nike, XEROX, Lufthansa, Ford, Lucent and Sony. Arena is sometimes used even in harbours and ports to model and simulate the terminal operation processes involving ship arrival, loading, unloading, and other related events. These can also be used in areas where Kanban a system of sending a instruction along with the production is done [6]. In lean manufacturing industry where the production can be studied and optimized this methods can be used [7]. All the information gathered from running the simulations, assisted further the understanding and improvement of the proposed system, particularly in certain issues, such as determination of the exact transportation facilities and of the optimal number of parallel-processing machines in the specified manufacturing system[8]. It was found that the simulation was able to achieve this because of its ability to both store attribute values and to show queuing levels at an individual product level[9]. In batch manufacturing systems, the flow of products can be monitored and optimized to propose a better layout design and work distribution using

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simulation models [10]. Overlong waiting time in emergency services is an important matter which has negative influence on healthcare quality[11]. Here, ARENA proves to be a very important tool to analyse and optimise various such parameters in order to make proper decisions based on the results obtained [12,13,14].

In the present industry which we are focusing on having only manual labors involved in the production and no automated process involved in the binding these PVC fill sheets. In the production area, manual labor will dip the fills in PVC solvent, stack them together and place weights above them for binding. When compared with the ideal capacity the actual production is very less and nearly its 50 %. In this work, we are attempting to increase the efficiency of the process or productivity and reduce the manual labor involved in designing an automation system in fills manufacturing. The efficiencies of the existing system and the introduced system was compared.

2. Present process layout -Simulation studies:

For the simplicity and easiness to understand the processes involved in the manufacturing of fills are further subdivided into 5 stages as is shown in figure 1. The simulation model used in the study created by arena software was shown in figure 2.

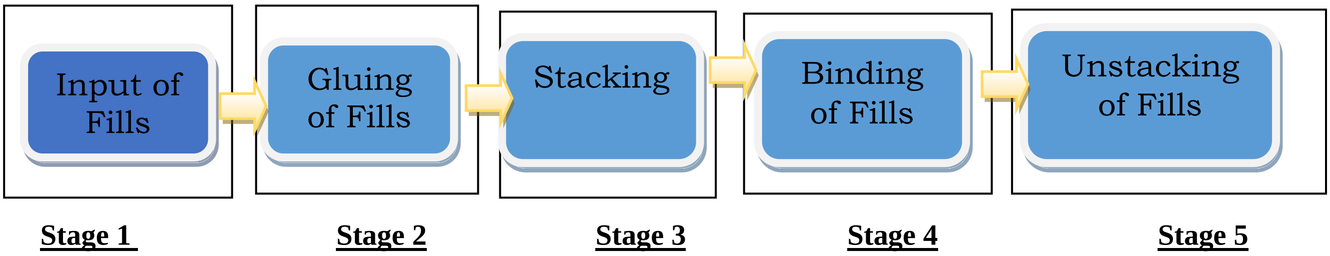

Fig 1. Process involved in Fills manufacturing

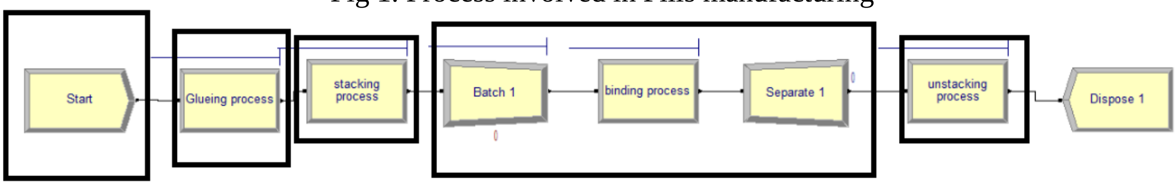

Fig. 2 Simulation model of Fills manufacturing process

2.1. Stage 1: Raw material entry

In this stage, the PVC sheets of dimension 120mm X 30mm and an average thickness of 10mm were transported from the storage to the fills manufacturing production plant. The time taken for bringing 30 samples together was noted down using a stopwatch and later converted into mathematical equation using input analyzer available in the Arena software. The details were shown in Table 1.

Table 1. Obtaining mathematical expression for the Input of fills process

Process involved	Time taken (seconds)	Mathematical expression
Input of fills	2,1,2,1,2,1,1,1,2,2,1,1,1,1,2, 2,1,2,1,1,1,1,2,2,1,2,2,2,1,2,2.	TRIA (0.5, 1.5, 2.5) Representation: Minimum – 0.5; Most likely – 1.5; Maximum – 2.5

Figure 2 represents the best fit for the data when using the input analyzer in Arena. The best fit in this case was a triangular distribution with Minimum, Most likely and maximum values as 0.5, 1.5 and 2.5 minutes respectively. Table 2 represents the data summary for the best fit, shows that square error value was 0.00. These data were fed into the create module as shown in the model.

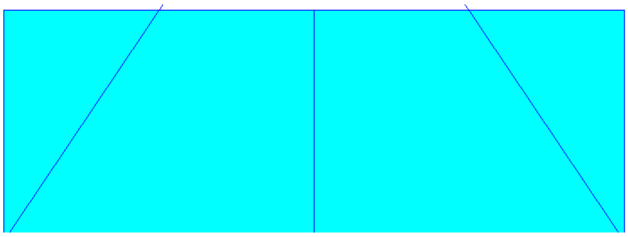

Fig. 3 Distribution of Fills input – Triangular Fit.

Table. 2 Statistical data summary of Input of Fill process

Distribution Summary	
Distribution:	Triangular
Expression:	TRIA(0.5, 1.5, 2.5)
Square error	0.000000
Data Summary	
Number of Data Points	30
Min Data Value	1
Max Data Value	2
Sample Mean	1.5
Sample Std Dev	0.527
Histogram Range	0.5 to 2.5
Number of Intervals	2

2.2. Stage 2: Gluing process

In stage 2, PVC solvent was applied to one side of the sheet using a basic roller setup. The schematic diagram is shown below fig.4. As shown in the figure one of the two rollers is always dipped into solvent so that the solution is applied to only one surface of the material. The time taken for the process is noted continuously using a stopwatch and using input analyzer a mathematical expression for the process is obtained as is shown in Table 3.

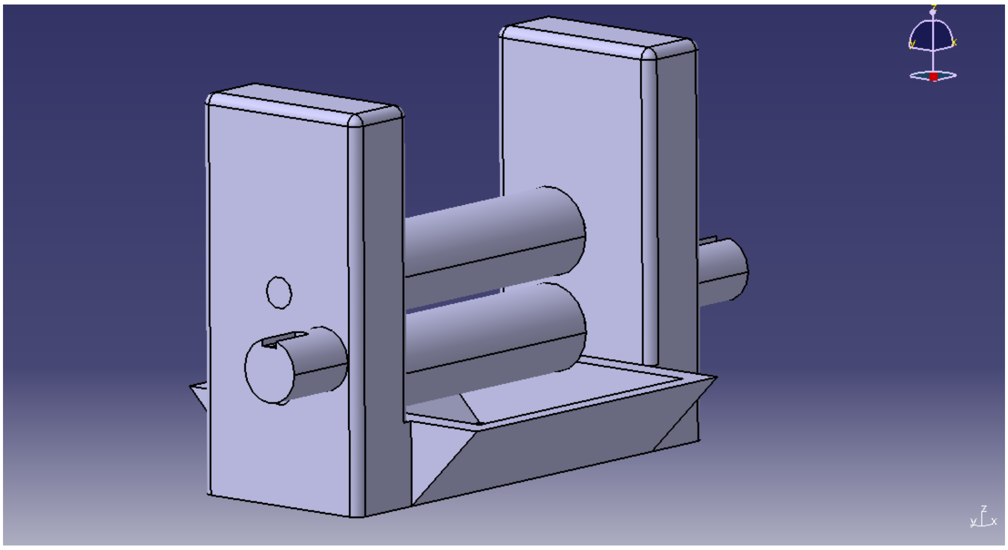

Fig.4 Application of PVC solvent using rollers

Table 3 Obtaining mathematical expression for the Gluing of fills process

Process involved	Time taken (seconds)	Mathematical expression
Gluing of fills	3.01, 3.54, 2.20, 3.22, 2.12, 2.73, 3.71, 2.24, 3.65, 3.69, 2.21, 2.19, 3.05, 2.97, 2.78, 3.96, 2.87, 3.26, 2.16, 2.22, 2.67, 2.95, 2.82, 3.91, 3.66, 2.02, 2.41, 3.59, 2.01, 3.30, 3.6	2 + 2 * BETA(0.7, 0.8) Representation: Shape parameter α =0.7 and β=0.8

The best curve fit for the values fed into input analyzer was shown in Figure 5 and summary of data fitting was shown in Table 4. We can see that the best statistical fit was reported for beta distribution.

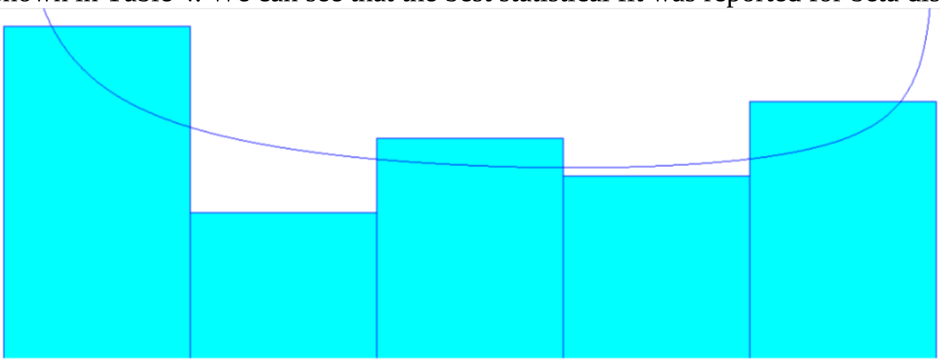

Fig. 5 Distribution of Gluing process – Beta Fit.

Table 4 Statistical data summary of gluing of Fills process

Distribution Summary	
Distribution:	Beta
Expression:	2 + 2 * BETA (0.7, 0.8)
Square error	0.000000
Chi-square test	
Number of intervals	5
Degrees of freedom	2
Test statistic	0.695
Corresponding p-value	0.713
Histogram Range	2 to 4
Number of Intervals	5

In the arena model, the process module is used to define this gluing process and time estimate is entered as a processing time in this module.

2.3. Stage 3: Stacking process

In this stage, the process involves the arrangement of fills in column position and stacks of size 12 numbers. The time taken for the process is noted as shown in Table 5 and a mathematical model is created using input analyzer is shown in the table below.

Table 5 Statistical data summary of stacking process

Process involved	Time taken (seconds)	Mathematical expression
Gluing of fills	1.96,2.26,2.43,2.39,2.49,1.52,1.71,1.93,1.75,2.36,1.58,2.02, 1.96,1.97,2.45,2.35,1.67,1.59,2.08,2.15,1.87,2.02,1.67,1.51, 2.46,1.52,2.48,2.37,1.60,1.77,2.27.	UNIF (1.41, 2.59) Representation: min as 1.41 and max as 2.59

Figure 6 represents the best curve fit for the values fed into input analyzer. The square error was 0.009157 for Uniform distribution and the summary is shown in Table 6.

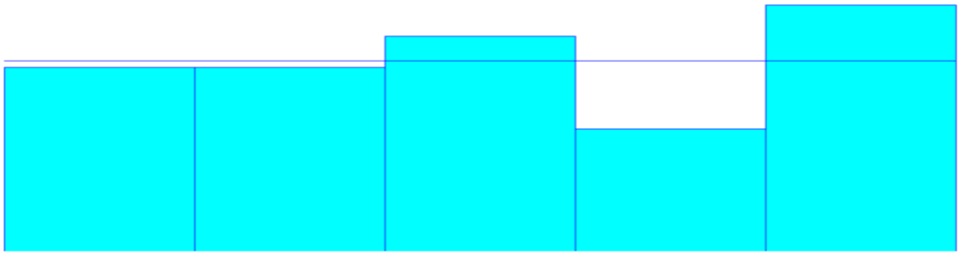

Fig. 6 Mathematical distribution of stacking process – Uniform distribution

Table 6 Distribution summary of stacking process

Distribution Summary	
Distribution:	Uniform
Expression:	UNIF (1.41, 2.59)
Square error	0.009157
Chi-square test	
Number of intervals	5
Degrees of freedom	4
Test statistic	1.42
Corresponding p-value	0.75
Histogram results	
Histogram Range	1.4 to 2.5
Number of Intervals	5

Batch and process modules are used to define the batching of 12 units as stack and process to define the processing time and later separated for the next operation.

2.4. Stage 4: Binding Process.

In this stage, the weights were applied on the top of Fills to ensure proper binding. The weight that is applied over fills will vary in the range of 8 to 10 kg at constant time of one hour. Table 7 gives the summary of expression for the unstacking process as constant 3600 seconds.

Table 7 Statistical data summary of the Binding process

Process involved	Time taken (seconds)	Mathematical expression
Binding Process	3600	Const (3600)

It's represented as a process and processing time was defined as 3600 seconds.

2.5 Stage 5: Unstacking process

This process involves the removal of fills from the column supports and transporting them to fit inside a cooling tower. The time taken for the unstacking process is noted and distributions were estimated as shown in Table 8.

Table 8 Statistical data summary of the Unstacking process

Process involved	Time taken (seconds)	Mathematical expression
Unstacking process	1.96,2.26,2.43,2.39,2.49,1.52,1.71,1.93,1.75,2.36,1.58,2.02,1.96,1.97,2.45,2.35,1.67,1.59,2.08,2.15,1.87,2.02,1.67,1.51,2.46,1.52,2.48,2.37,1.60,1.77,2.27.	UNIF(3, 5)

Figure 7 represents the best fit for the obtained time data and its summary is shown in Table 9.

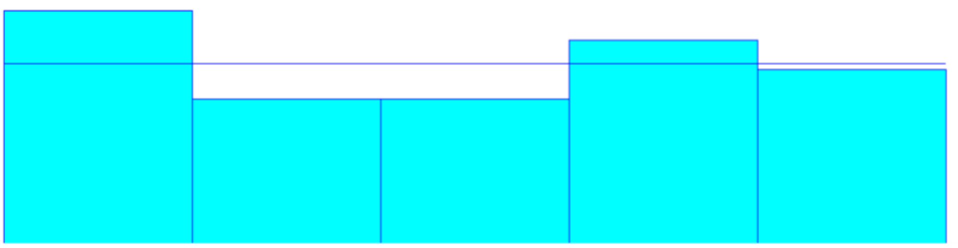

Fig. 7 Mathematical distribution of unstacking process – Uniform distribution

Table 9 Mathematical distribution of unstacking process

Distribution Summary	
Distribution:	Uniform
Expression:	UNIF (3, 5)
Square error	0.009157
Chi-square test	
Number of intervals	5
Degrees of freedom	4
Test statistic	1.42
Corresponding p-value	0.75
Histogram results	
Histogram Range	3 to 5
Number of Intervals	5

Process module is used to define unstacking and time is entered as processing time in the module. After the unstacking process, the parts leave the system. The detailed results were discussed in the subsequent chapters.

3.Results and discussions

As the industry is running only for an eight-hour shift per day the simulation was run for 1 day 8 hours duration for multiple replications to ensure the best result.

3.1 Existing system simulation results

It can be found from the results that the throughput was only 7 fills were only produced in an 8-hour shift per day against the ideal capacity of 16 per day. The queue statistics shown in the table indicates there is much waiting time for the binding process as well as gluing process. They can be considered as the bottleneck machines or processes. Table 11 indicates the number waiting which also tells us about the bottleneck processes since the process after gluing and binding were starving for the jobs.

Table 10 Process Waiting time

Waiting time for	Time (minutes)
Binding process	180
Gluing process	18
Stacking process	0
Unstacking process	0

Table 11 Number waiting

Number waiting	Time (minutes)
Binding process	657
Gluing process	830
Stacking process	0
Unstacking process	0

Improving or addressing the bottlenecks will definitely improve the productivity. Hence a new model was proposed by combining the gluing and stacking process.

3.2 Modified design

Presently manual stacking is done for the fills which are being mechanized by using a simple pulley and motor system as shown in the below figure 8. The bill of materials required are discussed below

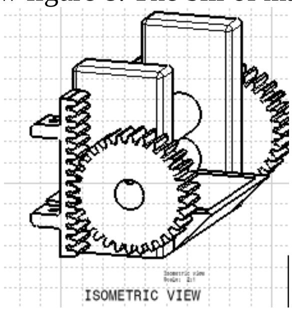

Figure 8 modified Gluing apparatus

The modifications suggested the optimizing the gluing and stacking process using two rack and pinion systems. The rack should run along the entire vertical face of the column, on which the gluing apparatus, with the mating pinion gear, will be fixed. The construction of the column has to be modified, to account for the additional load of the gluing apparatus. Table 12 shows the bill of materials required for the modification and also the cost involved to add these components into the system.

Table 12 Bill of Materials

Sl. No.	COMPONENT		APPROXIMATE COST(in INR)
1	Pinion gear (X2)		28000
2	Rack(X2) (for a length of 1800mm)		16800
		TOTAL	44800

3.3 Finite element analysis

After modeling the modifications, a Finite element analysis was carried out using ANSYS to study the structural integrity of the existing column. Since the integration with the existing system will reduce the final cost for implementation i.e. to the existing system a 6 kg motor need to be placed on the top of the column for the vertical motion of the machine. The deformation of the current system was shown in figure 9. From the results, it can be found that the existing system was prone to deformation and the thickness of the column needs to be improved or modified.

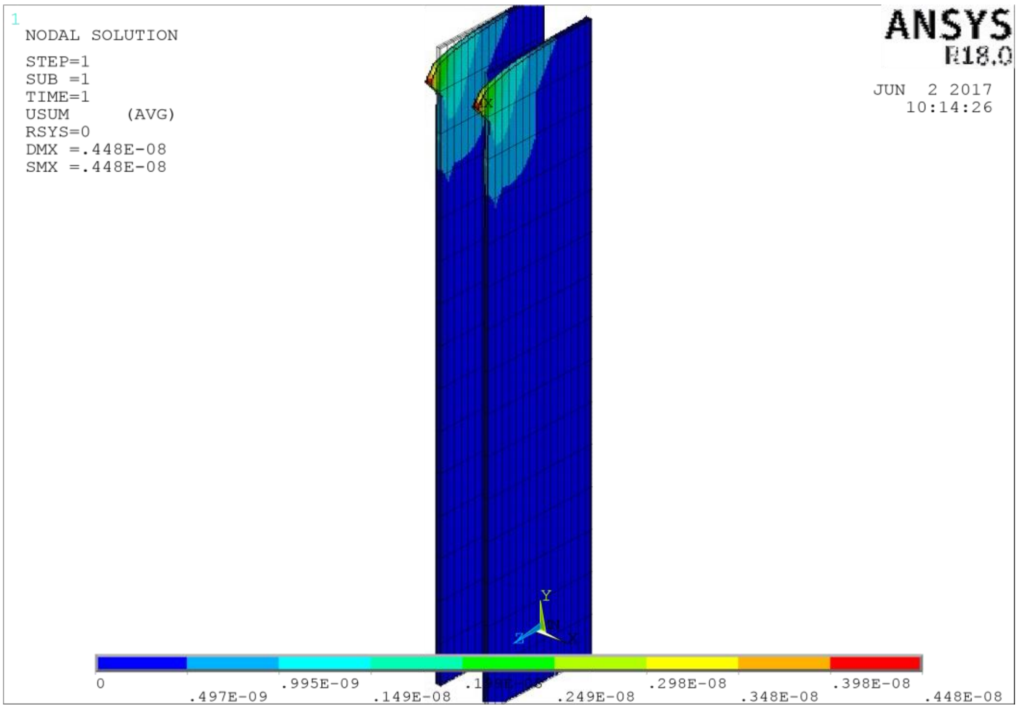

Fig. 9 Column FEM analysis result

The figure no 10 indicates the improved columns thickness with supports was given to the top side of the columns. The machine's weight was supported properly in the current model setting.

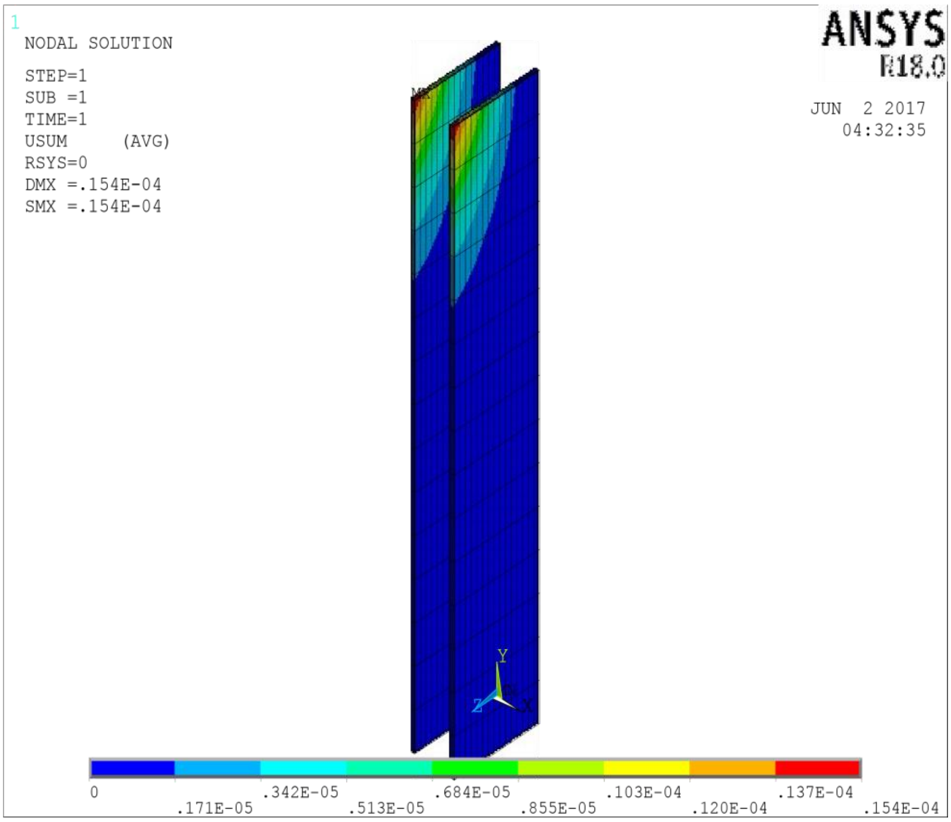

Fig.10 Acceptable column- FE Analysis

It can be found that the deflection was minimal when the column has an additional thickness of 4mm. The modifications suggested to optimizing the gluing and stacking process using two rack and pinion systems. The rack should run along the entire vertical face of the column, on which the gluing apparatus, with the mating pinion gear, will be fixed. The construction of the column has to be modified, to account for the additional load of the gluing apparatus. Considering these modifications, the final bill of materials was shown in Table 13.

Table 13 Bill of Materials

Sl. No.	COMPONENT	APPROXIMATE COST(in INR)
1	Pinion gear (X2)	28000
2	Rack(X2) (for a length of 1800mm)	16800
3	Modified column(X7) (Mild steel of thickness 4mm)	4200
	TOTAL	49000

Figure 11 indicates the modifications like rack and pinion system incorporated to the existing setup.

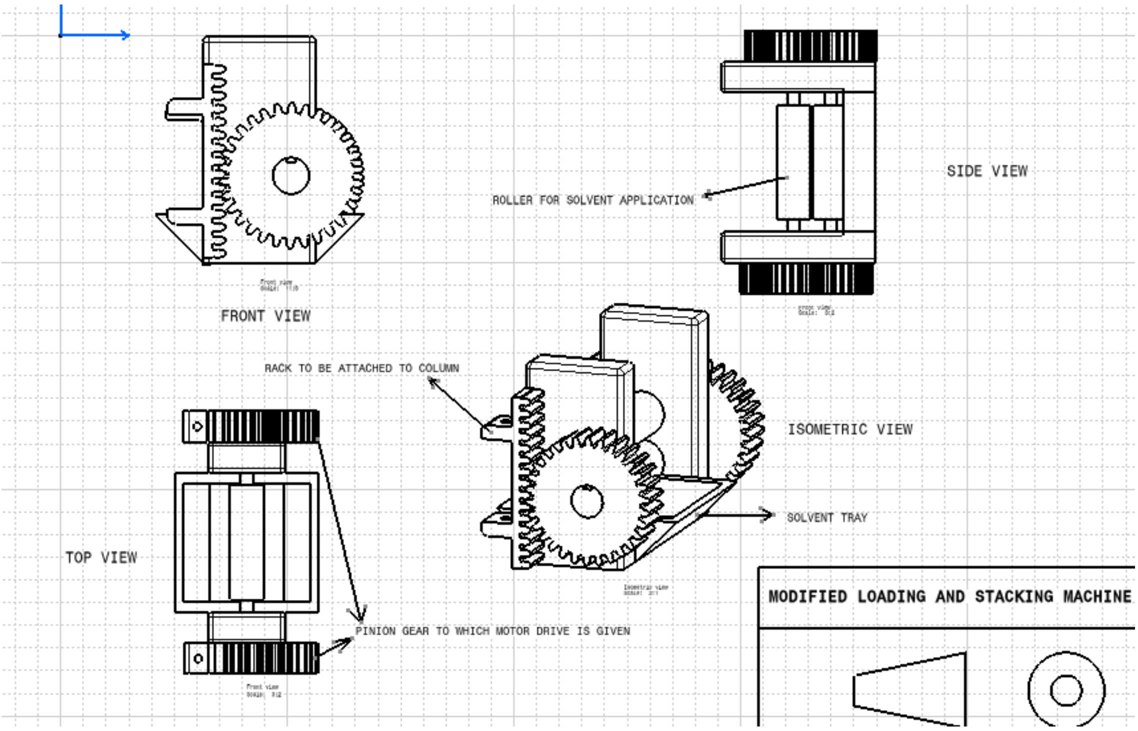

Fig.11 Gluing apparatus after modification (part of the rack to be attached to the column is shown here)

4.Verification for the process improvement after modification.

The process layout of the modified model is shown in figure 12. It involves mounting the previously available machine to the available vertical column so that Gluing and stacking were combined and thereby reduction in their operation time.

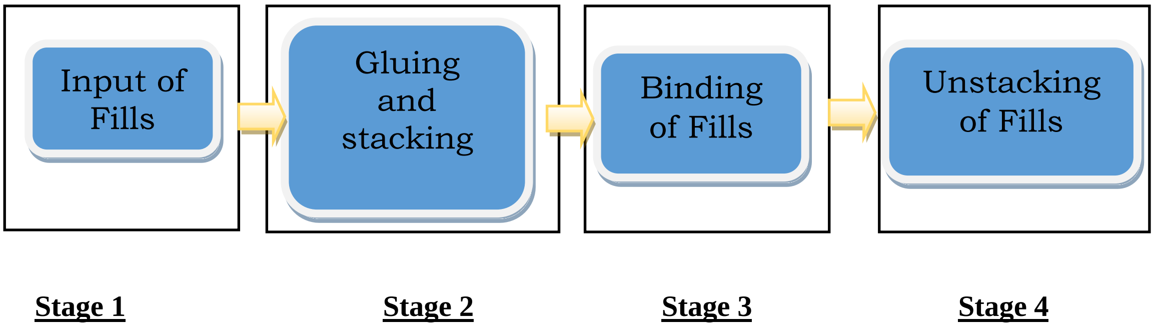

Fig. 12 Optimized process layout

The corresponding arena model was shown in the figure 13 where the processes were modifed for gluing and stacking, all other times will remain as the same in stage 1, 3 and 4.

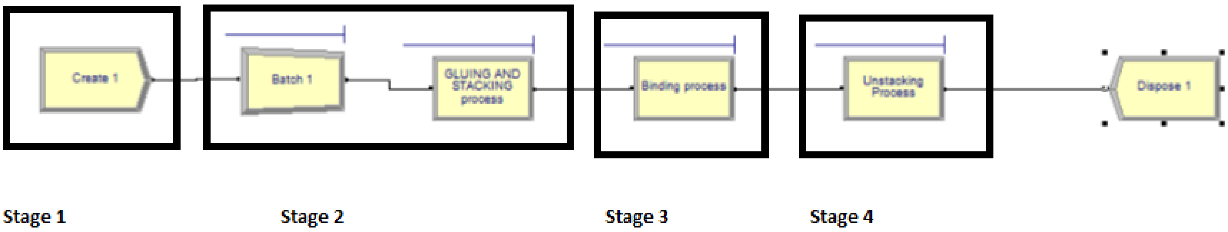

Fig. 13 Simulation of optimized model

During the stage 2 process in which combines both the gluing and stacking process by mounting the machine to the vertical column. The machine moves up and down right and left using a motor and a rack and pinion setup and the time taken will reduce to 1 second and 2 seconds as the maximum. Therefore we are going for triangular distribution TRIA (0.5, 1.8, 2.5) with minimum time as 0.5 seconds mean time as 1 seconds and maximum as 2 seconds.

4.1 Process modified results

The results obtained from the modified model shows that there is an increase in throughput. As its showing in figure 14, there were 14 completed fills after the modification.

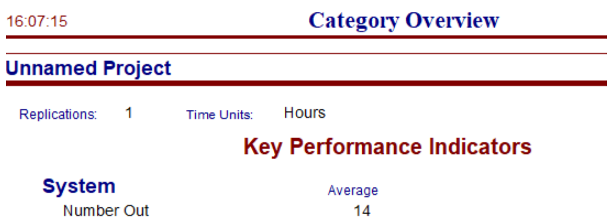

Fig 14: Number out from arena model

We can observe that there is a change in the waiting time and number waiting for each process as is shown in table 14 and 15. Previously gluing was a bottleneck process now it's completely removed from bottleneck process processes.

Table 14 Waiting time for modified model

Waiting time	Time (minutes)
Binding process	153
Gluing and stacking process	0
Unstacking process	0

Table 15 Number waiting for modified model

Number waiting	Time (minutes)
Binding process	557
Gluing and stacking process	0
Unstacking process	0

5.Conclusion

On comparison of both the models, it can be found that the number of pieces per day has increased from 7 to 14 fills per day as is shown in figure 15.

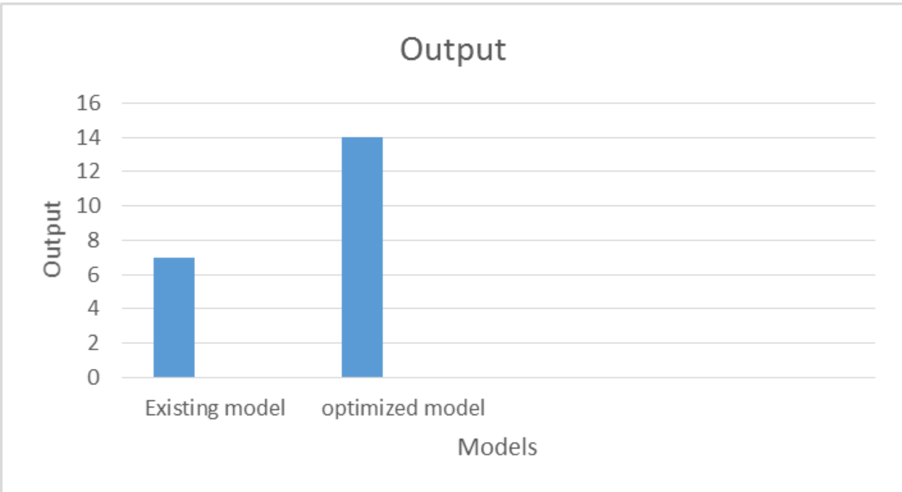

Fig. 15 Comparison between output of existing and modified model

It can also be noted that the waiting time involved in the processes are also able to reduce by the implementation of design modifications was shown in figure 16.

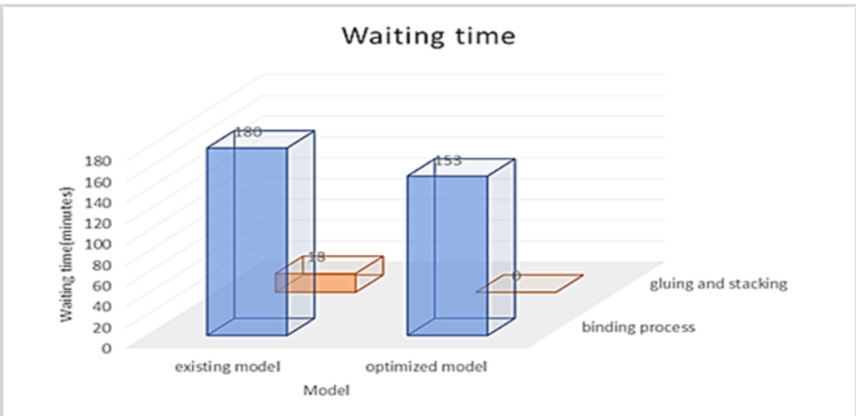

Fig. 16 comparison between waiting periods of existing and modified model

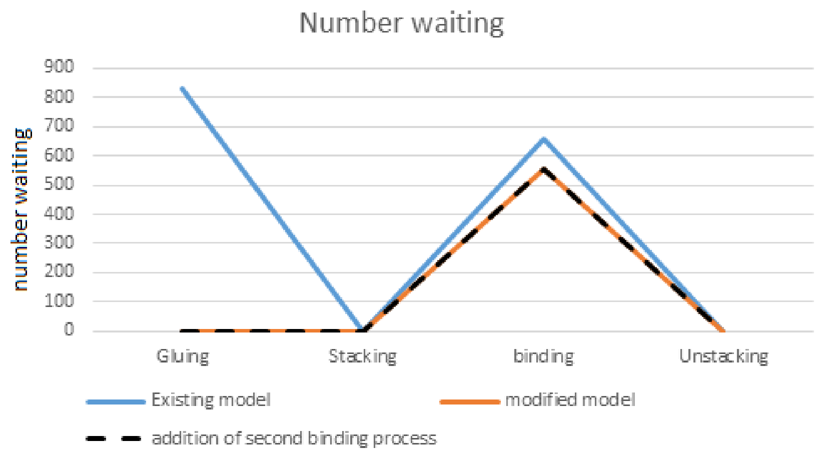

Fig.17 Graph comparing the number waiting time

Figure 17 indicates the comparison of existing model and modified model. In addition to this modified model, we added a second binding machine to check whether there will be any drastic reduction in the queue for the binding process. But it's shown that only a negligible change will occur to the binding process queuing system after the addition of the second machine. Therefore, the previous model will be the optimized one which can produce nearly 14 fills per day.

References:

[1]. Web reference http://www.enexio.com
[2]. Nyemba, W. R., & Mbohwa, C. (2017). Modelling, Simulation and Optimization of the Materials Flow of a Multi-Product Assembling Plant. *Procedia Manufacturing*, *8*, 59-66.
[3]. Fanti, M. P., Iacobellis, G., Rotunno, G., & Ukovich, W. (2013, August). A simulation based analysis of production scheduling in a steelmaking and continuous casting plant. In *Automation Science and Engineering (CASE), 2013 IEEE International Conference on* (pp. 150-155). IEEE.
[4]. Bekker, J., & Guittet-Remaud, S. (2000). Simulation in Supply Chains: An Arena basis. *The South African Journal of Industrial Engineering*, *11*(2).
[5]. Liong, C. Y., & Loo, C. S. (2009). A simulation study of warehouse loading and unloading systems using Arena. *Journal of Quality Measurement and Analysis*, *5*(2), 45-56.
[6]. K.Rameshkumar, K. M. mohanasundaram, P. Krishnakumar and A. sumesh. *Simulation optimization in a Kanban controlled Flow shop,* int. conference proceedings, ORSI, 2008.
[7]. K.Rameshkumar, Ciby Austin V T, P. Krishnaumar and A. Sumesh. *Productivity improvement of a Manufacturing Enterprise using lean tools: A case study in Discrete Manufacturing sector*, Indore Management journal, 2011, 3(2), 34- 49.
[8]. Adam, G.K., "Modelling and simulation with Arena of a mechatronics system for hydraulic tubes construction", In Book: Computational Methods in Circuits and Systems Applications, Electrical and Computer Engineering Series, N.•. Mastorakis, I.A. Stathopulos, C. Manikopoulos, G.E. Antoniou, V.M. Mladenov, I.F. Gonos (eds), WSEAS Press, ISBN: 960-8052-88-2, pp.105-108, 2003.*Modelling and simulation with Arena of a mechatronics system for hydraulic tubes construction*
[9]. Greasley, A. (2008). Using simulation for facility design: A case study. *Simulation Modelling Practice and Theory*, 16(6**)**, 670-677.
[10]. Aboueljinane, L., Jemai, Z., & Sahin, E. (2012, December). Reducing ambulance response time using simulation: The case of Val-de-Marne department Emergency Medical Service. In *Simulation Conference (WSC), Proceedings of the 2012 Winter* (pp. 1-12). IEEE.

[11]. Wang, T., Guinet, A., Belaidi, A., & Besombes, B. (2009). Modelling and simulation of emergency services with ARIS and Arena. Case study: the emergency department of Saint Joseph and Saint Luc Hospital. *Production Planning and Control*, *20*(6), 484-495.
[12]. Chetouane, F., Barker, K., & Oropeza, A. S. V. (2012). Sensitivity analysis for simulation-based decision making: Application to a hospital emergency service design. *Simulation Modelling Practice and Theory*, *20*(1), 99-111.
[13]. Zarkeshzadeh, M., Zare, H., Heshmati, Z., & Teimouri, M. (2016). A novel hybrid method for improving ambulance dispatching response time through a simulation study. *Simulation Modelling Practice and Theory*, *60*, 170-184.
[14]. RAHMAN, C. M., & SABUJ, S. U. (2015). PROCESS FLOW IMPROVEMENT PROPOSAL OF A BATCH MANUFACTURING SYSTEM USING ARENA SIMULATION MODELING. *Review of General Management*, *21*(1).