DISCRETE EVENT SIMULATION FOR SUSTAINABLE BATCH PRODUCTION IN FOOD PROCESSING

Mohamed Elmasry[a], FatmaTarek[b]

[a]Research Assistant, Department of Civil Engineering, Qatar University, Doha, Qatar
[b]Chief Executive Officer at Toukies, Inc, Mokattam, Cairo, Egypt

[a]Masry@qu.edu.qa
[b]toukies.orders@gmail.com

ABSTRACT

In a world faced with depleting resources and hazardous biodegradable food wastes, an efficient planning for the food processing operation is crucial to avoid the adverse potential impact of excess food production. This paper presents a framework for sustainable food batch production, to ensure efficient usage of raw ingredients required for producing the exact food amount required for a certain event. A discrete event simulation model is developed using STROBOSCOPE to determine the equilibrium points between the supply and demand in showcase events that involve showing food samples or products. The developed simulation model comprises two parts, namely the batch production plant and the food exhibition. To validate the model, actual case study was used to determine the amount of displayed food products in exhibitions and it was found that the MAE resulting from the model was equal to 85%. The developed simulation model and framework is expected to be a handful tool for stakeholders in small startups and young entrepreneurs in showcase events involving food sampling to minimize excess or surplus of food and raw ingredients required in food production.

Keywords: Food batch production, Sustainable Processing, Simulation, Food Exhibitions

1. INTRODUCTION

Simulation is considered as a powerful tool because of its ability to model real life situations with minimum cost and effort. Simulation tools enable users to apply what-if scenarios in which the simulation model is replicated and different alternatives can be modeled to determine the best available alternative based on the user's objective without the need to apply extra cost or time. Several simulation tools are available for that purpose such as MicroCyclone (Halpin, 1974), STROBOSCOPE (Marinez 1996), AnyLogic (AnyLogic Company), Arena (Rockwell Automation), ProModel (ProModel,Inc.),FlexSim (FlexSim Software Products, Inc.) and several others commercial and academic tools. Each of these simulation tool has advantages that make using each one of them more favorable than using the other. For instance, when using MicroCyclone, it is impossible to visualize the working model, while on the other hand commercial packages such as AnyLogic, Arena aren't affordable for customers because they aren't open source softwares. Also some of these tools aren't easy to learn and require the user to have a strong background in simulation languages and modeling techniques because of the broad spectrum of capabilities in these tools. As such and due to these aforementioned reasons, STROBOSCOPE is envisaged to be more appealing to use when compared to these other tools because of its simplicity and its capabilities in visualizing the working model. STROBOSCOPE is a general purpose simulation programming language widely used to simulate construction processes and operations. STROBOSCOPE has the ability to access the properties of the resources and can link the different activities in the model with these properties enabling the user to understand the logic and flow of the processes in the simulation model. Therefore, STROBOSCOPE can be used to simulate and analyze different operations and processes not only in the construction industry but also in any other fields as long as the operation is well defined and known to the user. When designing any operation, complex decisions regarding the processes involved in this operation are required to be made, such as determining the appropriate number of manpower or equipment used and selecting the method by which the tasks are performed. For every decision made, cost and times are associated with this decision, hence comes the usefulness of using simulation to determine the optimum scenario or decision that would give minimum cost and time.

Several researches have addressed food processing using simulation. McGarry and Watson, (1996) developed a dynamic simulation framework to assess the resources needed and the schedule of the operation's activity to maximize managing the operation. Diefes and Okos, (2000) compared different design processes as alternatives in manufacturing whole milk powder using food operations oriented design system block library and performing economic analysis. The comparison was done with the intent of demonstrating how using food oriented design system block library can help in saving time to perform analysis of design alternatives. The research aimed to minimize steam use in the operation and to maximize the net present worth over a 10 year planning horizon. Numerical finite element model was also used to analyze the freezing and thawing process for frozen food processing (Zhongjie and Shaoshu, 2003). In this research, the authors investigated the effect of freezing parameters on the freezing process concluding that the food shape and size, freezing air temperature and freezing air velocity are the most important factors affecting the freezing process. Longo et al., (2012) presented a simulation model to examine the behavior of industrial plants used in producing hazelnuts based products using different scenarios. The performance of the industrial plant process was investigated by using different alternatives for the plant line production capacities and machines. In this research it was concluded that the simulation model could be used in adjusting the system to improve the plant performances when using governing factors such as plant line production capacities and machines involved in the production process. In addition to the previously developed models, several models addressing food processing were introduced such as food drying, baking processes, and cold food processing (Sabarez, 2015, Flick et, al., 2015 and Tassou et, al., 2015). As for researches addressing sustainable food production, a framework was presented for industrial food processing using life cycle assessment approach while preserving environment (Sonesson et al., 2010). In this research two case studies were presented to examine using the life cycle assessment approach in industrial food processing towards sustainable environment. It can be concluded that the previously presented researches used either mathematical modeling or simulation tools to model or investigate the impact of a certain factor on the industrial food processing operations; however no research has used STROBOSCOPE for such purpose in these specific operations. The objective of this paper is to develop a generic simulation model for food production to be used in food exhibition and showcase events with the intent of minimizing the wastes as a result of surplus raw ingredients. The simulation model could help in determining the breakeven points of the processed food and the served people. The model considers the people's arrival rate, people's leaving rate, and service rate in the exhibition locations, in addition to the logistics required to transport food product from the batch plant to the exhibition yard and the food production rate. Iterations are performed to determine the governing factors in the aforementioned process and an actual data for a real food production process of sweet treats is used to validate the proposed simulation model.

2. PROPOSED SIMULATION MODEL

STROBOSCOPE is used to develop the proposed simulation model using different features of the tool; resources including manpower or equipments in STROBOSCOPE are modeled in the form of "*Queue*" which represents a pool for the resource from which activities access this pool and use the available resources. Activities of different processes are modeled using "*Combi*" which is instantiated using a resource from the Queue. Activities represented by Combi should have duration which are interpreted by the program as a time unit (i.e.: based on the users input the program interprets the duration, so it is crucial to ensure that the units used in defining the durations are the same). Similar to the Combi a "*Normal*" also represents an activity, however this type of activity doesn't require a queue (i.e.: a resource) to be instantiated. The simulation model comprises to main parts namely, the batch production unit and the exhibition unit. The former represents the activities and resources used in producing, packing and loading the produced food to the truck used in transportation. While the latter represents the activities and resources used in the exhibition hall, where products are presented and sold to customers. Figure 1 shows the proposed simulation model.

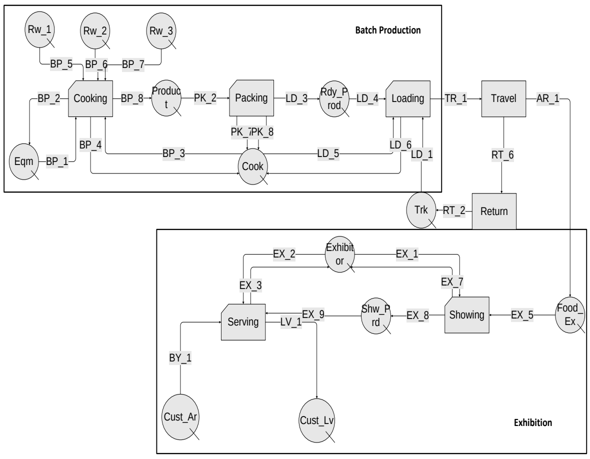

Figure 1: Proposed Simulation Model

2.1. Batch Production

The production of the food starts by the activity "Cooking" which uses the resources "Rw_1", "Rw_2", and "Rw_3" which represent the raw ingredients used in cooking the product. In addition to these resources, the "Eqm" representing the equipment used in processing/cooking the food is used by the "cook" which is the human being using the tool to perform the activity. STROBOSCOPE enables the user to define the characteristics of the different resources used, so if several equipment are used, different characteristics can be defined such as the capacity, horse power, the amount of electricity used,…etc. In this model generic type is used to define each resource where cook is defined as human being, Rw_1,Rw_2, Rw_3 are defined as raw ingredients and Eqm is defined as equipment. After food is cooked, a queue of generic type food called "Product" representing the food is introduced to the model. The activity of "Packing" then starts using the queue "Product" and "Cook" with a released queue of “Rdy_Prod” representing the packed product ready for “loading” in the truck “Trk” The Queue “Trk” represents the truck that would transport the product to the exhibition location. Two activities representing the trip of traveling to the exhibition location “Travel” and the return from the exhibition location to the batch production location “Return” are used. The released resource from the above processes is the products ready for exhibition “Food_Ex”. Figure 2 shows the different resources and activities in the first part of the simulation model batch production.

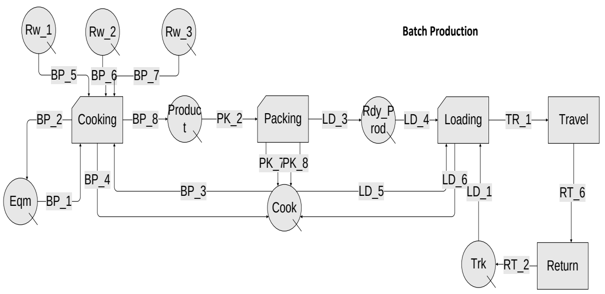

Figure 2: Batch Production in proposed simulation model

2.2. Exhibition

Exhibiting the product starts with the activity of arranging the products to be shown to the customers “showing” in which the queue “Food_Ex” representing the products to be shown and queue “Exhibitor” are used to instantiate this activity. The “Serving” is instantiated by arrival of customers “Cust_Ar” and the same queue used in arranging the products “Exhibitors”. The “serving” activity represents customers’ orientation and a short marketing operation to introduce the product to the customer and sell it after which the customer shall leave to a queue representing the customers leaving “Cust_Lv”.

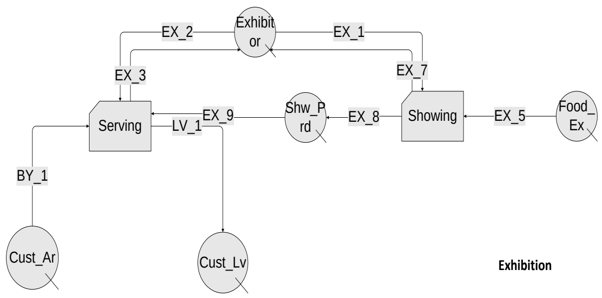

Figure 3: Exhibition in the proposed simulation model

3. SIMULATION MODEL PARAMETERS

3.1. Activities Duration

Durations for activities are crucial to run the simulation model from which the average wait for different resources shall be computed. The average wait for the different resources (i.e.: Queues) represents the idleness time of the resource and from which the rates can be calculated. Table 1 represents the different formula and durations of various activities. Some durations are stochastic while other are deterministic based on the user’s degree of certainty. The durations shown were elicited from personal interviews with entrepreneurs in the industry of sweet treats production.

Table 1: Simulation model Activities Duration

Activity/Duration (minutes)		
Cooking	Type	Uniform [120,150]
Loading	S	Uniform [20,30]
Packing	D	20
Return	S	(Dis/Speed)+t_d
Serving	D	Uniform[3,5]
Showing	D	15
Travel	S	(Dis/Speed)+t_d

Where (S) stands for stochastic duration and (D) stands for deterministic duration. Uniform [low, high] represents uniform distribution with two values representing a minimum and maximum. To determine the duration of transporting products to the exhibition location, the distance covered by the truck divided by the velocity of this truck and adding a delay factor as a result of traffic congestion as per Lomax (1997).

4. MODEL IMPLEMENTATION

In order to implement the model, a real case study has been chosen for exhibiting sweet treats in an event held in Cairo, Egypt. The model implementation would help in determining the exact number of products and raw ingredients used to minimize the waste generation and ensure sustainable food production. This goal can be achieved by carrying out two steps which are determining the best resources combination to minimize costs and time spent on the different processes, then determining the optimum number of food products and ingredients used to reach a breakeven point between the products and the number of customers in the event. To determine the different governing resources in the different processes of food production, multiple replications are performed using different number of alternatives.

4.1. Manpower and Crew Unit Costs

Table 2 shows the different alternatives used in model replication for which the different costs and duration shall be determined and best combination shall be determined accordingly. In the table the unit cost for the different resources (Equipment and manpower) is shown and the minimum and maximum number of resources to be used in the proposed model replication.

Table 2: Different number of resources used in model replication

Resources	Cost($/hr)	Number	
Eqm	3	1	3
Cook	6.5	1	3
Trk	15	1	3
Exhibitor	5	1	3

By performing several runs, it was found that one of the governing resources is the exhibitor numbers. The rest of the resources turn out to be equally important. To determine which resources are effective and which are not, several iterations were performed and the outcome of the simulation model was observed from which the cost using this alternative of combination was calculated. It should be noted that increasing the amount of a resource could result in system congestion leading to an increase in the total cost and the average waiting time of these resources which means an increase in idleness and accordingly the overall simulation time.

Figure 4 shows the plot for the different alternatives between the cost on the vertical axis and the simulation time on the horizontal axis. The solid dotted line joining these three alternatives represents the pareto optimal interface which indicates that this combination would most likely result in the optimum cost and time.

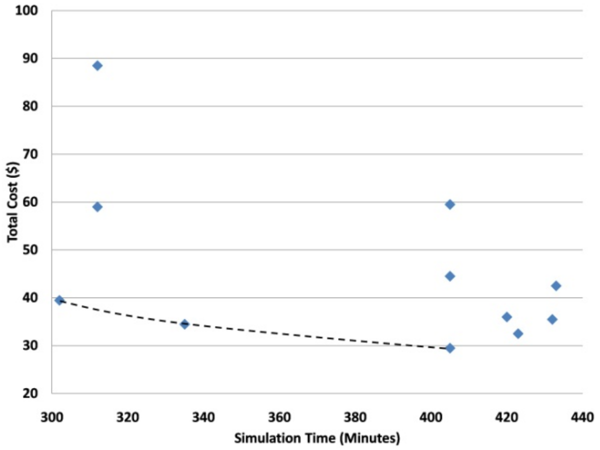

Figure 4: Optimal Resources combination Frontier

The line envelopes the three alternatives of having only one resource of the aforementioned resources, two exhibitors while having the same number of other resources and three exhibitors while having the same number of the other resources.

4.2. Breakeven Points between products and customers

Breakeven points are usually used in economics to define the point at which neither profit nor loss is made (David and Boldrin, 2008). In the context of this paper, breakeven point means the point at which the amount of raw ingredients required for processing food products that would be shown in exhibition and show case events balance the amount of customers in that event such that the waste as a result of using excess raw ingredients tend to a minimum.

To determine the number of products to be produced, the arrival, leaving and service rates in the exhibition location shall be at first calculated. The arrival rate by which the customers arrive to the location is denoted by (λ_a), while leaving rate by which the customers shall leave the showing booth is denoted by (λ_l). The service rate and as the name implies is how fast customers are served is denoted by (μ). The different rates were computed based on different number of exhibitors to determine the plausibility of the proposed simulation model and from which the raw ingredients amount shall be computed. Table 3 shows the increase in the service rate as a result of increase in number of exhibitors. The service rates were computed based on STROBOSCOPE average waiting times for the queues of arriving and leaving customers. As such and by using the above relationships, it can be concluded that the service rate is the difference between the arrival and the leaving rates as per Equation 1.

Table 3: Different rates based on different number of exhibitors

Exhibitor	μ (1/min)
1	1/5
2	1/4
3	1/3

$$\mu = | \lambda_a - \lambda_l | \quad (1)$$

To determine the amount of products to be produced, the service rate shall be multiplied by the total duration of the exhibition denoted by (D) as per Equation 2:

$$NP = \mu * D \quad (2)$$

Where NP is the number of products to be processed for the show case, which is used to determine the exact amount of raw ingredients as per Equation 3

$$RI_i = w_i * \frac{NP}{P} \quad (3)$$

Where RI_i is the raw ingredient component amount, (w_i) is the weight of the ingredient in the mix. P is the production conversion factor, taken in this study equal to 1.45.

5. CASE STUDY

To validate the model and verify the outcomes from the simulation process a real data from a case study were used from which results were compared to the actual ones. In this case study, the distance between the plant location and exhibition is estimated to be 13 kilometers. Figure 5 shows a Google maps image for the locations of exhibition and batch production plant along with the route taken to transport food. The exhibition was only for one day starting at 10:00 AM and ending at 5:00 PM. This exhibition was designated mainly for art crafts and handmade products however there was only one booth for food products. The estimated number for customers in this exhibition was approximately 500 customers with an average arrival and leaving rates of 11/6 and 25/12. The product that was displayed in the exhibition was sweet treats that consisted of three main ingredients with weights of biscuits 17%, cream cheese 60% and topping of different flavors 23%. In this event all the displayed products were sold out by the end of the exhibition with minimum wastes in the ingredients with a total number of 85 products.

By applying Equations 1 and 2, we find that the number of products is (|11/6 – 25/12|)*7*60 =105 units. By applying Equation 3 and using the different given weights $RI_1 = 0.17*(45/1.45) = 5$ units, $RI_2 = 0.6*(45/1.45) = 19$ units and $RI_3 = 0.23*(45/1.45) = 7$ units. When comparing these findings with the actual case study data the mean average error (MAE) was found to be 84% which shows plausibility of model results and that it can be used in real cases to optimize the amount of raw food ingredients.

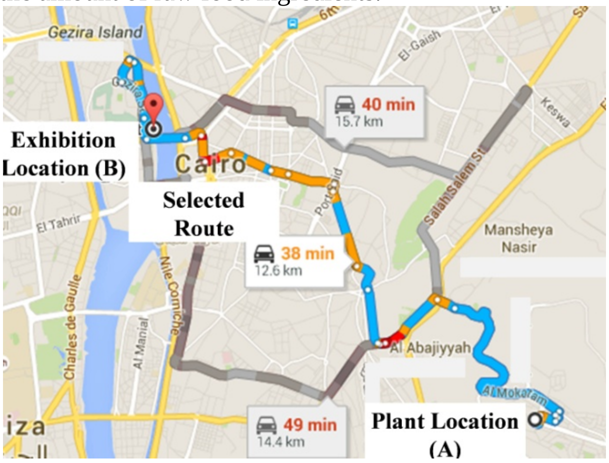

Figure 5: Google Maps imagery for the plant and exhibition location with the selected route shown

6. CONCLUSION

A discrete event simulation model is proposed for a food products and samples that will be used in exhibition and showcase events with the intent of minimizing the wastes as a result of using surplus raw ingredients. The simulation model comprised two main parts with the first part the batch production unit consisting all activities of processing, packing and loading the product, whereas the second part is the exhibition consisting all the activities and resources in the showcase event location. Different resources were examined to determine which one of them has a significant effect on the processes and the whole operation and it was found out the exhibitors are one of the governing factors that could drastically affect the duration of the activities in the event and the rate by which the products are sold. The intent of this paper was to provide a methodological framework to determine the amount of raw ingredients used in food processing to ensure sustainability by minimizing waste of raw ingredients and materials in addition to abortive work and additional electrical power required to process undesired surplus material. To achieve this goal, the service rate was linked with the duration of the event, from which the number of products can be computed. By knowing the weights for the different raw ingredients in the food product, the amount of each raw ingredient can be determined. Further investigation for the different processes and operations in the proposed model is recommended to be added to the model to include logistics and storage activities for future work to ensure that the proposed model is comprehensive. It is also recommended to compare the results from this model with other models using other simulation tools. Also, different types of simulation such as continuous event and agent based simulations can be used in building the same model and comparing the results. The developed simulation model and framework is expected to be a handful tool for stakeholders in small startups and young entrepreneurs in showcase events involving food sampling to minimize excess or surplus of food and raw ingredients required in food production.

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AUTHORS BIOGRAPHY

Mohamed Elmasry: A researcher and civil Engineer with nine years experience in infrastructure design works and construction management. He holds a Bsc in civil engineering from Cairo University in Egypt and Msc in Construction management for the American University in Cairo, Egypt. He has a variety of publications in different international conference proceedings in Europe and United States of America addressing automation in construction and simulation.

FatmaTarek: CEO and young entrepreneur in Toukies for homemade sweet treats in Cairo, Egypt. She has started this business in April, 2015 and has been working to increase her market share for that kind of industry. Since day one the mission for this startup was sustainable food production and preserving environment. She holds a Bsc in civil engineering from Cairo University in Egypt and has been involved in different social events