# Modeling the Fruit Processing Line and Understanding its Behaviour through Simulation, Designed Experimental Approach

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***Abstract*—This paper describes how simulation can be used in production optimization of fruit processing line. The project work is being carried out at ABC Company which exports various types of fruit pulp to different parts of the world. Due to high amount of demand with stringent requirement on meeting quality, delivery and serviceability, the company faces an important challenge. Thus there is a need for understand, improve the manufacturing system to meet these requirements. In order to accomplish this, the project's objective is to understand the behavior of manufacturing system and hence identify the factors which play a role in affecting the throughput and utilization of Fruit processing line. These set of objectives can be accomplished by using simulation and designed experiment approach and based on the results, the system performance under various scenarios can be understood. In this work ARENA (Demo version) software is used to simulate the fruit processing line. The results obtained from various scenarios analyzed. Based on the analysis, the effects of the significant factors on throughput and utilization of processing line were identified. Thus, this is a platform to improve Fruit processing line.**

***Keywords—Simulation; Design of Experiment; Analysis of Variance; Modeling, Fruit processing line.***

## I. INTRODUCTION

Fruit drink consumption have been a cultural tradition since the dawn of civilization. As changes happens in the civilization through innovation and technology, so did the concept of fruit drink consumption changed from home making to manufacturing of processed fruit drink. In the current world where innovation, technology has gained precedence and the impact of which is felt all over the manufacturing sector, the importance of various dimensions of quality (Garvin's eight dimensions of quality) have become a priority. The same applies to the fruit processing industry.

To understand and obtain a better picture about the dimensions (Deliverability: throughput) it could be worthwhile to obtain information on the crucial factor which a play a role in affecting these dimensions. Since the fruit processing line is a complex manufacturing system, a study of the system using various Industrial Engineering techniques such as simulation [1], Design of experiments [2] etc. would be necessary to understand the system.

## II. CHARACTERISTICS OF FRUIT PROCESSING LINE

In fruit processing, the raw fruits are cleaned, crushed into pulp, then these pulp are evaporated to make them concentrate and finally fill them in an aseptic bags. To achieve the concentrate pulp, Fruit processing line involves process like washing, inspection, crushing, preheating, pulping, evaporation and aseptic filling. In order to collect the required data for building a simulation model [3] the entire processing line can be divided into four units for better understanding of the process. The four units are as follows

- Front end operations
- Refinery Section
- Evaporation Section
- Aseptic Filling Section

*i) Front end operations*

Front end operations consists of process like Conveying, Cleaning (including Primary and Secondary washing), Inspection and Crushing. In this section generally minor stoppages of the processing line occurs and it leads to decrease in production volume. Some of the reasons are;

- Changing of water in the washing tank due to accumulation of dirt from fruits (once in a shift)
- Cleaning the conveyor line, Crusher and Hopper tank
- Minor mechanical adjustments and maintenance

*ii) Refinery Section*

Refinery Section includes process such as Preheating and Pulping. Here the crushed pulp of 20 mm thickness are heated up to 110 degree Celsius to remove bacteria using preheater. Then the pulp is fed to second stage of refining where it is meshed around to 2mm in thickness. A screening process is done where the pulp which are more than 2mm in thickness are rejected and those pulp which are below than 2 mm are fed to feed tank for further process.

*iii) Evaporation Section*

Evaporators are specifically designed to obtain high quality tomato paste. As a matter of facts, the low temperature profile of all the machines is the key factor in maintaining the organoleptic properties of the fresh fruits. Here the tomato paste of 4 degree brix are converted into a paste of 28 degree brix. In this process, a steam of pressure 5-6 bar is used to convert tomato paste having an initial brix level around 4.5 degree brix to 28 degree brix level . When there is an inadequate supply of steam from the boilers this process won't continue rather the tomato paste keeps on circulating (Recycling).

*iv) Aseptic Section*

Compact Aseptic double-head Compact Aseptic filler, designed with opportune accessories for the filling of 228 kg bags in drums. It is equipped with PLC technology, when it sense that two filling heads are not ready the control valve shut off and pulp flows back into the container/storage tank.

The figure 1 shows the schematic representation of the fruit processing line.

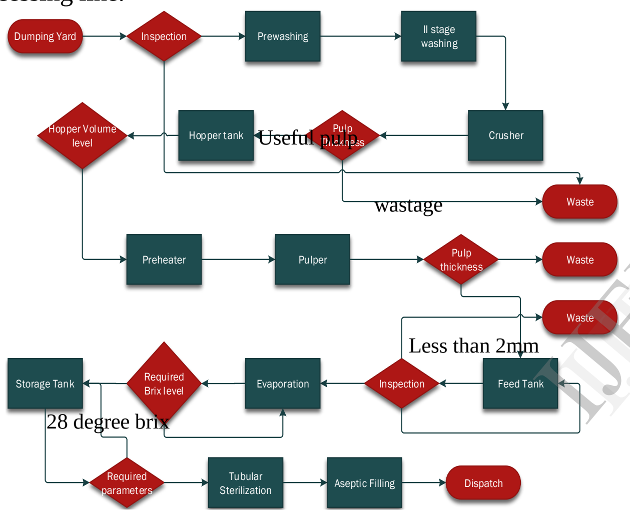


Figure 1. Tomato fruit processing line

## III. OBJECTIVES

- Understanding Fruit processing assembly using simulation with DOE approach.
- To assess the feasibility of process flow logic and relative impact of changing line configurations.
- By using Design of Experiments (DOE), the factors that are affecting the system's efficiency are identified.
- It is aimed to identify constraints or bottlenecks and development of improvement strategies accordingly.
- To improve the system's overall performance.
- Finally is it worthwhile going for more investment on new machines/line.

## IV. METHODOLOGY

Following steps are adopted to understand the behavior of fruit processing line.

### *A. Data Collection and Analysis*

A template was made to collect the data such as process time, downtimes, breakdowns, time between breakdowns [4] etc. The collected data are fitted into distribution and these distributions are tested using Chi-square test and Kolmogorov-Smirnov test. The table 1 provides the process data and table 2 provides the distribution of downtimes and breakdown time.

Table 1. Process data for fruit processing line.

| | |
|---|---|
| Front end Operations | |
| Maximum Capacity of the belt conveyor | 8 tons/hour (8*2=16) |
| Capacity of washing tank | 4 tons |
| Damaged fruits identified after Inspection | 150-200 kg/hr |
| Time taken for washing Fruits | 3-5 minutes at each level |
| Travel time taken (Dumping yard to crusher) | 4.75 to 6 minutes |
| Total processing time | 12 to 15 minutes |
| Crusher capacity | 6 tons/hr (2*6=12) |
| Output capacity | 80% for tomato |
| Idle time | 10 to 30 min (per shift) |
| Setup time | 100 to 140 minutes |
| Refinery Section | |
| Steam Pressure Required | 3 bar for preheating |
| Brix level (in feed tank) | 4 to 5 degree bx |
| Process time | 3-4 minutes |
| Pulp size | 0.2 to 2.0 mm |
| Product flow | 5500-6000 kg/hr |
| Evaporation section | |
| Temperature required | 60 to 70 degree Celsius |
| Steam Pressure required | 5-6 bar |
| Incoming brix level | 4 to 5 degree bx |
| Output brix level | 28 degree bx |
| Time taken to process | 1.5 hour |
| Input flow rate | 5500-6000kg/hr |
| Output flow rate | 1600-1900 kg/hr (from both evaporators) |
| Setup time | 1.66 to 2.5 hour |
| Aseptic filling section | |
| Input flow rate | 1600 to 1900 kg/hr (from both evaporators) |
| Storage tank capacity | 800 lts |
| Temperature required | 103 to 110 degree Celsius |
| Pressure required | 1 kg/sq. cm |
| Tube holding capacity | 123 lts |
| Filling capacity | 6 tons/hr (for pulp) 2.5 tons for brix (concentrated) |
| Clean in place requires | 100 to 150 minutes |
| Idle time | 180 to 220 minutes/day |

Table 2. Distribution of downtimes and breakdown time

| Factors | Expression (in minutes) |
|---|---|
| Front end operations | |
| Duration between Minor stoppages | 10 + GAMM(2.06e+003, 0.506) |
| Duration of Minor Stoppages | 5 + EXPO(21.9) |
| Evaporation Section | |
| Duration between Steam losses | 5 + LOGN(312, 1.02e+003) |
| Duration of steam losses | 4.5 + GAMM(14.5, 1. 29) |
| Mean time b/w machine failures | 5.4e+003 + WEIB( 5.85e+003 , 0.48 ) |
| Mean time to repair | 10 + GAMM( 318 , 0.299 ) |
| Aseptic filling section | |
| Mean time b/w machine failures | 1.18e+003 + 9.49e+003 * BETA( 0.525 , 0.693) |
| Mean time to repair | 15 + WEIB( 103 , 0.503 ) |
| Duration between Clean in Place | UNIF( 2.32e+003 , 1.25e+004 ) |
| Duration of Clean in Place | NORM( 700 , 100 ) |

### *B. Building a model for simulation*

Based on the input data collected as shown in Table 1 and Table 2, a model is prepared for the validation and benchmarking of the actual scenario of fruit processing line [5]. By using this model the mean values of cycle times, utilization time failure and the throughput are identified. The figure 2 gives the model of fruit processing line built using Arena software.

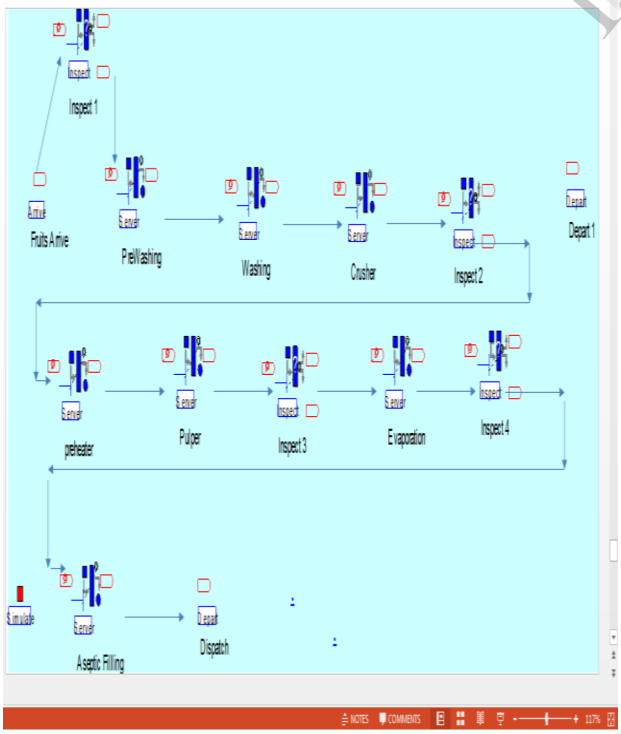

Figure 2. Screenshot of a fruit processing line model

### *C. Running the model and Model validation*

The model was simulated for a period of 72000 hours (50 days) to understand the factors that affect the line and thereby to improve the performance measures. The results obtained from the simulation were compared to measure the accuracy of the model. It was found that the simulated model had 94% accuracy.

The resource utilization graph obtained simulation output was analyzed and it showed that most of the machines in the fruit processing were underutilized (i.e. less than 70%) due to various factors affecting the production like Minor stoppages, Fruit quality etc.

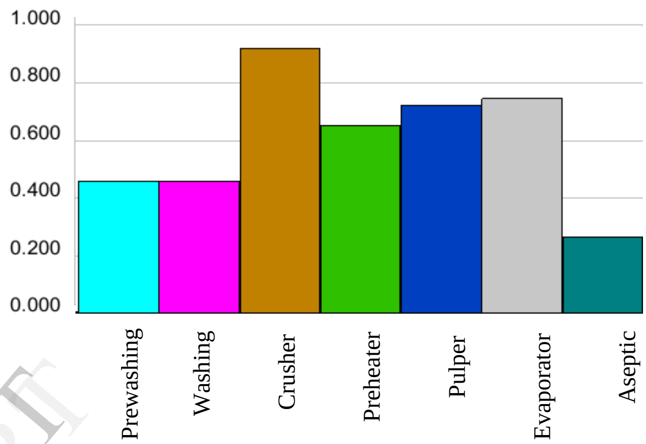


Figure 3. Resource utilization graph



### *D. Process Improvements through DOE*

From the simulated output, it was found that steam loss, minor stoppages and fruit quality were factors among several factors that affect the throughput largely. So these factors were chosen for designed experiments, to analyze the behavior of the fruit processing line when these factors are varied. Hence the factorial design includes $2^3$ design i.e. three factors and each factor has only two levels (i.e., high and low level) and 8 (2*2*2) different runs were carried out.

Table 3. Low and High levels of factors

| Sl no | Factors | High | Low |
|---|---|---|---|
| 1 | Time b/w Minor stoppages | 1400 minutes | 680 minutes |
| 2 | Fruit yield | 90 % | 85% |
| 3 | Time b/w Steam loss | 700 minutes | 340 minutes |

Randomization refers to the order in which the trials of an experiment are performed. A randomized sequence helps to eliminate effects of unknown or uncontrollable variables. The runs are randomized using MINITAB software as shown in the table 4. The simulation was run using the run order mentioned above (Randomization principle was used) for a period of 14400 hours, and accordingly the results were obtained.

Table 4. Run order to carry out simulation and estimated output obtained.

| Sl no | Steam loss | Fruit's Quality | Minor stoppages | | Run order | Estimated output in tons |
|---|---|---|---|---|---|---|
| 1 | 340 | 0.85 | 680 | 1 | 5 | 351 |
| 2 | 700 | 0.85 | 680 | A | 7 | 354 |
| 3 | 340 | 0.9 | 680 | B | 2 | 372 |
| 4 | 700 | 0.9 | 680 | AB | 1 | 370 |
| 5 | 340 | 0.85 | 1400 | C | 3 | 354 |
| 6 | 700 | 0.85 | 1400 | AC | 8 | 354 |
| 7 | 340 | 0.9 | 1400 | BC | 4 | 373 |
| 8 | 700 | 0.9 | 1400 | ABC | 6 | 378 |

*E. Analysis of Results*

The output obtained from the simulation was compared with the actual output. It was found that the percentage in increase in output was varying from 7.85% to 15.88 %. The figure 4 shows fives pictorial representation of the same.

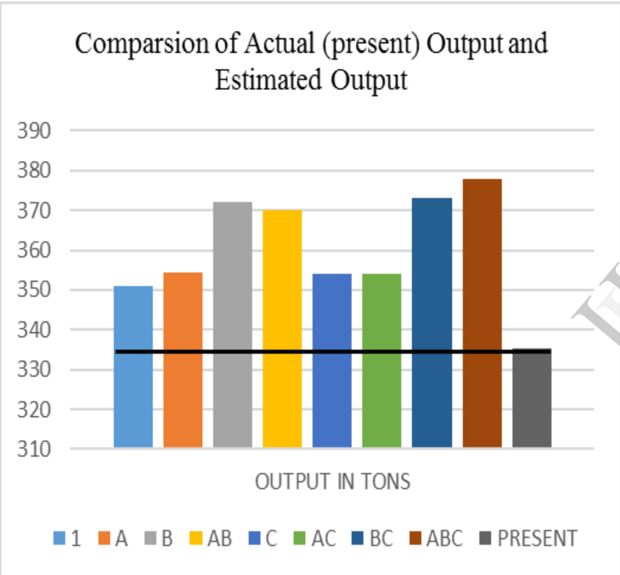


Figure 4. Comparison of Estimated outputs with the actual output obtained (in tons)

Analysis of variance [6] was carried out to identify the estimated effects of these on throughputs using MINITAB software (Student version). The table 5 provides the estimated effects, sum of squares, and F value of these factors.

Table 5. ANOVA for estimated throughput/output.

| Source | Effects | DOF | Sum of squares | P value | F value |
|---|---|---|---|---|---|
| Steam loss | -2.696 | 1 | 145.3 | 0.083 | 3.09 |
| Fruit quality | 13.752 | 1 | 3782.2 | 0.000 | 80.51 |
| Minor stoppages | 7.112 | 1 | 1011.6 | 0.000 | 21.53 |
| steam loss*fruit Quality | -2.451 | 1 | 120.1 | 0.115 | 2.56 |
| steam loss*minor stoppages | 2.517 | 1 | 126.7 | 0.105 | 2.70 |
| fruit Quality*minor stoppages | 4.175 | 1 | 348.6 | 0.008 | 7.42 |
| steam loss*fruit Quality*minor stoppages | 3.881 | 1 | 301.3 | 0.014 | 6.41 |

The main effects plots for factors like Steam losses, Fruit quality, Minor stoppages and Batches were plotted with the help of MINITAB software. The figure 5 shows the main effects plots for estimated output obtained from simulation.

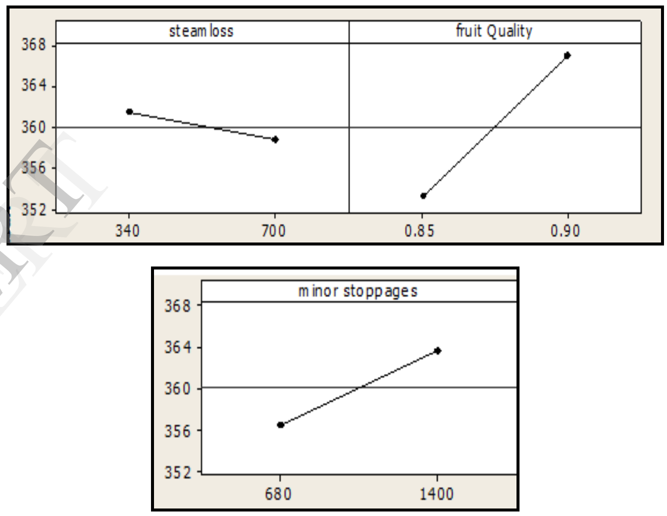


Figure 5: Main Effects plot

From the figure 5, it is clear that minor stoppages and fruit quality have a strong positive effect in increasing the production whereas there is some negative effect in production output if the steam loss are varied from low level to high level.

## V. CONCLUSION

This paper describes the behavior of fruit processing line under various scenarios using simulation and designed experiment approach. From the results mentioned, it is seen that on different performance measures, there are different set of factors which play an important role in affecting these measures. It also showed how each factor affects the throughput level when they were varied from low level to high level. This gives processing line managers to design, to alter the configuration of fruit processing line whenever there is a change in demand, change in the quality of fruit. With the designed experiments approach, the throughput can be increased at least by 7.85%. The ability to simulate real system's behavior according to some predefined parameters can be used an evaluation tool for new control methods.

## VI. SCOPE FOR FUTURE WORK

At ABC fruit processing unit, a variety of tropical fruits like Grapes, guavas, Papaya, mango, tomato etc. are being processed. To analyze the behavior of fruit processing line it takes at least a year because most of them are seasonable fruits. Due to these reasons, the behavior of fruit processing line was analyzed only under tomato fruit. So, there exists a space to understand the behavior of fruit processing line when other fruits are taken into consideration. Hence forth a simulation model which encompasses the other set of seasonal fruits needs to be created with a design of experiment approach to understand the system behavior.

The need for understanding the response values for various factor levels can be understood by the choice of using more level wherein variation in responses can be clearly understood, in the current model two levels (low, high) have been considered and this can be extended to a three level design or further levels if necessary.



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