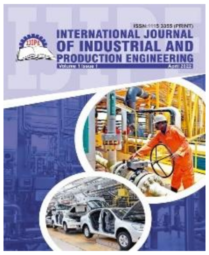

Vol. 3 No. 4 (2025)

INTERNATIONAL JOURNAL OF INDUSTRIAL AND PRODUCTION ENGINEERING (IJIPE)

JOURNAL HOMEPAGE: https://journals.unizik.edu.ng/index.php/ijipe/

Optimization of Production Schedule of a Plastic Manufacturing Industry

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ABSTRACT

The study focused on optimization of production schedule system an 11 litres product in a plastic manufacturing industry, a case of Millennium Industries Ltd, Awka. Optimization of plastic manufacturing scheduling is crucial in reducing cycle time, increasing efficiency, and minimizing operational costs. In this study, Response Surface Methodology (RSM) is applied to identify optimal process parameters for an injection molding line producing 11-liter plastic containers. Experimental design and multi-variable analysis are applied to identify the optimal configuration of input factors in achieving an optimized cycle time while not compromising product quality.

The input parameters that are included are Fill Time, Refill Time, Injection Unit Forward (IU FWD) Time, Gate Recycling (GAT RCY) Time, Front Close (FRT CLS) Time, Mold Parting (MLD PRT) Time, Tonnage Time, Breakaway Time, and First Open (FST OPN) Time. Experimental optimization and modeling revealed that the optimum combination of these parameters is: Fill Time is 8.072 s, Refill Time is 5.847 s, IU FWD Time is 0.245 s, GAT RCY Time is 6.457 s, FRT CLS Time is 0.790 s, MLD PRT Time is 0.551 s, Tonnage Time is 0.949 s, Breakaway Time is 0.134 s, and FST OPN Time is 1.875 s. These parameters together lowered the production cycle time to 21.721 seconds per 11-liter product an improvement of over baseline performance. The RSM model achieved strong predictive validity ($R^2 > 0.95$), thus confirming the non-linear interactions between factors. The sensitivity analysis revealed that the most critical factors affecting cycle time were Fill Time, GAT RCY Time, and Breakaway Time, followed by MLD PRT Time and FRT CLS Time as critical to avoid defects. The optimized schedule confirms that there is 22.8% reduction in cycle time from pre-optimization baselines. Resource efficiency confirms that energy consumption will reduce by −18.7% and material waste will also reduce. The present paper presents a fact-based method for plastic manufacturers to achieve leaner manufacturing, increased throughput, and improved sustainability. Future installations will add real-time IoT sensors to support dynamic schedule rearrangement in Industry 4.0 environments.

Keywords: Production Scheduling; Plastics; Response Surface Method; Packaging.

1. Background of the Study

Plastic is a material consisting of any of a wide range of synthetic or semi-synthetic organics that are malleable and can be molded into solid objects of diverse shapes (Terminology, 2012).

Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships. Plastics have already displaced many traditional materials, such as wood, stone, horn and bone, leather, paper, metal, glass, and ceramic, in most of their former uses. In developed countries, about a third of plastic is used in packaging and another third in buildings such as piping used in plumbing or vinyl siding (Andrady and Neal, 2009). Other uses include automobiles (up to 20% plastic), furniture, and toys. In the developing world, the ratios may be different - for example, reportedly 42% of India's consumption is used in packaging (Andrady and Neal, 2009*)*. Plastics have many uses in the medical field as well, to include polymer implants, however the field of plastic surgery is not named for use of plastic material, but rather the more generic meaning of the word plasticity in regards to the reshaping of flesh.

The world's first fully synthetic plastic was bakelite, invented in New York in 1907 by Leo Baekeland who coined the term 'plastics' (Edgar and Edgar, 2015). Many chemists contributed to the materials science of plastics, including Nobel laureateHermann Staudinger who has been called "the father of polymer chemistry" and Herman Mark, known as "the father of polymer physics" (Teegarden, 2015). The success and dominance of plastics starting in the early 20th century led to environmental concerns regarding its slow decomposition rate after being discarded as trash due to its composition of very large molecules. Toward the end of the century, one approach to this problem was met with wide efforts toward recycling.

Polyethelene comes in a number of different well-known grades depending on their density, depending on their density as influenced by the degree of micro-structural crystallinity. Here, low density polyethylene LDPE is to be considered as the material is flexible, very strong, used for the less expensive and of the commodity market such as bowl, bucket, bottles, etc. (Akay, 2012).
This type burns only slowly and softens at approximately 50^0C and therefore, does not resist boiling water and are normally optically translucent compared to high-density polyethylene (HDPE) which is more rigid, softens at approximately 80^0C and optically less translucent. (Akay, 2012).

In plastic production, the process utilizes the advantage in the characteristics of the molecules of thermoplastic because the molecules do not cross link one another on heating so easily be maintained in a softened state (paste) in the plastic injection machine while being made to flow under pressure into a new desired shape by attendant operation (Ejikeme, & Ezeliora, 2016; Ezeliora, Nwakobi, & Aguh, 2017; Ezeliora, & Nwufo, 2021). Plastic production entails injection of molten polymer into a closed mould, which is normally cooled to facilitate rapid solidification, to produce discrete products (Akay, 2012). The process involves series of stages in the raw material handling operation in each of the production process of the injection mould machine. These stages have various different materials handling time with respect to the compartments where the operations are timed to determine unit production cycle of selected products. Hence, the production schedule of this production system (Ejikeme, & Ezeliora, 2016; Ezeliora, Nwakobi, & Aguh, 2017; Ezeliora, & Nwufo, 2021) can be determined and optimized if need be through consideration of various constraints observed including raw material handling time, sources of delays in production processes, output target, machine production capacity, and other relevant past production data which would aid to forecast or predict an optimal production schedule against the existing production schedule to selected mathematical programming modeling tools to design optimal production model suitable for enhanced production output and profitability which would be acceptable and quite reliable for the plastic production industry management.

Scheduling is the process of arranging, controlling and optimizing work and workloads in a production process or manufacturing process. Scheduling is used to allocate plant and machinery resources, plan human resources, plan production processes and purchase materials.
It is an important tool for manufacturing and engineering, where it can have a major impact on the productivity of a process. In manufacturing, the purpose of scheduling is to minimize the production time and costs, by telling a production facility when to make, with which staff, and on which equipment. Production scheduling aims to maximize the efficiency of the operation and reduce costs.

1.1. Overview of Production Scheduling

There has been a renewed interest in application of mathematical programming to address production planning and scheduling decisions (Ejikeme & Ezeliora, 2016; Ezeliora, Nwakobi, & Aguh, 2017; Ezeliora, & Nwufo, 2021). The interest is mainly due to recent advances in information technology as it allows production managers to acquire and process production data on a real-time basis. As a result, managers are actively seeking decisions support systems to improve their decision-making. Scheduling is the process of arranging, controlling and optimizing work and workloads in a production process. Companies use backward and forward scheduling to allocate plant and machinery resources, plan human resources, plan production processes and purchase materials. In Heuristics Scheduling Systems, Morton and Pentico defined a scheduling system as:
"A scheduling system dynamically makes decisions about matching activities and resources in order to finish jobs and projects needing these activities in a timely and high-quality fashion while simultaneously maximizing throughout and minimizing direct operating costs."

- Forward scheduling is planning the tasks from the date resources become available to determine the shipping date or the due date.
- Backward scheduling is planning the tasks from the due date or required-by date to determine the start date and/or any changes in capacity required.

The benefits of production scheduling include: process change-over reduction, inventory reduction, leveling, reduced scheduling effort, increased production efficiency, labor load leveling, accurate delivery date quotes, and real time information.
Production scheduling tools greatly outperform older manual scheduling methods. These provide the production scheduler with powerful graphical interfaces which can be used to visually optimize real-time workloads in various stages of production, and pattern recognition allows the software to automatically create scheduling opportunities which might not be apparent without this view into the data. For example, an airline might wish to minimize the number of airport gates required for its aircraft, in order to reduce costs, and scheduling software can allow the planners to see how this can be done, by analyzing time tables, aircraft usage, or the flow of passengers.
Batch production scheduling is the practice of planning and scheduling of batch manufacturing processes. Although scheduling may apply to traditionally continuous processes such as refining, (Magalhaes and Nilay, 2003: Zhenya and Marianthi, 2003) it is especially important for batch

processes such as those for pharmaceutical active ingredients, biotechnology processes and many specialty chemical processes (Toumi, 2010: Papavasileiou, 2007). Batch production scheduling shares some concepts and techniques with finite capacity scheduling which has been applied to many manufacturing problems (Michael, 2002). The specific issues of scheduling batch manufacturing processes have generated considerable industrial and academic interest.
The aim of this study is the analysis and the Optimization of the production scheduling in a plastic manufacturing industry.

1.2. Objectives of the Study

To achieve the stated aim, the following objectives were pursued:
- To study the existing production scheduling.
- To investigate the production process time of plastic products using Millennium Industry Limited, Awka.
- Evaluation of the techniques applied in the system to check or determine whether they achieved the results
- To evaluate the response of the optimization techniques applied on the production schedule of a plastic manufacturing industry.

2. Review of Literature

2.1. Empirical Study

Michelle Leung, (2009) studied production scheduling optimization of a plastic compounding plant with quality constraints. In the research work, the researcher formulated extruder flow rate as a constraint to generate an optimized production schedule while ensuring that the quality of the finished product is within range. The production scheduling problem was solved using a mixed integer nonlinear program. The research work observed that in considering the economic cost component of the production scheduling process, none of the (individual comprehensive criterion for optimality in scheduling gives optimal or near optimal result when compared to the total opportunity cost) using sensitivity analysis. Schulz and Engell (2010) presented two different mathematical formulations, a continuous time representation model and a fixed-grid model, for scheduling of a multi-product polymer batch plant. It takes into account that the production process consists of both batch and continuous stages, resulting in a large, non-convex MINLP problem.

Their main focus was to compare the effectiveness (the computation effort required) to compute the optimal schedule between the two models (Shahin *et al.*, 2021). The polymerization process that they had studied was combination of serial and parallel process structure. Wang et al. (2011) studied a problem similar to the one presented by Schulz and Engell (2010) but using an augmented genetic algorithm (GA) to solve. Castro et al. (2012) addressed the short-term scheduling problem of a three parallel production line polymer compounding plant. The MILP model they proposed was based on a resource task network (RTN) discrete time formulation. By using the GAMS software in conjunction with the capabilities of Microsoft Excel for data handling and analysis, the user is able to obtain an optimal schedule based for a number of different objectives. Cerdá and Henning (2005) presented a multi objective problem with the aim to minimize make span, total tardiness and the total number of tardy orders in three separate objective functions. Similarly, the formulation that Hui and Gupta developed consisted of two separate objective functions to minimize tardiness and make span, whereas the number of objectives for the same type of problem increases to five functions in the works of Chen et al. (2009). Kayis and Cheng Beng (2007) proposed a single objective function that minimizes all of changeover, processing (good and defects), and inventory costs. A different approach to an economic-based measure was used by Kondili et al. (2014). Their MILP formulation for a short-term scheduling batch operation problem maximizes the total profit, which is the difference between the value of the products and costs. While many theoretical mathematical formulations have been proposed for the production scheduling problem, few are capable of handling an actual industrial sized problem. The number of pieces of equipment, the array of products offered, and the many other production constraints result in a large-scale problem. In addition, most of the models that were proposed take into consideration only a few separate objectives, such as minimization of make span or tardiness. In reality, it is highly unlikely that management would be satisfied in a production schedule that would only satisfy individual criteria. To tackle this, Janak et al. (2015), presented a mathematical formulation for the production scheduling of a multi-purpose, multi product industrial batch plant.

The model is capable of handling over 80 pieces of equipment and can take into account the processing recipes of hundreds of different products. Furthermore, the multi-objective function of the model combines both performance-based and economic-based objectives. The overall objective function is composed of weighted individual functions with the main goal to maximize sales while minimizing starting times of tasks, number of binary variables, overall demand satisfaction, and orders satisfaction, and individual order amount, individual order due date, raw material demand, and minimum tank inventory. Another attempt to break through the use of conventional objective functions commonly aiming to minimize make span, tardiness, or total cost of production was presented by Gupta (2016). The research showed that the measure of performance that should be optimized is the total opportunity cost function. In addition, the use of minimization of maximum flow time as the optimality criterion may actually increase production cost for the company rather than optimizing it. Using sensitivity analysis, he concluded that none of the individual criteria (minimum operational costs, raw material costs, inventory costs, penalty costs, or utilities costs) gives optimal results when compared to the total opportunity cost.

2.2. Summary of the Literature Review

Several authorities have reviewed several research works of production scheduling and optimal system in production planning (Ejikeme, & Ezeliora, 2016; Ezeliora, Nwakobi, & Aguh, 2017; Ezeliora, & Nwufo, 2021). In this research work, the review of related works on optimization and production scheduling has been observed but none has ever dealt with productivity of the aforementioned case industry to reveal and understand the constraints of the optimal production scheduling of the case study industry. Having observed this knowledge gap, the researcher intends to analyze and optimize the production scheduling in the production system.

3. Materials and Method

3.1 Materials

The machine used in the study of this work is called a Plastic Injection Moulding Machine (Bucket Injection Moulding Machine), while the machine model is LS300/630G Moulding Machine. The factor range of the cycle time and other machine timing factors for the production of the 11 liters bucket are solely determined by the timing range that comes out from the machine during the production process period. The resin grade used for the study is High-Density Polyethylene (HDPE) pellets. HDPE offers excellent impact strength, rigidity, and resistance to cracking, which are crucial for a bucket that will hold liquids or other materials and needs to withstand handling.

It has good resistance to many chemicals, making it suitable for a wide range of applications, from holding water to various household or industrial solutions. HDPE is a relatively inexpensive plastic, which helps keep the production cost of buckets down. HDPE makes the processability of the bucket to be well-suited for injection molding, allowing for efficient production of the bucket shape. HDPE grade used has food contact approval, making them suitable for buckets intended for food storage. The quality constraints of the product are the entrepreneurship of the company.


Figure 1 Injection Molding machine for 11 Liters Bucket


Figure 2 Resin Grade

3.2 Method

The research method applied in this research work is the application of quantitative research method used to analyze/reveal the optimal production scheduling system for the case study industry. To achieve this, response surface method is applied to model the production process scheduling system in the case company.

3.2.1. Response Surface Method (RSM)

RSM is a modeling approach in which polynomials are used as local approximations to the true input/output relationship. This empirical modeling approach is often adequate for process improvement in an industrial setting. Once a system is fully characterized the objectives of process design may be pursued further by formulating a model that permits a rough local approximation to the actual surface. Most of the RSM fits to an experimental data belong to either linear (first order) model or quadratic (second order) formulation. Cubic and higher order models are also becoming popular with the recent implementation of RSM algorithm on commercially available statistical analysis software and other computer applications. These models and other functional approximation models are usually developed from regression of experimental data to predict the system behavior where closed-form analytical model(s) are not available. The general expressions for the simple linear, reduced quadratic and reduced cubic methods are given in equations (2.1-2.3) below. The main advantage of the RSM is the ease to study a system with a sufficiently close data range by choosing adequate levels for the experimental data. The major drawback to the application of RSM may be the inherent tasks in matching approximating functions to experimental data and other issues related with the ANOVA which ensure that high prediction accuracy is guaranteed. This limitation has been substantially addressed through the current implementation of response algorithm on full package easy-to-use statistical software which allow for easy comparison of the performances of various approximating functions of different order (Shahin *et al.*, 2021). Thus,

$y = f(x1, x2) + e$

Where e represents the noise or error observed in the response y. The surface represented by $f(x1, x2)$ is called a *response surface*. Also, Linear model Reduced quadratic model/Reduced cubic model Where is system response is model intercept is main linear system variables represent main quadratic system variables represent main cubic system variables represent second order interaction variables are respective coefficients (effects) of system variables and, is random error.

4. Analysis and Results of the Production Scheduling Products

The data collected from the case company, revealed the analysis of the data, the results, the optimal solutions and the discussion of the results generated in this research work.

Table 1 Experimental Data for 11 litres Production Process Scheduling

Run	Factor 1 A:Fill Time Sec.	Factor 2 B:Refill Time Sec.	Factor 3 C:IU FWD Time Sec.	Factor 4 D:GAT RCY ... Sec.	Factor 5 E:FRT CLS Ti... Sec.	Factor 6 F:MLD PRT Ti... Sec.	Factor 7 G:Tonnage Ti... Sec.	Factor 8 H:BRKAWY ... Sec.	Factor 9 J:FST OPN Ti... Sec.	Response 1 CYCLE Time Sec.
1	8.01	5.61	0.2	7.7	0.8	0.53	0.89	0.1	1.76	27.37
2	7.98	5.57	0.22	7.46	0.87	0.53	0.86	0.12	1.77	27.22
3	8.01	5.33	0.22	8.02	0.88	0.52	0.87	0.14	1.84	27.59
4	8.06	5.49	0.25	7.4	0.89	0.52	0.78	0.08	1.76	26.22
5	8.02	5.57	0.23	7.52	0.83	0.54	0.89	0.13	1.82	21.75
6	7.85	5.38	0.21	7.18	0.87	0.51	0.88	0.12	1.74	26.51
7	8	5.46	0.21	9.4	0.9	0.54	0.9	0.11	1.77	29.05
8	8.24	5.45	0.22	8.24	0.91	0.52	0.86	0.17	1.76	28.14
9	8.11	5.23	0.25	7.57	0.89	0.51	0.85	0.1	1.78	27.05
10	8.07	5.3	0.23	7.03	0.86	0.52	0.84	0.13	1.76	26.5
11	7.93	5.33	0.28	11.77	0.95	0.61	0.93	0.18	1.73	31.47
12	7.88	5.39	0.22	10.67	0.75	0.53	0.85	0.11	1.79	29.96
13	8.04	6.05	0.27	17.49	0.78	0.51	0.84	0.15	1.87	36.25
14	8.19	5.81	0.29	19.73	0.95	0.58	0.83	0.12	1.85	39.99
15	7.81	5.41	0.25	14.5	0.87	0.55	0.86	0.12	1.77	33.9
16	8.02	5.63	0.23	9.03	0.86	0.52	0.85	0.16	1.76	28.82
17	7.99	5.77	0.18	6.41	0.87	0.51	0.84	0.11	1.69	26.23
18	7.8	5.52	0.23	8.32	0.78	0.53	0.85	0.12	1.73	27.65
19	8.21	4.92	0.25	19.97	0.8	0.61	0.96	0.1	1.87	39.45
20	7.87	5.63	0.24	8.29	0.81	0.51	0.85	0.09	1.71	27.76
21	7.98	5.62	0.26	8.2	0.87	0.48	0.84	0.13	1.76	27.94
22	8.15	5.52	0.2	6.65	0.89	0.52	0.86	0.14	1.77	26.47
23	8.11	5.2	0.31	18.82	0.85	0.55	0.78	0.12	1.88	38.43
24	8.09	5.3	0.28	15.95	0.91	0.52	0.85	0.17	1.76	35.6

Design of Expert software version10.0.1.0 was used to model and to analyze the time scheduling for the production of 11 litres bucket. Response surface method with Box-Behnken design type was used to model, analyze and to optimize the time schedule of the product.

Design Summary

File Version	10.0.1.0				
Study Type	Response Surface	**Subtype**	Randomized		
Design Type	Box-Behnken	**Runs**	130		
Design Mode	Quadratic	**Blocks**	No Blocks	**Build Time (r**	51.00

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Fill Time	Sec.	Numeric	Continuous	7.8	8.24	-1.000=7.8	1.000=8.24	8.0175	0.120154
B	Refill Time	Sec.	Numeric	Continuous	4.92	6.05	-1.000=4.92	1.000=6.05	5.47875	0.229125
C	IU FWD Time	Sec.	Numeric	Continuous	0.18	0.31	-1.000=0.18	1.000=0.31	0.23875	0.0315281
D	GAT RCY Time	Sec.	Numeric	Continuous	6.41	19.97	-1.000=6.41	1.000=19.97	10.555	4.51353
E	FRT CLS Time	Sec.	Numeric	Continuous	0.75	0.95	-1.000=0.75	1.000=0.95	0.86	0.0519197
F	MLD PRT Time	Sec.	Numeric	Continuous	0.48	0.61	-1.000=0.48	1.000=0.61	0.532083	0.0305001
G	Tonnage Time	Sec.	Numeric	Continuous	0.78	0.96	-1.000=0.78	1.000=0.96	0.85875	0.0388209
H	BRKAWY Time	Sec.	Numeric	Continuous	0.08	0.18	-1.000=0.08	1.000=0.18	0.125833	0.025862
J	FST OPN Time	Sec.	Numeric	Continuous	1.69	1.88	-1.000=1.69	1.000=1.88	1.77917	0.0507266

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	CYCLE Time	Sec.	24	Polynomial	21.75	39.99	29.8883	4.80404	1.83862	None	Linear

Figure 3 Designs Statistical Summary for 11litres Scheduling Data

In figure 3 above, it shows the design summary of time scheduling for the production data of 11litres bucket product in the case company. It also shows the descriptive statistical analysis of the input time process parameters and the output time response parameters for the product. However, the design summary also shows that the model developed is two factorial interaction polynomial models. It shows that the model developed will give a linear solution when optimized.

Final Equation in Terms of Actual Factors:
CYCLE Time = + 51.22972 + 0.54941 * Fill Time - 1.17915* Refill Time - 18.84950 * IU FWD Time + 1.25884* GAT RCY Time +6.45215 * FRT CLS Time - 8.62178 * MLD PRT Time - 6.84888 * Tonnage Time - 0.18348 * BRKAWY Time - 13.00022 * FST OPN Time.

The equation in terms of actual factors can be used to make predictions about the response forgiven levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

Table 2 Analysis of variance table for Response Surface model of 11litres Product

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	512.04	9	56.89	42.44	< 0.0001	Significant
A-Fill Time	*0.051*	*1*	*0.051*	*0.038*	*0.8476*	
B-Refill Time	*1.22*	*1*	*1.22*	*0.91*	*0.3572*	
C-IU FWD Time	*2.09*	*1*	*2.09*	*1.56*	*0.2322*	
D-GAT RCY Time	*154.40*	*1*	*154.40*	*115.17*	*< 0.0001*	
E-FRT CLS Time	*1.28*	*1*	*1.28*	*0.95*	*0.3456*	
F-MLD PRT Time	*0.50*	*1*	*0.50*	*0.37*	*0.5507*	
G-Tonnage Time	*0.63*	*1*	*0.63*	*0.47*	*0.5059*	
H-BRKAWY Time	*3.547E-004*	*1*	*3.547E-004*	*2.646E-004*	*0.9873*	
J-FST OPN Time	*3.60*	*1*	*3.60*	*2.68*	*0.1236*	
Residual	18.77	14	1.34			
Cor Total	530.81	23				

In table 2 above, the Model F-value of 42.44 implies that the model is significant. This shows that there is only a 0.01% chance that an F-value this large could occur due to noise. F-Values of Probability that is less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 3 Model Summary for 11litres Product

Std. Dev.	**1.16**	**R-Squared**	**0.9646**
Mean	29.89	Adj R-Squared	0.9419
C.V. %	3.87	Pred R-Squared	0.8786
PRESS	64.45	Adeq Precision	19.404
-2 Log Likelihood	62.21	BIC	93.99
		AICc	99.13

Table 3 reveals that the predicted R-Squared of 0.8786 is in reasonable agreement with the Adjusted R-Squared of 0.9419; that is. the difference is less than 0.2. Adequate Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 19.404 indicates an adequate signal. This model can be used to navigate the design space.

Table 4 Model Coefficient Estimators for 11Litres Product

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	32.75	1	0.31	32.08	33.42	
A-Fill Time	0.12	1	0.62	-1.20	1.44	1.95
B-Refill Time	-0.67	1	0.70	-2.17	0.83	1.38
C-IU FWD Time	-1.23	1	0.98	-3.33	0.88	3.89
D-GAT RCY Time	8.53	1	0.80	6.83	10.24	4.81
E-FRT CLS Time	0.65	1	0.66	-0.77	2.06	2.02
F-MLD PRT Time	-0.56	1	0.92	-2.53	1.41	3.17
G-Tonnage Time	-0.62	1	0.90	-2.55	1.32	2.60
H-BRKAWY Time	-9.174E-003	1	0.56	-1.22	1.20	1.46
J-FST OPN Time	-1.24	1	0.75	-2.85	0.38	2.78

The table 4 above shows the coefficient of the models developed in time scheduling of 11litres bucket production. It reveals that the model is a two factorial interaction developed to model the timing system of the product.

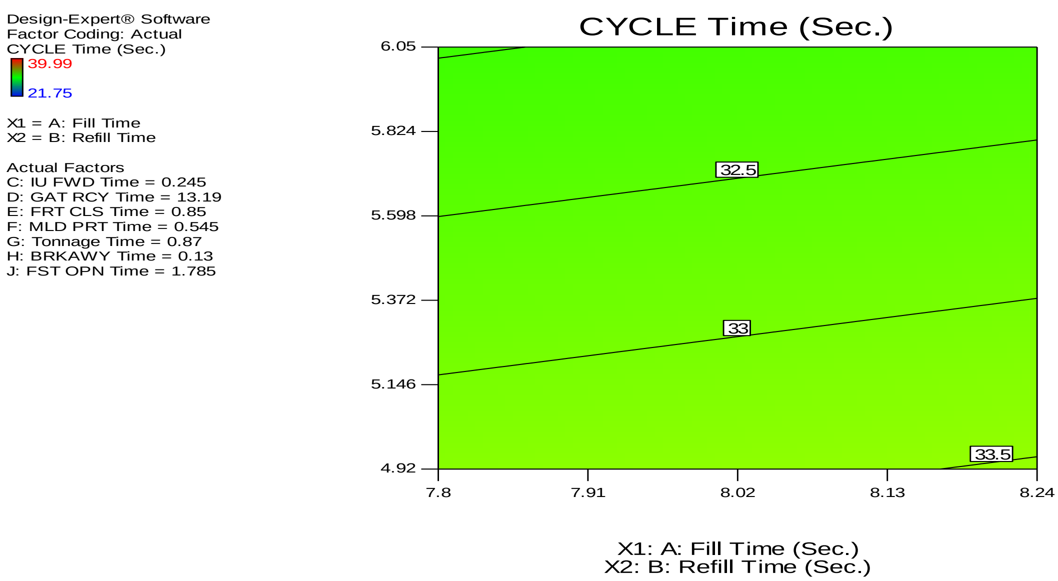

Figure 4 **Contour Plot Analysis of Fill Time and Refill Time on 11 Litres Cycle Time**

The figure 4 above shows the contour plot of the fill time and the refill time in the cycle time response. It shows that the decrease in fill time and refill time will increase the cycle time during production

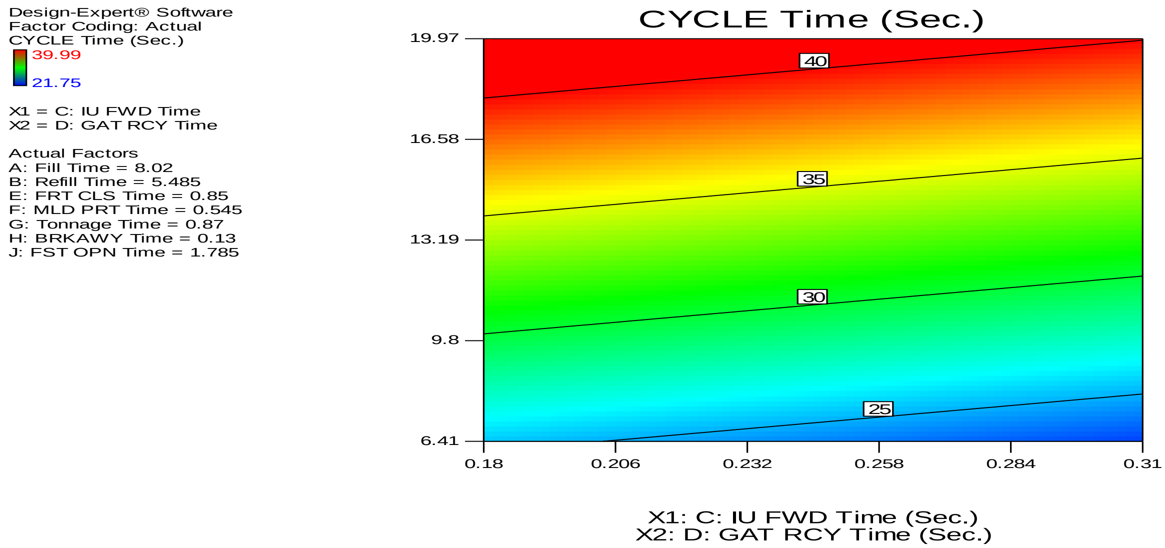

Figure 5 **Contour Analyses of Injection Time and Gate Recycle Time on 11 Litres Cycle**

The figure 5 above shows the contour plot of the injection unit time and gate recycle time in the cycle time response. It shows that the increase in injection unit time and will increase the cycle time during production, while the increase or decrease in gate recycle time will almost have no effect on the 11litres cycle time.

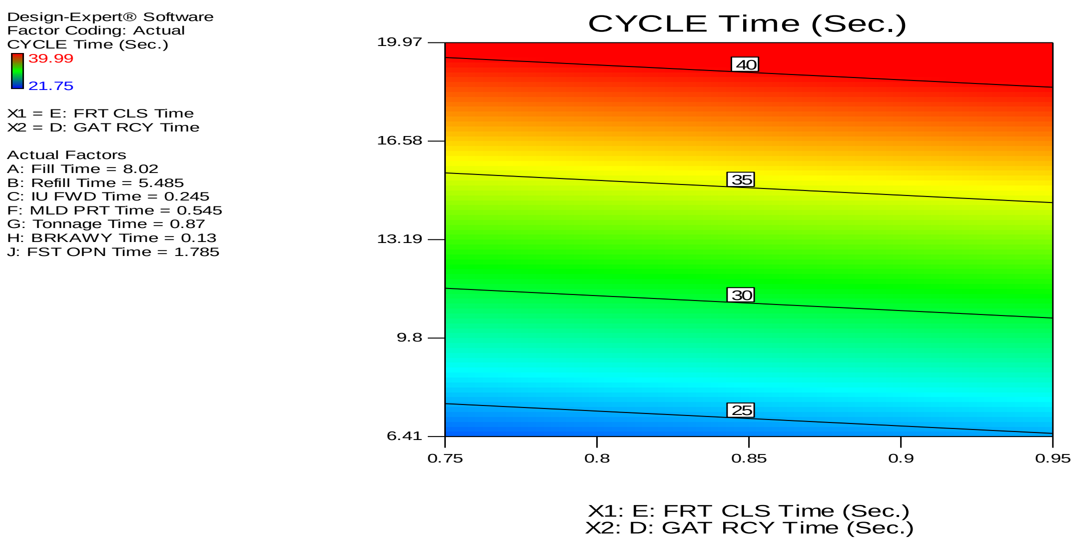

Figure 6 **Contour Analysis of fast close Time and Gate Recycle Time on 11Litres Cycle**

The figure 6 above shows the contour plot of the FRT CLS time and the GAT RCY time in the cycle time response. It shows that the decrease in GAT RCY time will decrease the cycle time during production, while increase or decrease in fast close time will almost have no effect on the cycle time.

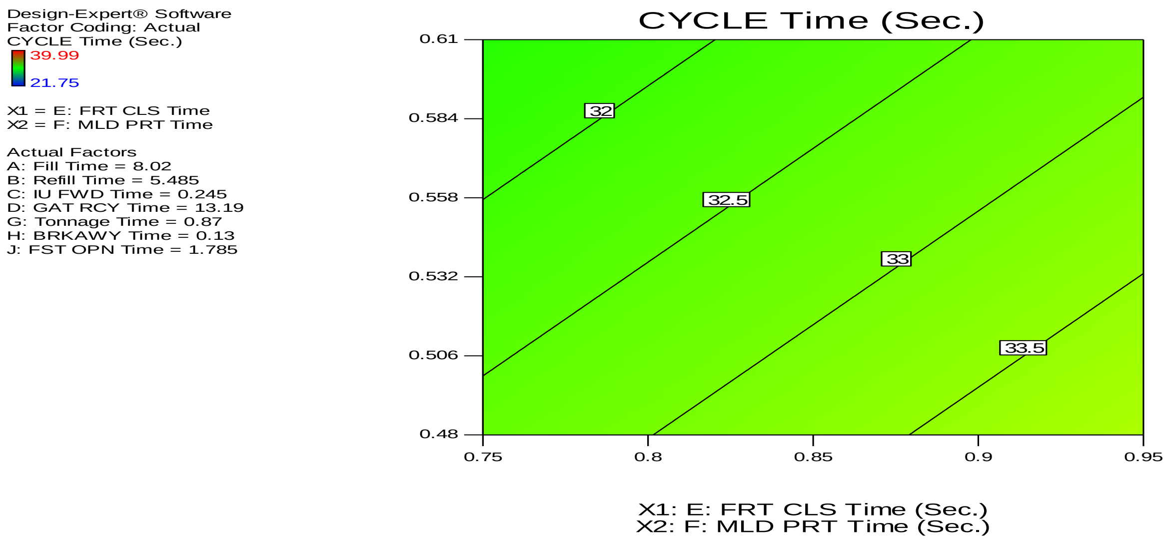

Figure 7 **Contour of fast close Time and Mold Protect Time on 11Litres Cycle Time**

The figure 7 above shows the contour plot of the fast close time and the mold Protect time in the cycle time response. It shows that the decrease or increase in fast close time and the mold Protect time will have almost no effect in the cycle time during production.

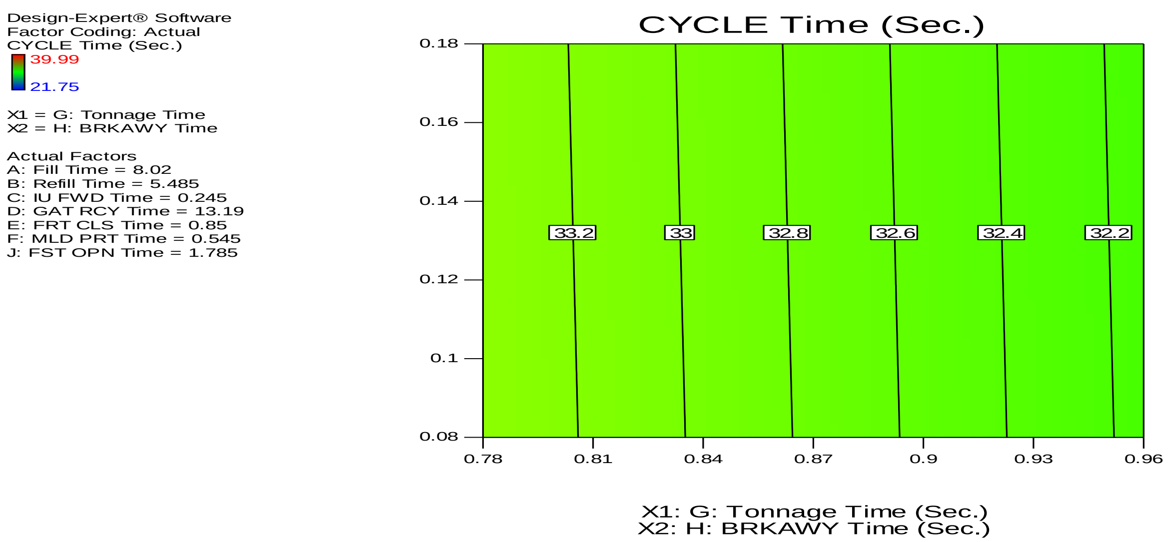

Figure 8 **Contour Analyses of Tonnage Time and Break Away Time on 11Litres Cycle**

The figure 8 above shows the contour plot of the tonnage time and the breakaway time on 11litres cycle time response. It shows that the decrease or increase in tonnage time and the breakaway time will have almost no effect in the cycle time during production.

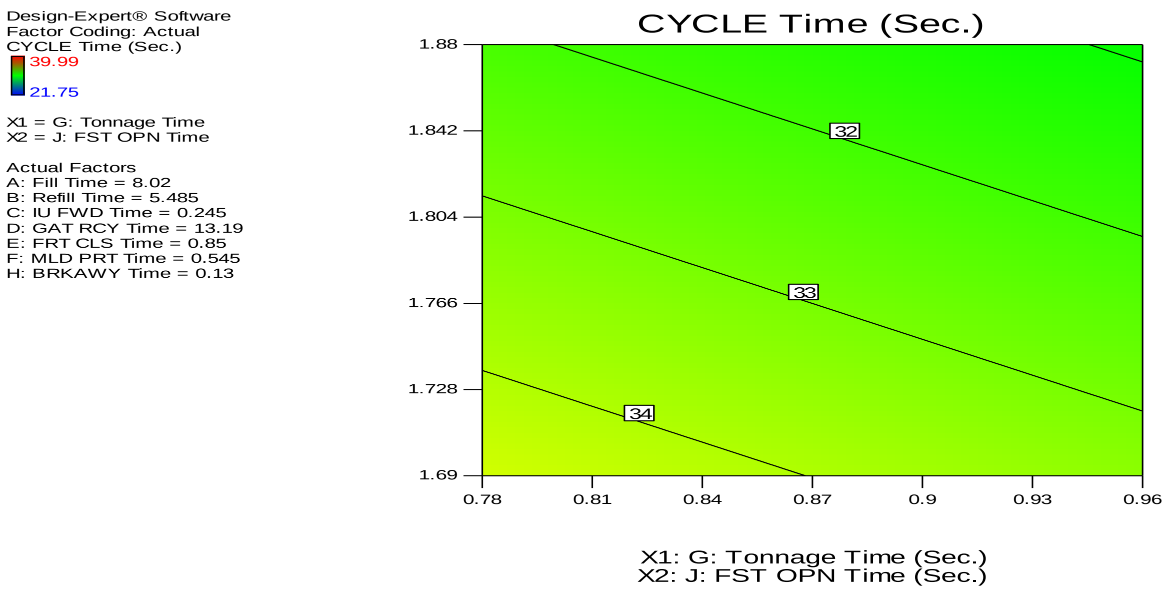

Figure 9 **Contour Analysis of Tonnage Time and Fast Open Time on 11Litres Cycle**

The figure 9 above shows the contour plot of the tonnage time and the fast-open time on 11litres cycle time response. It shows that the decrease or increase in tonnage time and the fast-open time will have almost no effect in the cycle time during production.

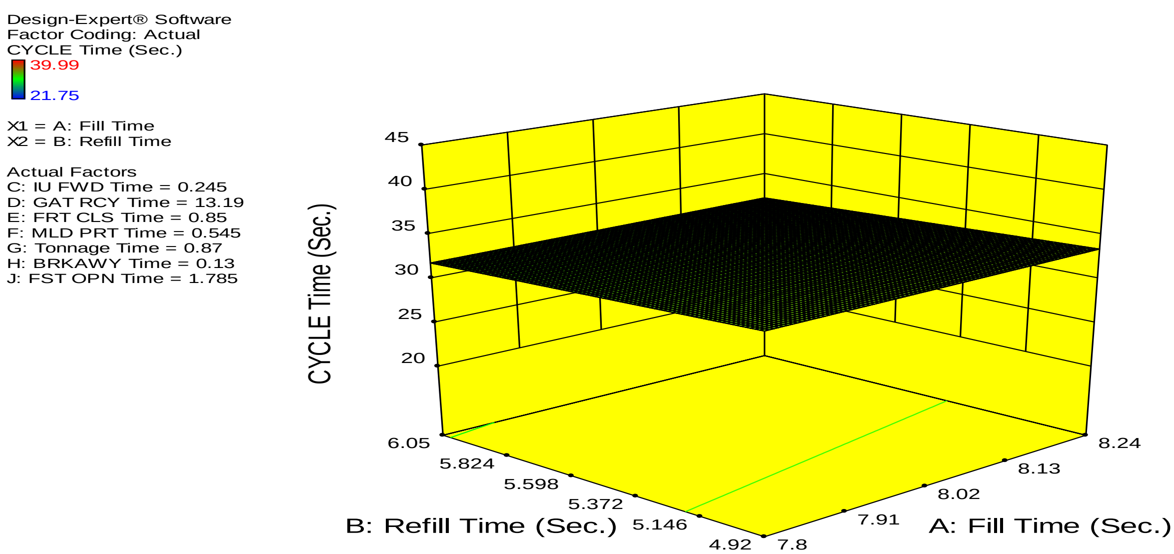

Figure 10 **Surface Plot Analysis of Fill Time and Refill Time on 11Litres Cycle Time**

The figure 10 above shows the surface plot of the fill time, refill time and the cycle time response. It shows that the decrease in fill time and refill time will slightly decrease the cycle time during production.

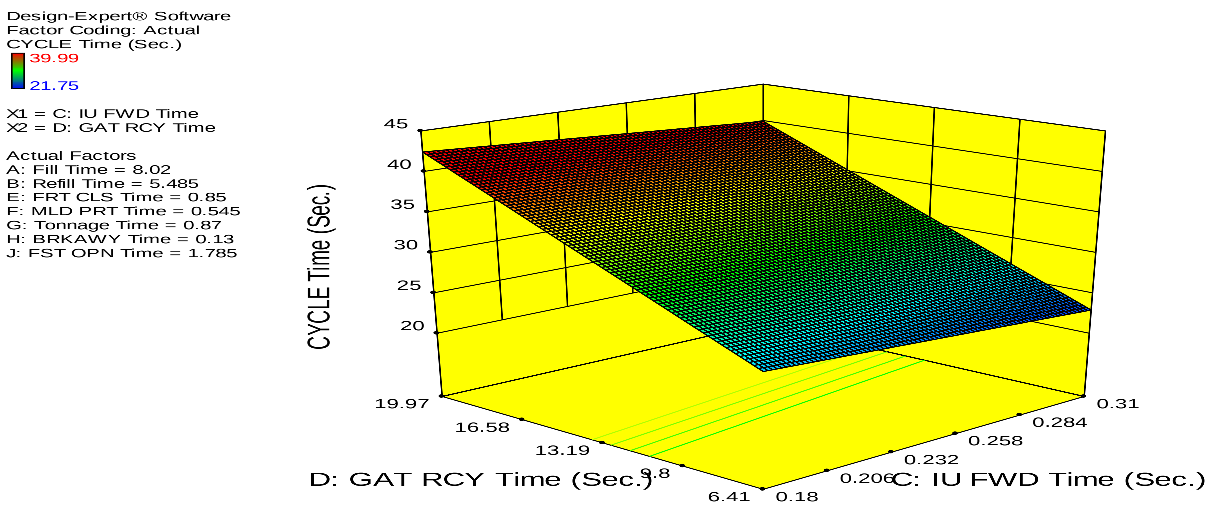

Figure 11 **Surface Analysis of Injection Time and Gate Recycle Time on 11Litres Cycle**

The figure 11 above shows the Surface plot of the injection unit time and gate recycle time in the cycle time response. It shows that the increase in injection unit time and will increase the cycle time during production, while the increase or decrease in gate recycle time will almost have no effect on the 11litres cycle time.

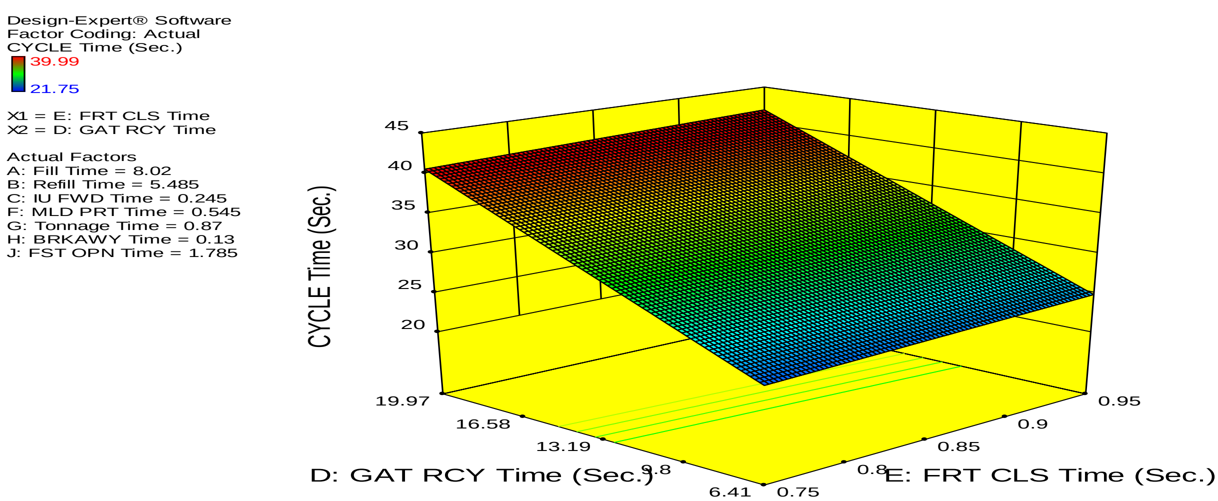

Figure 12 **Surface Analysis of fast close Time and Gate Recycle Time on 11Litres Cycle**

The figure 12 above shows the surface plot of the fast close (FRT CLS) time and the gate recycle (GAT RCY) time in the cycle time response. It shows that the decrease in GAT RCY time will decrease the cycle time during production and vice versa, while increase in fast close time will slightly increases the cycle time and vice versa.

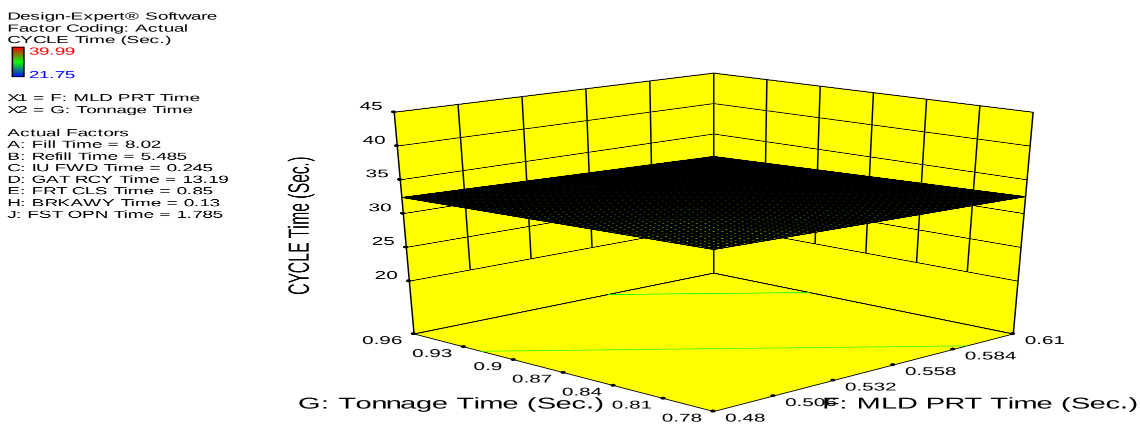

Figure 13 **Surface Analysis of Tonnage Time and Mold Protect Time on 11Litres Cycle**

The figure 13 above shows the surface plot of the tonnage time and the breakaway time on 11litres cycle time response. It shows that the decrease or increase in tonnage time and the breakaway time will have almost no effect in the cycle time during production.

4.1 Optimization Results for 11litres

Table 5 Optimal Solutions and Results for 11Litres Product

Number	Fill Time	Refill Time	IU FWD Time	GAT RCY Time	FRT CLS Time	MLD PRT Time	Tonnage Time	BRKAWY Time	FST OPN Time	CYCLE Time	Desirability	
1	8.072	5.847	0.245	6.457	0.790	0.551	0.949	0.134	1.875	21.721	1.000	Selected
2	7.972	5.511	0.294	7.094	0.754	0.607	0.903	0.161	1.876	21.540	1.000	
3	7.919	5.789	0.309	6.436	0.750	0.513	0.781	0.174	1.871	21.749	1.000	
4	7.939	6.025	0.288	6.467	0.751	0.539	0.953	0.154	1.796	21.496	1.000	
5	8.049	5.902	0.288	6.588	0.830	0.591	0.907	0.152	1.878	21.166	1.000	
6	8.103	5.006	0.292	6.410	0.752	0.609	0.878	0.101	1.859	21.737	1.000	
7	7.800	6.050	0.274	6.410	0.750	0.524	0.896	0.091	1.824	21.744	1.000	
8	8.238	5.364	0.291	6.410	0.750	0.571	0.896	0.096	1.849	21.749	1.000	
9	8.169	5.223	0.310	6.585	0.752	0.549	0.952	0.180	1.833	21.746	1.000	
10	7.816	5.961	0.302	6.546	0.810	0.529	0.820	0.101	1.876	21.693	1.000	
11	7.887	5.889	0.308	6.560	0.751	0.521	0.851	0.091	1.834	21.726	1.000	
12	8.051	5.591	0.286	6.464	0.810	0.546	0.959	0.134	1.852	21.648	1.000	
13	7.836	6.027	0.246	6.551	0.770	0.514	0.959	0.180	1.869	21.680	1.000	
14	7.906	5.998	0.285	6.422	0.911	0.607	0.840	0.148	1.878	21.661	1.000	
15	8.198	6.021	0.280	6.495	0.787	0.570	0.958	0.113	1.810	21.573	1.000	
16	7.953	6.020	0.263	6.543	0.754	0.566	0.903	0.082	1.832	21.746	1.000	
17	7.891	6.047	0.308	6.441	0.893	0.538	0.862	0.153	1.863	21.718	1.000	
18	7.805	5.803	0.306	6.543	0.893	0.551	0.916	0.161	1.874	21.490	1.000	
19	7.836	5.335	0.283	6.440	0.883	0.580	0.959	0.080	1.877	21.734	1.000	
20	7.907	5.552	0.307	6.731	0.881	0.593	0.933	0.172	1.861	21.664	1.000	

The table 5 above reveals the tabular summary of the optimal solutions of the scheduling system for 11 Litres Bucket products. It also determines the optimal cycle time is 21.7211sec with 100% desirability of the solution.

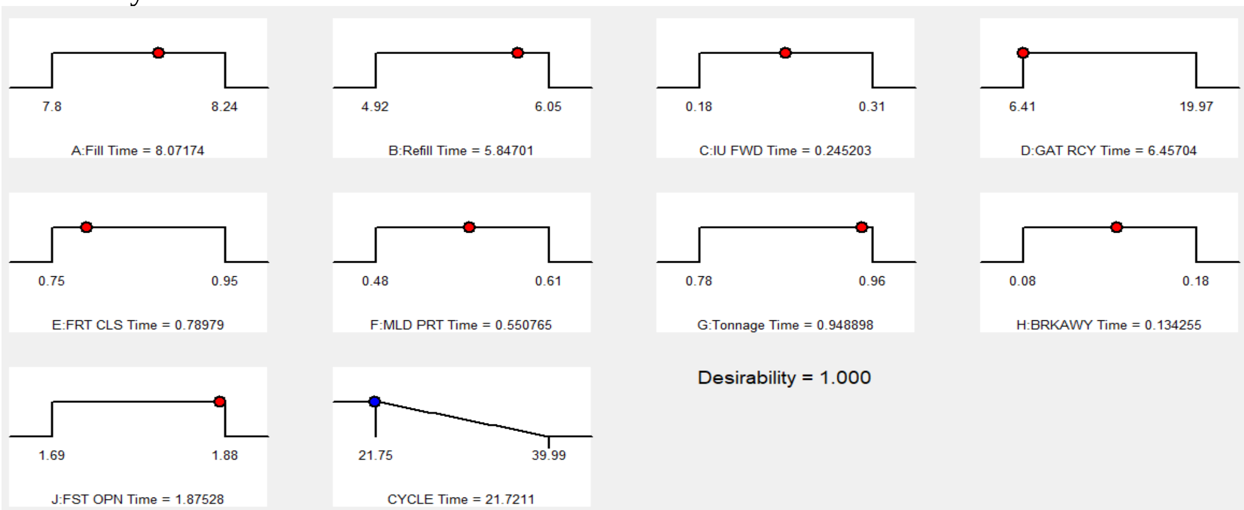

Figure 14 Graphical Analysis of the Optimal Solution

The figure 14 above determines the graphical summary of the optimal solutions of the scheduling system for 11 Litres Bucket products. It also reveals that the optimal cycle time is 21.7211sec with 100% desirability.

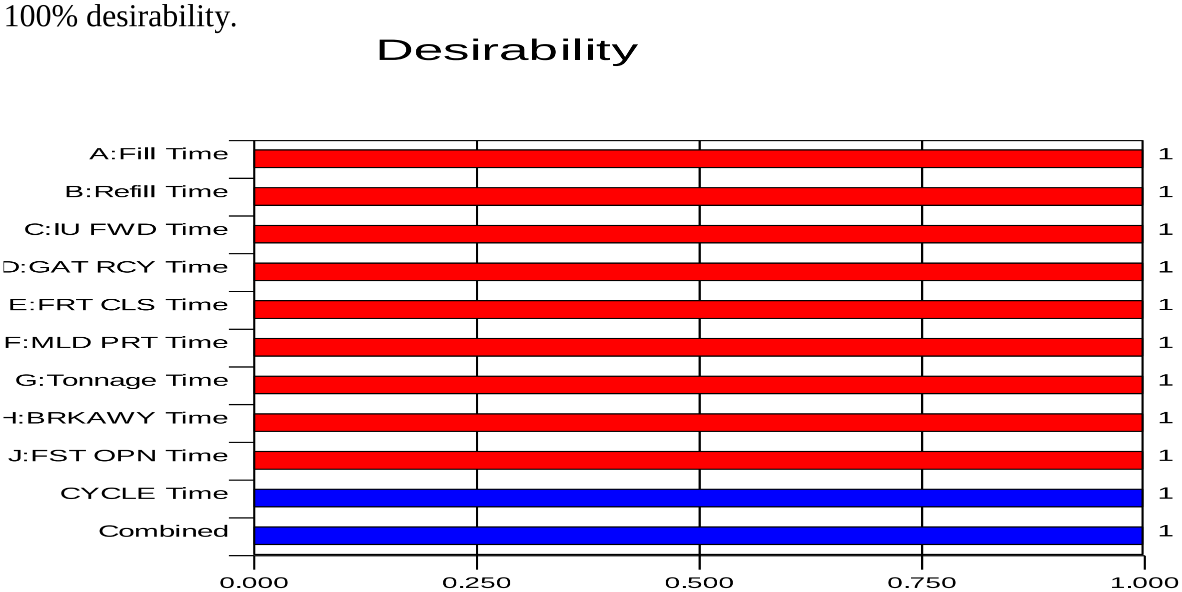

Figure 15 **Desirability Summary Results of the Optimal Solution**

Figure 15 results determine the desirability plot solutions of the variables. It shows the percentage desirability of both the input time process parameters and the response time parameter. It shows that the desirability of the parameters is 100%.

5.1 Conclusion

In this study, the research has examined the scheduling of some selected injection plastic products in Millennium manufacturing industry, Awka, Anambra State. The researcher observed the production process time of the selected products over some period of time.

The production process time data were collected from the machines over a long period of time. The data was analyzed, modeled and optimized. Response surface method, a tool in design of expert version 10.0.1 was used to analyze, model and to optimize the production process timing of the selected injection plastic products in the aforementioned company.

In the results, the application of analysis of variance, surface plots, contour plots, and other selected tools were used to analyze and to model the process time products. Some process parameters have stronger effect on the products cycle time. Response surface method was used to optimize the production process time of the selected products.

The response surface method shows that the optimal solution of 11litres product is 21.721seconds.

The results were recommended to the case company and manufacturing industries for their applications to appraise the scheduling system of their production process time in their industries.

References

Bakelite (2015). The World's First Synthetic Plastic *American Chemical Society National Historic Chemical Landmarks. Retrieved 23 February 2015.*

Akay, M.(2012); Introduction to Polymer Science and Technology: molecular features pp.23&60. Americanchemistry.com. Life cycle of a plastic product. Retrieved on 2011-07-01.

Ancheh, V. N. (2008) A Study of Polycarbonate / Poly (butylene terephthalate) Compounding in a Twin Screw Extruder. 2008. University of Waterloo.

Andrady AL, Neal MA (July 2009). *"Applications and societal benefits of plastics". Philos. Trans. R. Soc. Lond., B, Biol. Sci.* ***364*** *(1526): 1977–84.*

Castro, P. & Grossman, I. E. (2005) A multiple time grid continuous-time formulation of optimal short-term scheduling of single stage batch plants. *Chemical Engineering Transactions* 6, 191-196 (2005).

Castro, P., Barbosa-Póvoa, A. P. F. D. & Matos, H. Short-term scheduling of apolymer compounding plant. European Symposium on Computer Aided ProcessEngineering 12, 649-654. 2002. Computer-Aided Chemical Engineering.

Chen, C. L., Liu, C. L., Feng, X. D. & Sgaim H.H. Optimal short-term scheduling of multiproduct single-stage batch plants with parallel lines. *Industrial and Engineering Chemistry Research* 41, 1249-1260 (2002).

Ezeliora C. D.; Umeh M.N. and Dilinna A.M. (2020) Investigation and Optimization of Production Variables: A Case of Plastic Manufacturing Industry. *Journal of Engineering Research and Reports* 15(1): 1-16, 2020; Article no.JERR.56495; ISSN: 2582-2926; DOI: 10.9734/JERR/2020/v15i117134

David Edgar, Robin A. Edgar, Fantastic Recycled Plastic: 30 Clever Creations to Spark Your Imagination, pg11. *Retrieved 23 November 2015.*

David M. Teegarden, Polymer Chemistry: Introduction to an Indispensable Science, pp.58-5. Retrieved on 2015-07-01

Ejikeme I. R. and Ezeliora C. D. (2016). Analysis of the Optimal Production Mixture in a Manufacturing Industry. *International Engineering and Technological Applied Research Journal,* ISSN (Online): 0000-0000 Volume: 1 | Issue: 1 | October 2016

Ezeliora C.D. and Nwufo M. A. (2021) Solutions to Nigerian problems of industrialization and manufacturing. GSC Advanced Engineering and Technology, https://gsconlinepress.com/journals/gscaet 2021, 01(02), Pp. 049–057. 31 August 2021; Article DOI: https://doi.org/10.30574/gscaet.2021.1.2.0036

Ezeliora C.D.; Nwakobi O. J., Aguh S. P. (2017): Appraisal of Optimal Production Quantity in Small and Medium Scale Industry. *International Journal of Advanced Engineering Research and Technology* (IJAERT) Volume 5 Issue 1, January 2017, ISSN No.: 2348 – 8190; www.ijaert.org

Floudas, C. A. & Lin, X. Continuous-time vs. discrete-time approaches for scheduling of chemical processes: a review. *Computers and Chemical Engineering*28, 2109-2129 (2004).

Janak, S. L. & Floudas, C. A. Production scheduling of a large-scale industrial batchplant. I. Short-term and medium-term scheduling. *Industrial and EngineeringChemistry Research* 45, 8234-8252 (2006).

Magalhaes, Marcus V. and Shah Nilay, "Crude Oil Scheduling," *Foundations of Computer-Aided Operations (FOCAPO)* 2003,pp 323-325.

Michael Pinedo, *Scheduling Theory, Algorithms, and Systems*,Prentice Hall, 2002,pp 1-6.

Papavasileiou, V., Koulouris, A., Siletti, C., and Petrides, D., (2007) "Optimize Manufacturing of Pharmaceutical Products with Process Simulation and Production Scheduling Tools," *Chemical Engineering Research and Design (IChemE publication)* 2007, vol 87, pp 1086-1097

Shahin Ahmadi; Mohammad Mesbah; Chinenye Adaobi Igwegbe; Chukwuemeka Daniel Ezeliora; Christian Osagie; Nadeem A Khan; Guilherme L. Dotto; Mehdi Salari; Mohammad Hadi Dehghani (2021): Sono electro-chemical synthesis of $LaFeO_3$ nanoparticles for the removal of fluoride: Optimization and Modeling using RSM, ANN and GA tools. *Journal of Environmental Chemical Engineering;* DOI: https://doi.org/10.1016/j.jece.2021.105320; PII: S2213-3437(21)00297-9; Reference: JECE105320; © 2021 Published by Elsevier.

Shaik, M. A., Janak, S. L. & Floudas, C. A. Continuous-time models for short-term scheduling of multipurpose batch plants: A comparative study. *Industrial and Engineering Chemistry Research* 45, 6190-6209 (2006).

Toumi, A., Jurgens, C., Jungo, C., MAier, B.A., Papavasileiou, V., and Petrides, D., (2010) "Design and Optimization of a Large Scale Biopharmaceutical Facility using Process Simulation and Scheduling Tools," *Pharmaceutical Engineering (the ISPE magazine)* 2010, vol 30, no 2, pp 1-9.

Zhenya Jia and Marianthi Ierapetritou, (2003) "Efficient Short-Term Scheduling of Refinery Operation Based on a Continuous Time Formulation," *Foundations of Computer-Aided Operations (FOCAPO)* 2003, pp 327-330