RESEARCH ARTICLE OPEN ACCESS

Modeling and Analysis of Productivity Enhancement in Sm Paint Plant Using Arena Software

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ABSTRACT
This paper presents the use of a simulation software to analyze the productivity of a paint manufacturing plant by building a model that represents the current situation, and enhance the productivity by suggesting new improvements to the existing system, and to evaluate the impact of capital investment in equipment. A model that represents the existing system was built using ARENA simulation software, and the suggested improvements were evaluated by utilizing the “OPTQUEST for ARENA” optimization tool, according to which recommendations and suggestions are provided.
Keywords: simulation model, Arena software

Date Of Submission: 20-05-2019 Date Of Acceptance: 03-06-2019

I. INTRODUCTION

Enhancing operating performance represents a main concern for any manufacturing company. Productivity as a performance measure is one of the most important indicators to gauge the overall efficiency of a manufacturing plant. However, since manufacturing systems are not static entities, there will be many factors that affect the overall productivity. Among these factors, product volumes and lead times, people, capacity, inventory, cost and quality and customer satisfaction. The factory layout can be determined by the configuration range and choice of products which, in turn, affects the process flows and scheduling, which, in turn, affects the process selection and, ultimately, the level and degree of automation employed [1].

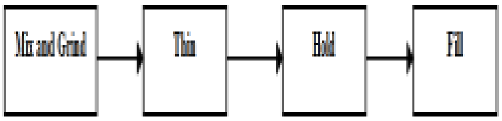
In manufacturing organizations, improving system performance might mean improving their productivity, reducing cost associated with production or inventory while maintaining high level of customer satisfaction. By using a simulation model, productivity improvement could be experimented without physically disrupting or affecting the real system [2],[3].

In the current study, a simulation model representing The SM paint plant who's management recently embarked on a lean initiative with a cost-reducing objective of lowering the inventory in the distribution centers while still meeting the requirements of the retail stores is implemented. The problem identified in this production line is that, the significant cost reductions could be achieved if their manufacturing plants could fill orders for the distribution centers in three working days or less. In addition, they are considering accepting a request by a nationwide chain of home improvement stores to produce paint that would be marketed under their private label. The simulation model tracks the percent of the existing orders finished within three days and the percent of the private orders finished within five days as a performance measure. The main goal of the current study is to evaluate the current system and propose modifications that result in minimizing operating cost while still achieving the desired performance level, also to decide whether or not to accept the private orders. After using Arena simulation software to examine the possible improvements to the production line of the SM paint plant, the management should consider two cases. new changes to the current system are proposed to achieve the desired level of performance at minimum cost.

II. PROBLEM STATEMENT AND OBJECTIVES

The SM paint plant management recently embarked on a lean initiative with a cost-reducing objective of lowering the inventory in the distribution centers while still meeting the requirements of the retail stores. The management believes that significant cost reductions could be achieved if their manufacturing plants could fill orders for the distribution centers in three working days or less. Currently none of their manufacturing plants are able to meet this three-day delivery requirement consistently. In addition, it is not clear what improvements would be necessary in order to remedy this situation. Due to this uncertainty, the management is seeking some recommendations based on an analysis of a single manufacturing facility .In addition, they are considering accepting a request by a nationwide chain of home improvement stores to produce paint that would be marketed under their private label. This paint would be produced in same the facility.

Fig1: The four-step process of the production line



The goals of this work are:

- To reduce the operating cost of the SM paint plant so as to meet the 98% of all orders within three days.
- To reduce the operating cost of the SM plant when considering another private order to meet 98% of the traditional orders within 3 days and 95% of the private orders within 5 days.

The simulation model tracks the percent the existing orders finished within three days and the percent of the private orders finished within five days.

III. PROCESS DESCRIPTION, ASSUMPTIONS AND MODEL DESIGN

The manufacture of paint at this plant is a relatively simple four-step process. It starts by combining the various components and pigments with a base liquid at the mix and grind tanks. The components are first ground together and then mixed in a relatively small tank that looks somewhat like a kitchen mixer. Once this step of the process is complete, the resulting mixture is pumped to a Thinning tank where the remaining liquid is added.

The Thin tanks also have mixers that assure that the resulting paint is homogenous. After Thinning, the mixture is transferred to a hold tank where the paint remains until a fill line becomes available. Once the filling process is complete, the resulting finished product is sent to shipping. Figure 1 shows a high-level view of this flow.

The manufacturing facility under study runs 24 hours a day, seven days a week, with new orders being released once each day. The number of new orders averages about 23 per day and appears to follow a Poisson distribution. The classification of the new orders is based on to the order batch size as small, medium, or large (in gallons). The small batches make up 10% of the orders. The medium batches make up 35%, and the large batches make up the remaining 55% of the orders. Table1 gives the composition of each of these (e.g., 40% of the medium batches are orders for 6,000 gallons).

The packaging of each the product for each order can be as quarts, gallons, or five-gallon buckets. A single order may require one package type (all gallons), two, or all three types. All orders include a percentage of gallon-size fill. Of the total orders, 75% require quarts and40% require buckets. If quarts are required for an order, that portion of the order varies from 10% to 40% by volume. If buckets are required, that portion of the order varies from 5% to 20% by volume. The remainder of the order is packaged as gallons.

Table1: The composition of batches

Small Batches		**Medium Batches**		**Large Batches**	
Percent	Size (gal.)	Percent	Size (gal.)	Percent	Size (gal.)
60	1,000	25	4,000	15	10,000
40	2,000	40	6,000	20	12,000
		35	8,000	25	14,000
				20	16,000
				15	18,000
				5	20,000

There are seven identical mix and grind machines available. The time required to complete this operation follows a triangular distribution with parameters 1.5, 2.4, and3.5 (hours). Note that the facility currently only operates the mix and grind system for 16hours per day. Upon completion of this first operation, the resulting liquid is transferred to an available Thin tank, but this transfer can only occur if a Thin tank of the proper size is available. There are nine Thin tanks of differing sizes in the facility. Table2 shows the number and capacity(in gallons) of the nine Thin tanks.

Table2: The number and the capacity of the Thin tanks

Number of Thin Tanks	**Capacity (gallons)**
2	6,000
2	10,000
2	14,000
3	20,000

The batch size control the allocation of product to the Thin tanks, larger batch sizes reserve the larger tanks , but the smaller batches reserve the smaller tanks and only limited larger tanks. For example, orders for batches of 6,000gallons or fewer can only reserve and transfer to the two 6,000-gallon or the two 10,000-gallontanks. The table below shows the allowable allocation by batch size to the various Thin tanks. Note that the 12,000- to 14,000-gallon batch sizes can only use two of the three large 20,000-gallon Thin tanks.

Table3: Allocation of the batches to the Thin tanks

Batch size (gallons)	**Thin Tanks (capacity in gallons)**
1,000 to 6,000	6,000 or 10,000
8,000 to 10,000	10,000 or 14,000
12,000 to 14,000	14,000 or two of three20,000
16,000 to 20,000	2,0000

Once a Thin tank is available, the transfer time follows a triangular distribution with parameters of 20, 35, and 45 minutes. This transfer time is independent of the batch size. After the transfer is complete, the now-empty mix and grind machine requires a cleaning cycle before starting the next batch. This follows a uniform distribution with parameters of 18, 24 minutes. The Thinning operation consists of adding additional liquid to the product from the mix and grind operation. The time to complete this operation is dependent upon the batch size of the order since the liquid is added at a rate of 175 gallons per minute. Mixing the batch is happening at the same time of adding the liquid. Once the Thinning operation is complete, the batch transfers to an available hold tank. The transfer rate is 195gallons per minute. There are 10 hold tanks in this facility, with capacities, table 4 summarizes this information.

Table4: The number and the capacity of the Hold tanks

Number of Hold Tanks	**Capacity (gallons)**
2	8,000
4	12,000
4	20,000

As was the case with the Thin tanks, it is not desirable to use the larger tanks for the smaller batches. The table below shows what batch sizes can use the various hold tanks.

Table5: Allocation of the batches to the Hold tanks

Batch size (gallons)	**Hold Tanks (capacity in gallons)**
1,000 to 8,000	8,000 or two of four12,000
8,000 to 12,000	12,000 or one of four20,000
12,000 to 20,000	2,0000

The batches are held in the hold tanks until the required fill lines become available. There are four quart lines, four gallon lines, and two bucket lines. Table 6 shows the fill rates and clean times for these lines.

Table6: Fill lines rate and clean time

Line	**Fill Rate (gallons per minute)**	**Clean Time (minutes)**
Quart	8	20
Gallon	40	15
Bucket	38	18

The filling process is not allowed to start until transferring the entire batch to a hold tank. Once that transfer is complete, the filling operation can start. If a batch requires all three filler types, the fillers do not all have to be available at the same time. For example, if only a gallon line is available, that part of the operation can be started. Once the other lines become available, those remaining portions of the operation can be started. The hold tank is only made available to the next batch when all of the filling operations for an order are complete. The facility has been configured so that any mix and grind tank can be connected to any Thin tank, any Thin tank can be connected to any hold tank, and any hold tank can be connected to any filler.

The management is considering accepting a request by a nationwide chain of home improvement stores to produce paint that would be marketed under their private label. This paint would be produced in the same facility, and the management expects that this would require the production of an average of three additional orders or batches per day. Table 7 shows the estimated mix of batch sizes.

Table7: Private order information

Private Label Batches	
Percent	**Size**
25	10,000
45	15,000
30	20,000

There are few assumptions regarding the operating system. First, in the Thin tanks, when the batch are between 12000-14000 gallons, it can go to 2 out of 3 Thin tanks with capacity of 20000 gallons. It is clear when there are only three tanks. However, when the management needs to adjust the system, they may decide to add more of the Thin tanks with capacity 20000 gallons. Therefore the batch with size 12000-14000 gallons can go to more than two of the large Thin tank, so the assumption is to let the 12000-14000 go to two thirds of the number of large Thin tanks keeping the integrality into account. Similarly, with the hold tanks, the batch of 1000-8000 gallons can flow to half of the hold tanks with capacity 12000 gallons, and the batch of 8000-12000 gallons can flow to one fourth of the hold tanks with capacity 20000 gallons. Once again the number of large tanks available for small batch must be integer. Second, when the number of days per replication the plant operates is small, no problem may appear in the plant. However, as the replication length increases, more and more orders accumulate in the queues and the problem will appear. Therefore, the assumption is to use a 30 days replication length at which the problems of satisfying the demand will appear then adjustments may make a difference. Third, in the optimization part we assume that the cost calculations based on 8 years with no preventive or corrective maintenance cost.

The Arena simulation model consists of six major sub models and five modules connecting them. The first sub-model is for creating orders, at this model, the distribution of arrivals and service timer known, so no need to collect and analyze the data of the arrivals. When an order arrives and gets its unique information such as order ID and size, it goes to seize the available mixer and grinder with a mixer ID. After that, the order goes to another sub-model to decide what Thin tank is appropriate for that order. After deciding on the appropriate Thin tank, it will seize the next available one with specific Thin Tank ID from the regulator set that includes the Thin tanks with different numbers and sizes. Next, the order will flow to that specific Thin tank, and the cleaning operation is required for the mixer and grinder before releasing it with specific mixer ID and become available for the next order. This happens in the release mixer sub-model where the duplicate module let the order flow to the Thin tank using the flow module, and the mixer and grinder to get cleaned and released. After completing the flow process, the order information will determine, using the select hold tank sub module, what allowed hold tank with a specific ID to flow to, then using another seize module to seize that specific hold tank from a regulator set of hold tank inputs. The next module is a duplicate module that sends formation to locations, one for the flow the order to a specific hold tank, and the other for collecting statistics. In the first location, the order will flow from a specific Thin tank that already determined from a Thin tank set to a specific hold tank that already determined from a hold tank set using a flow model. After that, by using the fill line sub-model and depending on the composition of the order, a specific amount of paint (quarts, gallons or buckets) will flow from a specific hold tank using a specific fill line. Next, when removing all the order from the hold tank, and cleaning all corresponding filling lines, the release regulator module releases the fill line and makes it ready for the next amount of paint from different order. In the second location, the statistics sub-model , using a duplicate module to send the order information to two hold modules waiting for a unique signal from a specific thin or hold tank. This signal comes from a sensor that monitors each tank and sends a unique signal when it is empty. The next step is to record the system time for that order by subtracting the arrival time from the current time TNOW, then test it if it satisfies the desired level or not.

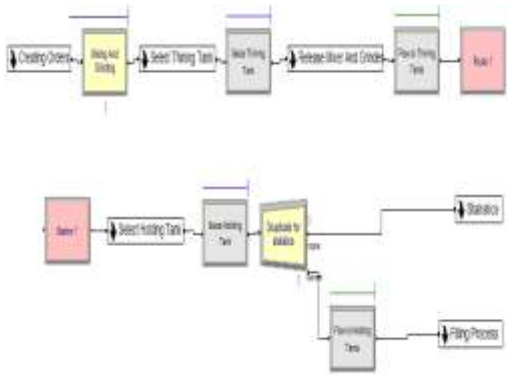


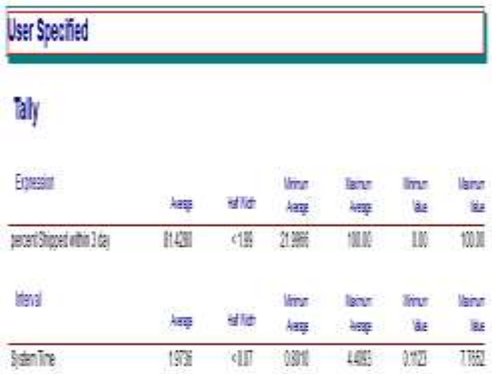
Fig2: Arena simulation model for the production line

IV. EXPERIMENTATION AND OUTPUT ANALYSIS

We used the CRN concept In order to reduce the variability in the model. Using the same stream for the same category is important. For example, in creating the orders whether they are the existing or the private should have the same stream of random numbers.

In the first scenario, since the goal is to find an optimum configuration that helps the company to achieve the desired level, which is to ship at least %98 of orders within three days, with minimum additional cost, we need to see how well the company is doing with the current settings by examining the most important statistic in this model which is the percentage of orders that is shipped within three days. Before making any judgment, we need to make sure that the model provides a good representation of the real life situation and provides reliable results. To do this, both the replication length and the number of replications should be selected carefully. To find an appropriate replication length, however, we need to balance the trade-off between the accuracy of the results and the time. Therefore, we assumed a replication length of 30 days will be reasonable as it covers the study of more than 4000 order per replication and will not consume our time during evaluating the alternatives in the analysis phase. With regard to the choosing of the number of replications, we made use of “The Sequential Method” to determine the required number of replications that gives a half width of %2 for statistic under consideration, and the required number of replications was 381 replications.

After setting the appropriate replication length and number of replications, we ran the model with the original configuration, and as we expected, the percent of orders shipped within three days was %81.4 which is for sure will not satisfy the desired service level, and we need to find a configuration that meets the required service level while keeping the encountered cost as minimum as possible. Figure 3 Shows a snap shot of results from the base model.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Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
percent Shipped within 3 day	81.4288	< 1.99	21.3966	100.00	0.00	100.00

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
System Time	1.9736	< 0.07	0.3918	4.4865	0.1123	7.7652

Fig3.Arena’s results for the base model

To evaluate the potential alternatives, we used the optimization tool “OptQuest for Arena”, which requires a set of decision variables, an objective function and constraints. The decision variables were: the number of mix and grind machines, the number of Thin tanks for each tank size, the number of holding tanks for each size, the numbers of quart, gallon and bucket filling lines, and whether or not to use the mix and grind area for a third shift. The objective function minimizes the weekly total cost of changing these variables; it sums up the fixed and variable cost of every added Thin tank, holding tank, and filling line plus the fixed cost of adding mix and grind machine and the daily cost of using the mix and grind area for extra shift. To smooth the weekly cost over the assumed length of contract, we multiplied the cost of adding third shift by 2920 days and converted the resulting total cost into weekly cost by multiplying it by (7days per week/2920 days). The only constraint was to keep the service level not less than %98.

Since the mix and grind machines are considered as resource, it was easy to provide the optimization tool with a range to choose from. However, this was not the case with the Thinning tanks and the holding tanks rather; we assigned an “advanced set” from the advanced process panel for each tank type and each size and let the optimization tool turns on and off the proposed number for every single scenario. For the sake of illustration and to save time we let the optimization tool to evaluate 200 different scenarios with 30 replications each. Figure 4 shows OptQuest output for the first scenario.

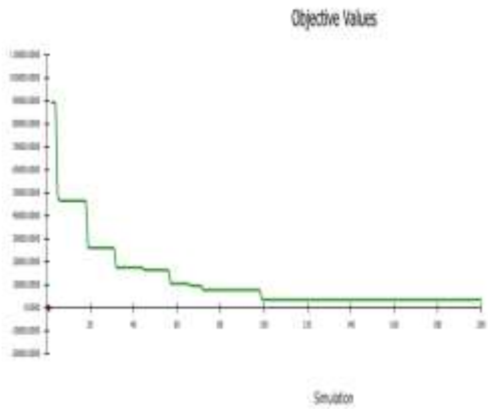

Fig4. A chart tracking the value of the objective function for different alternatives for the first scenario

Based on the recommendations from the OptQuest, the best scenario was to add one more holding tank of size 20,000 gallon, which will yield a percent of orders shipped within three days of %99.5 and weekly cost of $3,595.

In the second scenario, we needed to watch both the conventional and the private party orders. After making the changes suggested in the first scenario and adding the arrival pattern of the private party orders, we added the new record that calculates the percentage of private party orders that are being shipped within five days. After running the model with the new changes, the percentage of conventional orders shipped within three days was %39.5 and percentage of private party orders shipped within five days was %77.5; it is clear that neither requirement was met. Therefore, we needed to turn to the optimization tool to help us deciding what changes should be made to meet the two constraints while minimizing cost. Figure 5 Shows a snap shot of results from the second scenario.

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
percent Shipped within 3 day	38.5325	<1.63	10.1852	98.1132	0.00	100.00
percent Shipped within 5 day	77.5324	<1.78	29.8507	100.00	0.00	100.00

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
SystemTime	3.7257	<0.08	1.5487	5.9176	0.1107	10.9225

Fig5. Arena's results for the second scenario before optimization

The OptQuest analysis suggested a new configuration that requires adding seven mix and grind machines, one 10,000-gallon Thinning tank, one 14,000-gallon Thinning tank, three 20,000-gallon Thinning tank, one 8,000-gallon holding tank, one 12,000-gallon holding tank, two more 20,000-gallon holding tanks and one gallon filling line. This configuration will raise percent of conventional orders shipped within three days up to %98.5 and the percent of private party orders shipped within five days to %99.7 with a weekly cost of $50246. This configuration is considered profitable when comparing the weekly cost with the additional income of $50,000/day or $350,000/week, in other words this change will make a profit of almost $300,000 per week. Figure 6 shows OptQuest output for the second scenario.

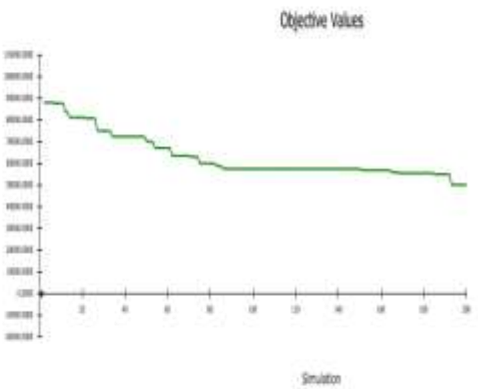

Fig6. A chart tracking the value of the objective function for different alternatives for the second scenario.

The third scenario was almost the same as the second scenario with the exception that the suggested configuration for the first scenario will not be considered. After adding information about the private party orders and running the model with the original configuration, the percentage of conventional orders shipped within three days was %29 and percentage of private party orders shipped within five days was %59, these low percentages indicate that the changes will be more significant than in the second scenario. Again we used the optimization tool to decide on what changes should be made to meet our goal. Figure 7 Shows a snap shot of results from the third scenario.

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
percent Shipped within 3 day	29.3455	<1.07	10.1512	72.3608	0.00	100.00
percent Shipped within 5 day	59.3407	<1.45	28.1250	100.00	0.00	100.00

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
SystemTime	4.7181	<0.09	2.3858	7.1418	0.1107	12.8603

Fig7. Arena's results for the third scenario before optimization

The OptQuest recommended a new configuration this proposal included adding three mix and grind machines, two 6,000-gallon Thinning tank, one 10,000-gallon Thinning tank, three 20,000-gallon Thinning tank, one 8,000-gallon holding tank, three 20,000-gallon holding tanks, three quart filling lines, and four bucket filling lines. This suggested setting met the two constraints and yield a weekly cost of $52547, this configuration make a profit of 350,000 – 52547 = $297453 per week. . Figure 8 shows OptQuest output for the third scenario.

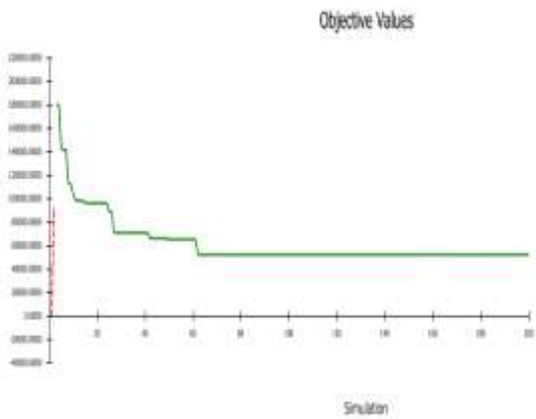

Fig8. A chart tracking the value of the objective function for different alternatives for the third scenario

At a glance, the second scenario seems to be more profitable than the third scenario. However, when we include the cost encountered in the first scenario to the cost of the second scenario, the total weekly profit will be 350,000 – (50246+3595) = $296159 per week. Therefore, we would recommend the management to accept the request of the private party and make investments to meet both the existing and private-label production requirements in one time as this make more economical sense based on the weekly cost and income

V. CONCLUSION

After using Arena simulation software to examine the possible improvements to the production line of the SM paint plant, the management should consider two cases. First, In the case of dealing with the traditional orders only, the management should consider adding an additional Hold tank with capacity 20,000 gallons to the production line to achieve 98% of the orders completion within three days. In addition, in the case of the private orders, the management should accept the contract for the private orders since they are profitable. However, the management should not make any the adjustments before considering the private orders; rather, they should make adjustment one time for the production line. These adjustments help to satisfy the traditional orders within three days and 95% of the private orders in 5 days resulting in a profit of $30000/ week.

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Magdi Ahmed El Hadiri" Modeling and Analysis of Productivity Enhancement in Sm Paint Plant Using Arena Software " International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.05, 2019, pp. 53-59