A Simulation Study To Increase The Capacity Of A Rusk Production Line

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Abstract: - This study was conducted in a food processing company on its Rusk production line. The goal of the study was to increase the production rate of the line to meet the continuously increasing demand on its product within the existing limited space in the plant. The production line was thoroughly studied and analyzed. Several bottlenecks that were causing sever congestions in different areas on the production line were found. An Arena Simulation model was developed and used to resolve all bottlenecks found on the line and a simulation experiment consisting of seven different scenarios was conducted to search for a good feasible solution to increase the production rate.The changes made in the production line resolved all bottlenecks, improved utilization of all production equipment, eliminated all congestions and most of the queues at all production stations. An increase of about 50% in production and a decrease of 11.4% in average total production time for a box of Rusk in the system were achieved. The capital investment required to implement the new improvements can be paid back in a period of 35 days from the expected profit that would be realized from the additional increased quantity produced. The changes that were made on the production line to achieve the above improvements were adding two new machines, replacing three other old machines, modifying two other machines and decreasing the time of one of the processes, without affecting the quality of the product.

Key-Words: - Production planning, Food processing, Productivity, Simulation models, Business Process Reengineering.

1 Introduction

The extreme fluctuations in the demand pattern of food products in the Kingdom of Saudi Arabia is unique to the country and is primarily due to the enormous floating population which amounts to about 8 to 10 million annually; represented by visitors (Pilgrims) visiting the holy lands; Makkah and Madinah. Drawing a balance between meeting this variable demand and maintaining the quality of food products is a challenging decision problem of the Kingdom's food processing industry. Process optimization turns out to be a major concern of the management in such situations.

Process optimization is an application area where Design of Experiments (DOE) has found a niche of its own. A simple, but effective, strategy of experimentation involves optimizing the formulation via mixture design and optimizing the process with factorial design and response surface methods. Industrial experimenters typically turn to two-level factorials as their first attempt at DOE. These designs consist of all combinations of each factor at its high and low levels. With large numbers of factors, only a fraction of the runs is needed to produce estimates of main effects and simple interactions. However, when the response depends on proportions of ingredients, such as in chemical or food formulations, factorial designs may not make sense. Mixture design offers a better solution procedure to analyze the dependence of the response variable, namely quality of food, on the proportionality of ingredients. However, the cost of time, precision required, and materials involved may not justify such experiments.

Simulation, being a 'what if' experiment, is a useful technique to study the effects of system changes, the processes involved as well as the proportion of ingredients. A case study conducted gives a template for action. The results of the simulation revealed all bottlenecks at the various stages of the production line. The Arena model provided the platform where virtual experiments are conducted to study different solutions and to find the best one.

1.1 Literature Review

Fisher Len [5] points out that the application of scientific analysis called Baconian science to food production dates back to Francis Bacon. The search review also revealed that the most commonly applied optimization technique in food processing areas is response surface modeling (Bang Julio R. et.al.[4]**.** Response Surface Methods (RSM) was introduced in the 1950s associated with design of experiments methods (Box, Hunter & Hunter,[1]; Myers & Montgomery,[8]). Hammami Chokri et.al [2] presents a central composite design of RSM taking working pressure (P) and heating plate temperature (T) as the most important factors affecting the kinetics of the freeze-drying operation for apple slices as well as the criteria of final product quality (appearance/shape, color, texture, re-hydration ratio). By superimposing all quality criteria contour plots, the optimum levels of processing conditions yielding the best quality freeze-dried apple slices, they arrived to the optimal values of the operating pressure as 50 Pa, and heating plate temperature as 55 °C.

Anderson Mark J. and Whitcomb P.J.[10] points out the drawbacks of using two-level factorials which consist of all combinations of influencing factors at its high and low levels. With large numbers of factors, only a fraction of the runs needs to be completed to produce estimates of main effects and simple interactions. However, when the response depends on proportions of ingredients, such as in chemical or food formulations, factorial designs may not make sense. They prove their argument quoting a case study on lemonade processing. In contrast, a number of powerful model-based optimization methods have been developed during the last decades which use more rigorous, time-dependent models. These model-based optimization methods have great potential for improving food processing.

Simeonov S. and Simeonovová J.[12], discussed the potential uses of simulation for increasing productivity and profit, by reducing cycle time, improving due-date performance, reducing work in progress (WIP), providing plant-wide synchronization, etc. through a case study on coffee production. Synchronization of production capacity and material inputs to meet the promised delivery dates are simulated through a model that incorporates roasting, grinding and packaging processes. They obtained the basic features of the coffee production system, solutions for scheduling and capacity planning problems, and optimization. A module of the simulation software is used for improving the current structure of the production system.

Garay Loza M. and Flores R.[6] focused on the flow characteristics of the product through the flour mill at the total flow rate. This is considered following a flow with normal distribution patterns. The model describes the flow of total matter in a stochastic analysis. The mass flow is linked directly to wheat attributes and to the specific process conditions of the pilot mill. Minegishi and Thiel [11] discuss the industrial management behavior in food industries where products have short or long manufacturing processes and short or long expiry dates. Three simulation models were tried by them according to the duration of the manufacturing processes and the expiry dates. Bailey K. et.al [7] presents a simulation study on dairy farms focusing on the evaluation of the impact of economies of scale on the profitability of alternative unit sizes. In a study by Lucian L. C. et.al [13] modeling and simulation were used to apply multi-criteria decision making techniques in reengineering manufacturing processes. A multi-agent based system that would enable small and medium-size manufacturing organizations to dynamically achieve cost-effective aggregate sales and operations plans in supply chain contexts was proposed by Massimo et al [14]. In this study simulation was used which provided multiple scenarios with respect to the balance between supply and demand**.** In a study by Behnman et al [15] a comprehensive review and analysis on the proposed production-distribution models with special emphasis placed on the optimization and simulation studies were presented. The paper described the main characteristics of the selected models outlining the strengths, weaknesses and the level of complexity for each study

It is quite evident from the literature review that statistical and simulation techniques had been tried in various fields of food processing. It is felt that probably the DOE is more appropriate in food processing area, where experiments with various mixtures and combinations of food components are used until the expected results are reached. On the other hand simulation has proved to be efficacious in virtual experiments of food production. The literature review also reveals that simulation technique is more suitable in production areas.

2. Problem Formulation

In this section the problem being studied will be clearly stated, the production system will be described, the goal of the study will be stated and its objectives will be defined.

2.1 Description Of the Production Process

The Rusk Company in Jeddah has the largest market share in the Saudi Rusk market. The company produces two main types of Rusk with different flavors, one with white flour and the other with whole wheat. The company has only one Rusk production line that is over 25 years old. The line was upgraded and production capacity was increased several times before. The company is facing a situation where it cannot make any new upgrades on the line or any expansions in the existing plant due to the limited space. The company is also faced continuously with a higher demand on its products. This study was conducted to attempt to increase the production rate of the existing line to the highest feasible rate taking into consideration the space constraint. The objectives of the project included an in-depth study of the production processes involved, analysis of these processes in details, finding out the ways and means by which these processes can be optimized. A schematic diagram representing the production process is shown in Figure 1.

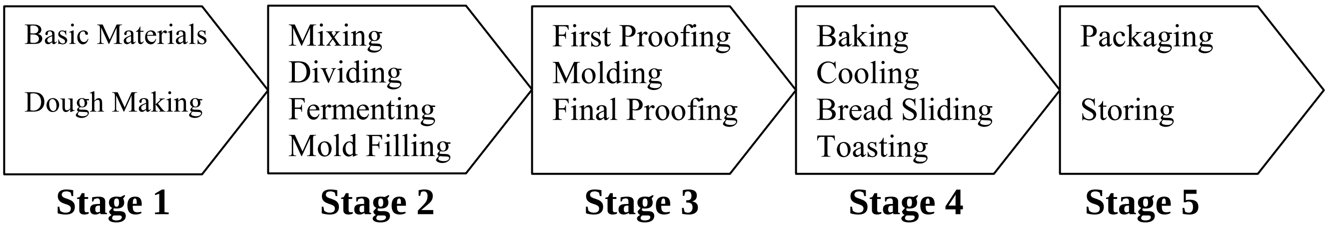

Figure 1 Stages in the Rusk Production Process

The production line of the Rusk has been divided into five main stages, namely preparation of the basic materials for Rusk & dough making, dividing and fermenting the dough and moulds filling, dough baking and cooling, bread slicing and toasting and finally Rusk packaging and storage. The entire production process consists of around 56 activities of which 17 activities are focused on for the research reported here. The selection of these seventeen activities was made based on the fact that these are directly associated with the actual production processes and include all production activities right from moving the trolley carrying the long dough prepared at the early stages to the proffer, fermentation of the dough, moving trolley to the baking ovens, baking the dough, cooling the bread, moving the trolley to the baskets area, removing breads from metal moulds, placing bread in the baskets, transporting baskets to the trolley, moving the trolley to waiting area before carrying them to the refrigerator, the bread waiting, and finally moving the trolley to refrigerator for cooling purposes. After cooling the toasted Rusk slices on the conveyor they are packed in the packaging section and ready for dispatch.

2.2 Goal of the Study

As mentioned earlier that the Rusk Company has the largest market share in Saudi Arabia and is continuously facing a higher demand. The company wants to increase production capacity and it has very limited space for expansion in the existing plant; it also did not have any immediate plans to relocate and to allocate the required investment to build another plant. The goal of this study was to maximize the production capacity of the Rusk production line with a minimum investment within the existing plant.

2.3 Objectives of the Study

To achieve the goal of the study the following objectives were identified:

1. To study and analyze the production line.
2. To identify and collect all necessary relevant data of the production processes.
3. To build a valid simulation model of the existing production line.
4. To use the model to find ways to increase the production capacity and enhance the production rate.

3 Methodology

To accomplish the objectives of the study and achieve its goal the following methodology was devised and executed:

- The production line should be studied in details; all departments should be analyzed, their processes, activities, resources, material and timings should be identified and documented.

- All data related to activities and resources should be identified and collected.
- Then, a simulation model that truly represent the real production line and mimics its behavior, should be designed, developed, verified and validated.
- Once, a valid model is built, a simulation experiment should be designed and conducted to search for a feasible solution to maximize the capacity of the production line and increase the production rate within the existing constraints.
- All alternatives that increase the capacity of the production line should be documented and the best solution which maximizes production should be selected.
- Define the enhancements required on the production line to reach the capacity of the best solution and estimate its cost.
- Determine the additional investment required to implement the proposed solution to maximize the production rate.

4 The Simulation Model

As seen in the literature review, simulation is one of the useful techniques for conducting studies in food production. It could be a system for handling paperwork, a call center, distribution center, or any other systems that result in products or services (Kelton D. et.al, [3]). Arena 10.0, which is one of the most powerful software for simulation, was used to build the model. The Rusk production line model was designed and developed to consist of four sub models namely:

- Submodel-1: This sub model simulates the process of mixing raw materials for dough making, dividing it to small pieces, circulating and fragmenting these pieces and finally molding it.
- Submodel-2: The main feature of this sub model is to simulate the molded dough in the proffer and baking ovens, followed by the cooling process.
- Submodel-3: The logic of this sub model is to simulate cutting and slicing the bread then toasting it, cooling it on the conveyor and finally packing and packaging the Rusk produced.
- Submodel-4: Terminating and sequential-sampling control logic, this sub model is used to determine the required number of replications (i.e. sample size), to get a 95% confidence-interval half width of certain output performance measures.

Data on arrival rates, inter-arrival times, waiting times and activity times were collected for those activities. The data were fed to the Input Analyzer application of Arena for analysis to obtain the probability distributions and their parameters of the raw data. Table 1 shows the probability distributions with their parameters of the main activities in the Rusk production process.

Table 1: Probability Distributions with their parameters of major activities in Rusk Production

Activity	Distribution
Trolley Arrival	6 + Gamma (0.423, 0.385)
Oven Proffer	Resources Const (30)
Baking Oven 1	32.3 Weibull (0.981,2.35)
Baking Oven 2	TRI (22, 23, 24)
Baking Oven 3	TRI (22.4, 23.2, 24.5)
Baking Oven 4	TRI (22.6, 23.3, 24.6)
Fan Cooling	10 + Exp (0.191)
Mold Changer	Normal (7.46, 0.306)

4.1 Verification and Validation

In the Rusk production line, model verification and validation steps were implemented. For verification, the animation method was used to show the entities movement inside the model and to ensure that the movement is similar to what the designer think it should be and it is in accordance with the flow of the trolleys in the real production line.

Validation of the Arena model was done by comparing the model output with the real system output. To check the validity of the model the number of Rusk boxes produced per day from the model was compared by the number of boxes produced per day from the real system. The number of Rusk boxes produced per day from the model was 2280, while the real system production rate per day is 2100 boxes, which is pretty valid.

The nature of this production system is a steady state --not a terminating system-- because it works continuously for 24 hours a day and 7 days a week. Therefore we needed to warm up the model to reach to steady state condition before collecting any statistics to get good unbiased results. The warm up period for the simulation model was determined by the Arena Output Analyzer on the basis of the oven utilization. It is clear from Figure 2 that 'warm up period' is very small. These statistics include utilization of the resources,
number of entities in the system, number of entities out of the system and number of entities in the queue.

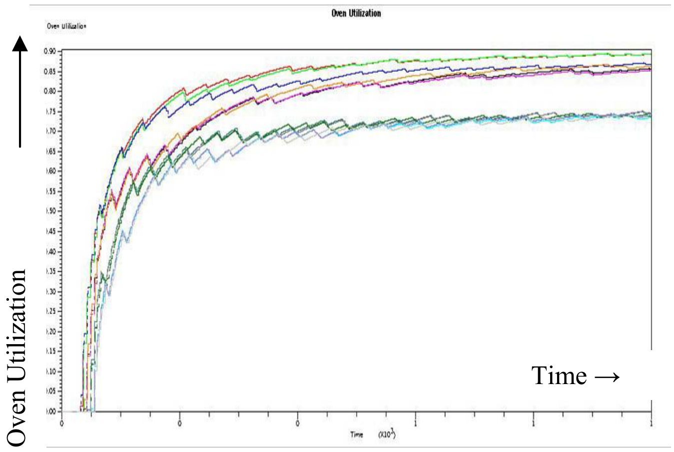

Fig 2.Warm Up period and Oven Utilization Results

4.2 Performance measures

The following output variables were considered to measure the performance of the system**:**

- Production equipment utilization
- Average length of the queue at every production station
- Average waiting time in every queue
- Average total production time for a box in the system

5 Problem Solutions

In this section the different solutions that were considered to solve the problem will be presented and discussed.

5.1 Simulation runs

line are summarized in Table 2, Table 3 and Table 4. Table 2 shows the ovens utilization which considered quite low. Table 3 shows very high utilization of the other key equipment at the main production stations on the line. Most of those equipment are having 100% utilization After the simulation model of the Rusk production line was developed, verified and validated, the first simulation run was made to simulate the current situation of the production line. The run length used was seven days and three replications were made.

The results produced from the model was studied and thoroughly analyzed. The most important output system variables of the production except for few that have medium and low utilization because of bottlenecks and congestions at previous stations. Table 4 shows bottleneck areas at different stations. Bottlenecks are identified by the very large number of entities waiting in the queue and long average waiting time in the queue at a station. From table 3 it can be seen that there are high congestions and sever bottlenecks shown by the very alarming figures at the basket Trolley Area (BTA), Cooling Room (CR) and Basket Trolley in Cooling Room for Center Cutting Machine (BTCCM). Table 4 also shows that the average total time for a box in the system is 1077 minutes and the average number of boxes produced per day is 2280 boxes. From these output variables it can be clearly noticed that the system is very congested and bottlenecks are at almost at every station of the production line and the line is not balanced.

5.2 Simulation experiment

The approach that will be taken to solve the problems of the production line is to solve the bottleneck at every station one by one starting with the most sever bottleneck indicated by the highest congested area. This was the basis for developing the different scenarios of the simulation runs. A scenario is developed by defining additional resources at a production station that would be enough to resolve the bottleneck and eliminate congestions in that area. Every scenario will be run for 7 days with 3 replications.

Table 2. Percentage utilization of ovens under current system

Utilization of Proffer oven	Utilization of Baking oven1	Utilization of Baking oven2	Utilization of Baking oven3	Utilization of Baking oven4	Utilization of Mould changer	No of Trolley out / days
47.53	77.10	69.91	60.46	50.19	50.16	375

Table 3. Utilization of other Production Equipments

Percentage Utilization (Current Values and Optimal Values from Scenario 7)										
	Basket T	CCM	cooling R	CM	Feeder	LDM	Rouling M	Slicing M	Cooling Cov.	Toaster Cov.
Current Situation	100	100	100	100	74.95	75	100	100	48.31	53.68

Table 4. Bottleneck areas identified in the current system model

	BTA	CR	BTCCM	CCM	MFT	HCA	CMP	BTCSM
Avg. No. in Queue	438.808	13.936	26.001	2.403	6.498	1.035	1.414	0.049
Avg. waiting time (min)	4673.11	167.23	466.16	28.84	69.3	22.08	15.04	0.84
Avg. total time for box in system	1077.380 min							
Avg. number of Rusk box produced	2280 boxes per day							

BTA = Basket Trolley Area, CR=Cooling Room, BTCCM = Basket Trolley in Cooling Room for Center Cutting Machine,
CCM = Center Cutting Machine, MFT = Men who Feed Trolleys, HCA = Hold Container Area,
CMP=Cutting Machine Process Area, BTCSM = Basket Trolleys in Center Cutting Machine area for

Table 5 - Results of the proposed scenarios from the simulation

Scenario		BTA	CR	BTCCM	CCM	MFT	HCA	CMP	BTCSM	Toaster	LDM	ATST	ANP
1	ANQ	437.443	13.936	26.001	2.589	6.498	1.035	1.41	1.049	0	0	1076.300	2280.000
	AWT	4658.26	167.24	519.44	31.09	69.3	22.08	15.04	14.848	0	0		
2	ANQ	0.34	0.642	0	0.041	6.498	1.035	1.414	0.001	344.662	0	1030.404	2359.694
	AWT	3.625	6.85	0	0.439	69.3	22.08	15.04	0.584	3669.64	0		
3	ANQ	0	0	0	0.021	0.118	1.035	1.414	0	0.848	0	904.359	2565.000
	AWT	0	0	0	0.227	1.26	22.08	15.04	0.547	9.045	0		
4	ANQ	239.704	13.908	0	0.067	0.468	0.132	0.619	0.002	711.461	937.562	1208.252	2838.565
	AWT	1918.56	116.44	0	0.56	3.744	2.971	4.262	0.658	5956.24	6452.89		
5	ANQ	239.716	13.908	0	0.067	0.468	0.132	0.619	0.002	711.461	0	1208.252	2838.565
	AWT	1918.56	116.44	0	0.56	3.744	2.971	4.262	0.658	5956.66	0		
6	ANQ	239.716	13.908	0	0.067	0.468	0.132	0.619	0.002	2.232	0	1208.252	2838.565
	AWT	1918.56	116.44	0	0.56	3.744	2.971	4.262	0.658	18.658	0		
7	ANQ	0	0	0	0.076	0.468	0.132	0.619	0.002	17.866	0	955.146	3411.907
	AWT	0	0	0	0.612	3.744	2.971	4.262	0.596	143.036	0		

ATST = Ave Total time in System ANP = Ave Number of boxes produced ANQ = Ave number in Queue AWT =Ave Waiting Time

1) **Addition of a Center Cutting machine**: from Table 5 it was noticed that the severest bottleneck is occurring at Basket Trolley Area (BTA) which indicates that the Center Cutting Machines are not enough and therefore a long queue is building up with a long average waiting time. Therefore, the breads in the basket trolley in the cooling room have to wait for a very long time till a center cutting machine becomes available. To resolve the bottleneck in this area, one center cutting machine was added. This scenario was simulated and its, result are shown in Table 5. The results of this scenario shows that the bottleneck at the BTA is resolved however, the bottleneck moved to the next production station; the Slicing Machine Area.
2) **Addition of a Center Cutting Machine and a Slicing Machine:** A second scenario was defined by adding one machine in the bread slicing area. The results of this scenario are presented in Table 5. The results shows the bottlenecks at (BTA), Cooling Room (CR), (CCM), and (SM) areas were resolved however, the bottleneck moved to the next station; the Toaster area.
3) **Increasing the toaster length by 5 meters and employing one worker to feed the trolley:** In order to overcome the bottleneck appearing at the toaster area, the third scenario is created by increasing the length of the toaster by 5 meters and adding one more worker to feed the trolley. The results of this scenario are presented in Table 5. It can be seen now that the bottleneck moved to the cutting machine area where the cutting, rolling and intermediate proffer machines are located.
4) **Changing the cutting, rolling and intermediate proffer machines:** The fourth scenario is created to overcome the bottleneck now appearing at the dough cutting machine area, by changing the cutting, rolling and intermediate proffer machines. This change is brought about by replacing the old machines with new high speed machines of 6 minutes per container. All the three machines had to be simultaneously replaced because changing one of them will cause bottlenecks to appear at the other two machine locations. The results of this scenario are presented in Table 5.
5) **Changing the long dough machines:** It can be seen now that the bottlenecks have moved from the dough cutting area to the long dough machine. Therefore this area needs improvement by replacing the long dough machine that has 10.2 minutes as the service time, with a new one that has 6 minutes' service time. Results of the simulation runs of this scenario are presented in Table 5. The bottleneck has now disappeared from long dough area but it appears again in the toaster area.
6) **Decreasing the cooling conveyor length by 2 meters:** Scenario 6 is developed by decreasing the cooling conveyor length by 2 meters. Due to the space limitation at the toaster area the toaster length could not be increased. From the experiments on Rusk moisture contents it was established that the length of the conveyor can be reduced by 2 meters without affecting the moisture content or the taste quality of rusk. Scenario 6 is thus created and the results of this experiment are shown in Table **5**. Now it can be seen that the bottleneck appears in the basket trolley area again.
7) **Decreasing the cooling time of bread at the cooling room from 12 to 8 hours:** The new bottleneck appears at the basket trolley area again as a result of creation of scenario 6. The cooling room causes this bottleneck since the bread congestion is now occurring at the basket trolley in the cooling room to complete the cooling time. So, the cooling room needs to be improved by decreasing its process time. From the experiment of Rusk taste and moisture degree, the cooling time can be reduced from 12 hours to 8 hours without affecting the taste quality. Thus the scenario 7 is created and results are presented in Table 5.

From the results of the simulation run of scenario 7 it is seen that all bottlenecks were resolved and congestions in all areas on the production line were cleared. It required 7 trials to reach to a good feasible solution were all problems on the production line were solved, product flow process was well tuned and the whole production line was well balanced.

6 Results

It can be seen from the last table that the average number of Rusk boxes produced per day has increased from 2280 to 3412 i.e. a 49.5% increase from the current situation shown in Table 4. Similarly the average total time for a box in the system has been reduced from 1077.38 minutes to 955.15 minutes, i.e. an 11.35% decrease. The average number in queue and the average waiting time for both the cooling room and the basket trolley areas became zero, which means that the bottlenecks have disappeared from those two areas and all other stations on the production line.

The ovens utilizations have improved a lot after the proposed changes in the production line were made. Table 6 shows the low ovens utilizations before changes and the good improvements in the utilization of all the ovens after the changes were made.

The utilizations of all other equipment on the production line have also improved. Table 7 shows the utilization of those equipment before and after the suggested improvements were made. The utilization of those equipment were extremely high (100%) for most of the equipment causing sever bottlenecks, high congestions and very long delay to the product flow in some areas of the production line; and show low utilization of some equipment in other areas due to the bottlenecks on prior stations on the production line. The figures in Table 7 also show very good balanced utilizations of all the production equipment after the proposed improvements to the production line were made, the product flow was tuned and the line was well balanced.

Table 8 shows queues statistics before and after improvements were made. It is clearly seen that there were very long queues with very long average waiting times before improvements and those queues at major congested areas have totally disappeared while some short queues with reasonable delay times are still there in some other areas on the production line after the improvements.

Table 6. Oven Utilization

Percentage Utilization (Current Values and Optimal Values from Scenario 7)						
	Proffer oven 1	Proffer oven2	Baking oven1	Baking oven2	Baking oven3	Baking oven4
Current Situation	69.69	47.53	77.1	69.91	60.46	50.19
Optimal Scenario	84.05	72.2	91.63	87.32	82.77	80.1

Table 7. Utilization of other Production Equipments

Percentage Utilization (Current Values and Optimal Values from Scenario 7)										
	Basket T	CCM	cooling R	CM	Feeder	LDM	Rouling M	Slicing M	Cooling Cov.	Toaster Cov.
Current Situation	100	100	100	100	74.95	75	100	100	48.31	53.68
Optimal Scenario	60.09	71.16	69.76	87.35	50.4	87.35	87.35	74.95	68.61	59.26

Table 8. Queue Statistics at Major Stations – Bottleneck Areas

		BTA	CR	BTCCM	CCM	MFT	HCA	CMP	BTCSM	Toaster	LDM
Current Situation	AWT	4673.1	167.23	466.16	28.84	69.3	22.08	15.04	0.84	—	—
	ANQ	438.8	13.93	26.001	2.403	6.498	1.035	1.414	0.049	—	—
Optimal Scenario	AWT	0	0	0	0.574	3.744	2.953	4.268	0.615	7.7	0
	ANQ	0	0	0	0.072	0.468	0.132	0.624	0.002	0.962	0

6.1 Cost Analysis

The implementation of the proposed solution to increase the capacity of Rusk production by replacing or adding new machines in the production line means that an additional cost will be incurred. Table **9** shows the total cost for each scenario and the time needed to recover that cost which depends on the net profit per box, which is S.R 8. In scenarios 3,4,5,6 and 7 the additional net profit is calculated by subtracting the cost of employing additional worker which is SR 33 per day from the value of daily profit.

Table 9. Cost Analysis of Scenarios

Scenarios	Total cost of the scenario (SR)	Cost of added labor (SR/day)	Boxes/day (boxes/day)	Additional boxes/day (boxes/day)	Additional net profit of scenario per day (SR/day)	Days required to cover the scenario cost (days)
	(a)	(b)	(c)	(d)=((c) – 2280)	(e)=(8(d)-b)	(f)=(a/e)
Current	----	----	2280	0	0	----
Scenario 1	10,000	0	2280	0	0	----
Scenario 2	30,000	0	2359.69	79.69	637.52	47.05735
Scenario 3	105,000	33	2565	285	2247	46.72897
Scenario 4	208,000	33	2838.57	558.57	4435.56	46.89374
Scenario 5	228,000	33	2838.57	558.57	4435.56	51.40275
Scenario 6	311,000	33	3268	988	7871	39.51213
Scenario 7	311,000	33	3411.91	1131.91	9022.28	34.47022

7 Conclusions

- The goal of the study was achieved by increasing the production rate by almost 50% and reducing the average total production time of a box of Rusk by 11% within the constraint imposed on the problem. The production line was thoroughly analyzed and found to have many bottlenecks that were causing congestions in different areas on the line. Simulation was used to resolve the problems found, tune and smooth the flow of the product in the production line and thus increase the production rate. The changes that were made on the production line to achieve the above improvements were adding two new machines, replacing three other old machines, modifying two other machines and decreasing the time of one of the processes (cooling time), without affecting the quality of the product. The payback period of the capital investment required for implementing the new proposed capacity from the additional net profit that will be realized is estimated to be 35 days.
- Simulation is the best tool that can be used in such a study because it allowed experimenting with the system through the simulation model to search for a good feasible solution without disrupting its operation.
- It could be easily seen that when studying a system, a total solution should be developed from a global system view and not from a local problem view. When a solution is developed from a local view, the problem would be solved locally and would either move to another part of the system or might create a new problem somewhere else in the system.

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