Abstract—The declining demand for fluorescent lamps, along with a recent currency floatation, forced a major glass tube manufacturer in Egypt to adopt a mixed Make-to-Stock (MTS) - Make-to-Order (MTO) strategy. In this research, a production control policy is proposed to effectively guide the involved product-mix decisions towards reducing the total cost. A simulation model is developed which is divided into three interconnected modules, namely decision, production, and order fulfillment. Along with the simulation model, a randomized search algorithm is applied to find appropriate values for the control variables of the proposed policy. Results provide evidence for the effectiveness of the proposed production control policy in reducing the total cost. Sensitivity analyses are conducted to investigate the effects of raw material and energy prices on the production parameters and the control variables of the proposed policy. It is found that the increase in raw material prices influences the production parameters; however, it does not affect the control variables of the proposed policy. On the other hand, the increase in energy prices influences both.

Keywords—Make-to-Stock (MTS); Make-to-Order (MTO); production control policy; glass tube manufacturing; simulation-based optimization

I. INTRODUCTION

The demand for fluorescent lamps is declining as consumers prefer less energy-consuming light emitting diode (LED) lamps despite their higher prices [1]. Alongside this declining demand, in 2016, the Egyptian government embarked an economic reform program which involved the floatation of the Egyptian Pound. This led to large increases in the inflation rate and energy prices. This economic situation forced Elaraby, a major fluorescent lamps producer in Egypt, to adopt a mixed make-to-stock (MTS)-make-to-order (MTO) production strategy in its glass tube factory. Such a strategy would justify the continuation of the energy-consuming facilities used for glass tube manufacturing. Furthermore, it is believed that such a strategy can increase the utilization of the available capacity.

A glass tube is one of the main components of fluorescent lamps. The manufacturing of glass tubes involves large investments in energy-consuming facilities. The raw materials used in manufacturing glass tubes are divided into natural material such as silica sand and synthetic material such as soda ash and glass cullet. The manufacturing process starts with mixing the raw material to obtain a homogeneous blend that provides uniform properties of glass tubes. By a screw machine, the mixture of raw materials is sent to the furnace to be melted. The furnace operates continuously without any stoppage except for performing regular preventive maintenance activities. The melting process is done using a few natural gas burners working sequentially.

Glass tube formation is done by forcing the molten glass to flow into a sleeve while air is being blown to form the tube’s cavity. The dimensions of a glass tube are determined by the rotation speed of the sleeve, the amount of air blown, the glass pull rate and the amount of glass flown into the sleeve. After forming the straight glass tube, tubes are cut according to the required lengths along a conveyor. The conveyor allows the glass liquid to cool down and to solidify. Along the conveyor, automated cutting, glazing and cullet removing operations are conducted. At the end of the conveyor, manual packaging is performed.

Production control decisions for glass tube manufacturing involve the determination of the glass pull rate and the percentage of glass cullet in the mixture. Glass cullet is obtained by crushing part of the output products. It constitutes an important element in the input mixture to the furnace as it helps in reducing energy consumption and improving the quality of the mixture. The main constraints in glass tube manufacturing include:

- The furnace must work continuously.
- The storage space of the final products is limited.
- Make-to-Stock (MTS) demand must be satisfied.
- Glass pull rate and cullet ratio have specification limits.
- Changes to glass pull rate and cullet ratio are constrained.

In this paper, a production control policy for the product-mix decisions for Elaraby’s glass tube manufacturing factory is proposed. The control variables of the proposed policy are optimized using simulation-based optimization. Sensitivity analyses are conducted to study the effect of some critical process parameters on the control variables of the proposed policy along with the main production parameters.

II. LITERATURE REVIEW

Recently, the planning decisions for hybrid MTS-MTO production systems started to receive more attention in the
literature. Soman et al. (2007) [2] developed a framework to manage an environment which uses both MTS and MTO production strategies for production planning and inventory control of a food processing factory which produces more than 230 products. The framework includes applying at first demand variability followed by medium-term capacity planning through applying economic lot scheduling problem (ELSP). Finally, a detailed schedule of both MTO and MTS products is generated. Kalautari et al. (2011) [3] presented a decision support system to assist in order acceptance-rejection decisions. In five steps, that system starts by prioritizing customers using a fuzzy TOPSIS method, followed by estimating the rough-cut capacity and rough-cut inventory based on capacity and material availability. Then, prices and delivery time is estimated using an MILP model. Next step includes a set of proposed guidelines to help the organization to negotiate with customer over prices and due dates. If the order is accepted detailed scheduling is prepared at the fifth step. Both papers do not provide tools to support decision making process for continuous manufacturing processes.

Discrete event simulation (DES) has been used extensively in simulating manufacturing systems. One of the limitations for DES is the difficulty of modeling continuous manufacturing processes. Kuo et al. (2001) [4] demonstrated how DES can be used to model continuous flow of chemical plant products. It is proposed to discretize the flow into fixed volumetric units that occurs between fixed time intervals. Schultz (2006) [5] developed a simulation model for a glass float production line. The float line starts with a continuous process of liquid glass flowing out from furnace. After that, glass ribbon is cut into individual stream of discrete products according to a cutting algorithm. The first obstacle in modeling that system was the combined continuous-discrete nature of the process. It was proposed to neglect the furnace modeling because glass furnace works without any shutdown. Therefore, the model focuses on the conveyor system.

Glass manufacturing optimization models were developed by different researches. Almada-Lobo et al. (2008) [6] developed an optimization model considering production planning and scheduling problems of colored glass containers manufacturing with the objective of minimizing average inventory level, setup time and number of stockouts. Near optimum solution for weighted objective function was achieved using a variable neighborhood search technique (VNS). The developed model did not consider a case of hybrid MTS-MTO production. Faragallah and Elimam (2017) [7] developed an integrated optimization model for glass tube and florescent lamps at Elaraby group. The model comprises all production steps from raw material mixing, continuous flow of glass furnace and inventory with the objective of minimizing total cost. That model does not take into consideration the variability of demand nor the customization of products; neither does it consider the mixed MTS-MTO production decisions for hybrid glass tube manufacturing.

This research aims to develop a production control policy that is easy to implement and can provide appropriate decisions for combined MTS-MTO production in glass tube manufacturing. A simulation optimization approach is used to optimize the control variables of the proposed policy.

III. THE PROPOSED POLICY

The proposed production control policy provides decisions for two control variables, namely the glass pull rate and the percentage of glass cullet used daily. As shown in Fig. 1, the policy prioritizes which product to be produced in the factory. The highest priority is given to crushing glass output in case of having shortage of cullet glass. After which, the priority is given to MTS products followed by MTO products. The policy utilizes lower and upper levels for glass cullet inventory, denoted z and Z respectively. If the current inventory of glass cullet (IGC) reaches the lower level z, the produced glass is crushed till cullet inventory reaches the upper level Z. Similarly, the lower and upper levels for MTS inventory (s, S) are used. If the inventory of glass cullet reaches the upper level Z, and MTS inventory (IMTS) reaches s, the factory will produce MTS product till its inventory reaches S. After which the MTO product can be produced. MTO products can be produced until the order quantities are fulfilled. If there is remaining capacity, MTS products are continuously produced with no limit on the quantity since the furnace cannot be stopped.

![Diagram](image_url)

Figure 1. Proposed Production Control Policy

IV. SIMULATION MODEL

A simulation model is developed for the glass tube manufacturing process and the proposed production policy is integrated to it. The simulation model consists of three modules for (1) the glass tube continuous manufacturing
process, (2) the inventory status of the products and of the glass cullet and (3) decisions made by the proposed policy. The decision module defines which product will be produced according to the proposed policy.

Glass production is continuous throughout the whole year. Since the molten glass level must be maintained at constant level, glass pull from the furnace will not impact the level as it is compensated directly by feeding raw material. Therefore, the change of molten glass level inside the furnace can be neglected. Accordingly, continuous production can be discretized. In the production module, cut losses and defects rate are taken into consideration and the amount of cullet produced are added to cullet inventory. MTS and MTO Inventory levels are updated according to the proposed policy. The considered total cost is the summation of raw material, energy and inventory costs.

Regarding product inventory and order fulfillment, the factory receives MTS and MTO orders at the beginning of every month. Acceptance/rejection decisions for received MTO product orders are not considered in the current study. Generally, the acceptance criterion is based on the available-to-promise capacity. The developed model considers MTS as a daily demand where MTO is a monthly demand. In addition to that, the following assumptions are considered.

- Glass pull rate and cullet ratio can be changed once a day.
- Switching from one product to another takes negligible time.
- MTO products are delivered at the end of the month.
- Production capacity is fixed.

The model was implemented using Rockwell Arena simulation software. The required number of replications is determined by conducting several runs at different number of replications. It was found that 15 replicates are sufficient. Warm-up period was estimated by running the simulation for 3000 days and using moving average method to find when the average reaches steady state. It was found that a warm-up period is 21 days is sufficient.

The simulation model was initially verified using visual test through keeping track of generated entities and how the model corresponded to different entities. Another way to verify the model is by estimating the arrival rate for an entity. Arrival rate theoretically is 1 per hour. The output value is 1.02 per hour.

The model was validated using the same production policy used in the factory. The production policy entails producing MTS whenever MTS inventory levels reaches below the safety stock level. MTO product is produced when MTS inventory level is higher than the safety stock. Table I lists the total weights in kg of both MTS and MTO products that are actually produced (real data) based on the reported historical data in the factory. Table I also lists the average and the half width results of the simulation runs. As shown in Table I, the real values of production quantities lie between the upper and the lower limits of the confidence interval, which is calculated as the mean ± the half width.

<table>
<thead>
<tr>
<th>TABLE I. SIMULATION MODEL VALIDATION RESULTS</th>
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<tbody>
<tr>
<td>MTS produced quantity (kg)</td>
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<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>Real data</td>
</tr>
<tr>
<td>Simulation mean</td>
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<tr>
<td>Half width</td>
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</table>

V. SIMULATION-BASED OPTIMIZATION

Near-optimum values for policy parameters can be obtained by applying simulation-based optimization through the OptQuest tool in Arena software. The main objective is to minimize the total cost. According to the proposed policy, the decision variables are glass pull rate, cullet ratio, MTS product limits (s, S), and cullet limits (z, Z). Simulation run length is one month as MTO orders arrive once a month, and production planning for glass manufacturing is prepared monthly.

OptQuest software, developed by F. Glover, J.P. Kelly and M. Laguna [8], has several optimization engines; however, the main optimization engine is scatter search methodology coupled with tabu search strategies. Scatter search methodology can handle continuous or discrete variable with one or multiple objective functions.

There are several factors in the application of OptQuest to solve any optimization problem. The first factor is the number of replications which depends on number of control or decision variables. If the number of controls exceeds 100 controls, results might deteriorate. As we have only six controls (decision variables), there is no problem regarding the accuracy of results. We decided to have 1500 simulation runs to have better results despite the recommended number of replications is only 100 [8].

A. Case Study

Simulation-based optimization is applied to the studied problem based on collected data at Elaraby glass factory. The monthly demand ranges for MTS and MTO product are shown in Table II, where glass pull rate was originally 780 kg/hr. and cullet ratio was 27.5%.

<table>
<thead>
<tr>
<th>TABLE II. DEMAND INFORMATION FOR MTS AND MTO PRODUCTS</th>
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<tbody>
<tr>
<td>MTS</td>
</tr>
<tr>
<td>Average weight (kg)</td>
</tr>
<tr>
<td>Demand lower level (units)</td>
</tr>
<tr>
<td>Demand upper level (units)</td>
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</tbody>
</table>

B. Results

The best value found for glass pull rate was found to be 800 kg/hr. to be used throughout the month with no change from day to another. The best values found for the proposed production policy are s =15000 kg, S =35000 kg, z =6000 kg and Z =15000 kg.

The cullet ratio changes from one day to the other. The range of the optimized cullet ratio values is from 25% to 40%, with an average value for the whole month of 34.5% and a standard deviation of 6.27%. The minimum total cost is found to be EGP 863,058. Optimization results were
applied to the previous case to validate the results with 15 replications to test the effect of optimized values on the profit the factory is making.

For MTS inventory, it was found that the average hourly MTS inventory lies between the lower and the upper MTS production levels as shown in Fig. 2.

![Figure 2. Optimized Average MTS Inventory](image)

For the case of cullet inventory, it was found that average hourly cullet inventory falls between the upper and the lower control levels, z and Z, as shown in Fig. 3.

![Figure 3. Optimized Cullet Inventory](image)

Considering raw material, it was found that raw material increased due to the increase in glass pull rate from 780 kg/hr to 800 kg/hr. However, total raw material without considering glass cullet decreased as cullet ratio increased from 27.5% to 34.5%. Actual raw material consumption without considering glass decreased, where energy consumption was decreased since increasing cullet ratio of the mixture decreases the value of energy consumption.

VI. SENSITIVITY ANALYSIS

Pareto analysis was performed to find the most significant cost elements. It was found that more than 80% of the total cost depends on raw material cost, energy cost and lost added value. Lost added value is the material and energy costs that is lost in crushing glass to make cullet. Therefore, raw material and energy are the most dominant factors for the total cost.

A. Raw Material Costs

Pareto analysis was performed on the elements of the raw material cost. It was found that soda ash and sand silica are dominant raw materials in the raw material cost. Optimization was run for expected cost for new raw material prices. The results show increase in cullet ratio that the average cullet ratio used 39.9%. Glass pull rate is set to 800 kg/hr. it was found that production policy limits did not change.

It was found that the glass pull rate did not change due to the increase in raw material prices. On the other hand, cullet ratio increased from 34.5% to 39.9%. Increasing cullet ratio decreases the amount of raw material required and decrease energy consumption used. Accordingly, energy cost decreases, but raw material cost increases due to increase in its prices. The lost added value cost did not change with the increase in raw material cost as it is balanced by a decrease in energy cost. Crushing cost increased as there is an increase in the cullet ratio used in the batch which required increase in crushing activity. Inventory cost decreased as the average inventory level for MTS product has decreased as shown in Fig. 2.

![Figure 4. Sensitivity Analysis Results for Raw Material Cost](image)

B. Energy Costs

Natural gas prices increased through years due to economic regulations in Egypt. Optimum cullet ratio is 38% for expected new price. Optimum glass pull rate remains 800 kg/hr. production parameters are changed due to change in energy prices as shown in Table III.

<table>
<thead>
<tr>
<th>TABLE III. ENERGY COST SENSITIVITY ANALYSIS</th>
<th>New values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper MTS limit (S)</td>
<td>35000 Kg</td>
</tr>
<tr>
<td>Lower MTS limit (s)</td>
<td>9024 Kg</td>
</tr>
<tr>
<td>Upper Culler limit (Z)</td>
<td>15000 Kg</td>
</tr>
<tr>
<td>Lower Culler limit (z)</td>
<td>4335 Kg</td>
</tr>
<tr>
<td>Optimized Cost</td>
<td>EGP 1197621</td>
</tr>
</tbody>
</table>

Raw material cost decreased due to the increase in cullet ratio which means less raw material quantity is used for the mixture. Inventory cost decreased due to a decrease in average inventory level for MTS product and Cullet.
Crushing cost increased slightly due to increase in cullet ratio required for making batch. Besides, energy cost and lost added value increased due to the increase in energy prices as shown in Fig. 5.

![Graph showing raw material, inventory, energy, crushing, and lost added cost for energy model and base model](image)

**Figure 5. Sensitivity Analysis for Energy Cost**

**VII. CONCLUSIONS**

This paper proposed a production control policy for a hybrid MTS-MTO glass tube production system. The studied production system consists of a continuous process of mixing and melting raw material for glass production, followed by a discrete process of forming and cutting glass tubes of different sizes for both MTS and MTO demands. The control variables of the proposed policy are optimized using simulation-based optimization. The Developed simulation model is divided into three modules. Such a division adds large flexibility to change the policy parameters. The developed simulation model can save a lot of money and effort associated with conducting experiments in factories. A simulation-based optimization algorithm is applied to generate optimized values for the control variables of the proposed policy as well as other related production parameters.

Sensitivity analyses were conducted to study the effect of changes in raw material prices and the energy cost on the simulation-optimization results. It was found that the increase in raw material prices will lead to change in production parameters; however, policy control variables will not change. Therefore, there will be increase in total cost, raw material cost, crushing cost and decrease in energy cost. Increase in natural gas prices will have effect on production parameters and the policy control variables.

There are different issues can be taken into consideration in a future research:

- Having multiple delivery times to fulfill MTO order.
- Price discounts according to product demand.
- Expanding the model to consider more than one customer for MTO products.
- Including penalty cost when the delivery time for MTO order exceeds predefined dates.

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**REFERENCES**


