Energy-Based Aggregate Production Planning For Porcelain Tableware Manufacturer in Egypt

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Abstract

Manufacturing activities although vital to economic development, are considered a large consumer of electrical energy. To ensure sustainability of manufacturing operations, an energy-efficient production planning is necessary. Aggregate planning plays a major role in shaping the master production scheduling and consequently the shop floor scheduling operations. This work presents a case study for developing an energy-based aggregate production plan for a porcelain tableware manufacturer in Egypt. The mathematical model used is a mixed integer linear programming model targeting the maximization of the profit while explicitly using the energy cost as one of the cost elements. The model proves its superiority to current management practices in terms of cost reduction and order fulfillment. Total costs are reduced by 23.2% from the real case. The model further assists the decision maker in studying the effect of changes in electricity prices.

Keywords
Aggregate production planning, porcelain manufacturing, optimization, energy.

1. Introduction
Energy consumption is a growing concern for researchers, practitioners and governments due to the limited availability of non-renewable resources and the adverse environmental effect the conventional electricity generation methods have. Furthermore, unstable economic conditions have enforced governments to restructure the subsidy of energy. Manufacturing, despite its indispensable role in economic development, has always been considered a large energy consumer. Nevertheless, this problem may be mitigated by appropriate production planning. Energy-efficient production planning (EEPP) is defined as the efforts in saving energy through managerial production related decisions (Biel & Glock 2016). Aggregate production planning (APP) is a mid-term planning level defining the production, workforce, inventory, and backorder levels in a period ranging from 3 to 18 months. Integrating energy consumption to classical APP model is an emerging trend experiencing growth in the literature (Biel & Glock 2016). In Egypt, electricity is among the major subsidized resources. In 2012, the electricity production constituted 3.7% of the total subsidy in Egypt [Subsidy report]. Yet, economic reform calls for removing subsidy, the process gradually undertaken by the government. The aim of this study is to investigate the effect of the changes in electricity prices on manufacturing activities. A mixed integer linear programming (MILP) model has been developed to maximize profit while including the electricity cost as one of the cost elements in the objective function. Hence, the applied model integrates energy consumption in setting an aggregate production plan and can be used to study the effect of changes in energy prices on production, inventory, and backorder levels and on the total profit as well. The model is applied to a case study using real data for a porcelain tableware manufacturer that exports most of its production from Egypt to other countries. This industry has been chosen as in a recent annual report by the Egyptian Electric Utility and Consumer Protection Regulatory Agency (Egypt ERA), the ceramic and porcelain manufacturing industry was classified in 10^{th} position with regard to electricity consumption.
The remainder of this text is structured as follows. In the following section a literature review is presented focusing on the APP models with consideration of energy aspects. Section 3 presents a detailed description of the developed MILP model. The case study of the porcelain manufacturer and model implementation are given in Section 4.

Results are presented and discussed in Section 5. Finally, conclusions drawn and suggestions for future research directions are emphasized in Section 6.

2. Literature Review

Aggregate production planning is a tactical planning problem concerned with determining the production, inventory and workforce levels to meet anticipated demand given resource capacities (Wang & Fang, 2001). It plays a critical role as it provides the basis for subsequent decision making regarding the master production schedule and subsequently scheduling at the shop floor level (Gansterer 2015). The increased concern about the environmental impact of manufacturing activities has urged researchers to include environmental aspects in production planning. Aggregate production planning has recently been addressed in conjunction with environmental aspects in green supply chains (Entezaminia et al. 2016). A multi-objective model has been developed to investigate economic and environmental performance in a green supply chain (Entezaminia et al. 2016). Uncertainty has been also been incorporated in developing an aggregate production plan for green supply chains considering multi-objectives (Mirzapour Al-e-hashem 2012).

Due to the increased concern about the depletion of natural resources and the calls for sustainable manufacturing, recent research work concentrated on energy-efficiency in manufacturing. Biel and Glock (Biel & Glock 2016) conducted a review which considered the role of medium and short-term production planning in saving energy consumption. In the mid-term planning models they identified two classes of models addressing energy efficiency: master scheduling and capacity planning. They also stressed that existing models in these categories mainly focused on including the energy cost when evaluating total cost to arrive at a master production schedule identifying the production and inventory levels and that the developed approaches mainly addressed the dynamic energy prices and determined production schedule to minimize energy consumption. Yet, the main findings of this review were directed towards the machine-scheduling problem.

A multi-objective linear programming model was developed in (Modarres & Izadpanahi 2016) to integrate the energy consumption in the classical aggregate production planning formulation. Three objectives were considered: minimizing operation cost, energy cost, and CO_2 emissions. The model further addressed uncertainty in objective function parameters (operational cost, energy, and carbon), maximum capacity, and demand. Robust optimization approach has been used to deal with uncertainty.

A non-linear mixed integer programming model has been proposed in (Mirzapour Al-e-hashem et al. 2013) to formulate the aggregate production planning problem in supply chain context under demand uncertainty while considering environmental aspects. In their work, the authors laid emphasis on calculating the transportation cost and considering quantity discounts. Environmental aspects were also included and presented by the GHG emissions in addition to the environmental impact initiated by the products.

Among the research gaps identified in (Fahimnia et al. 2013) was the limited consideration of production cost elements incurred by each machine when setting the aggregate plan. Furthermore, the scarcity of testing the applicability of developed models or showing implementations to real life case studies was criticized in (Díaz-Madroñero et al. 2014). They observed that the majority of aggregate planning models were validated with random created instances. Thus, the aim of this study is to consider the energy cost as a separate element and validate the applied model via a real-life case study.

3. Model Development

The model aims at determining the production quantities, inventory levels, backordered quantities, workforce level, as well as quantities of raw materials purchased and final products shipped per each period. The following assumptions are made to facilitate model formulation:

1. A single facility is considered.
2. All cost elements and demand are deterministic.
3. For the products of the same product family fixed production cost is the same.
4. No overtime is used at the factory.

The problem has been formulated as a mixed integer linear programming model. Indices *i*, *n*, and *t* indicate customers, products, and time period; respectively. A single objective is considered which maximizes total profit, given the input parameters in Table 1.

Table 1. Declaration of model input parameters

D_{nit}	Demand for product *n* for customer *i* in period *t*.	CI_n	Inventory holding cost for product *n*.
C_n	Variable production cost for product type *n*.	CM_{nk}	Cost of product type *n* provided by supplier *k*.
PC_n	Fixed production cost of product type *n*.	CP	Product storage capacity.
P_{ni}	Sale price of product *n* for customer *i*.	CS_{nk}	Amount of product type *n* provided by supplier *k*
W	Labor cost.	π_{ni}	Shortage cost of product *n* off customer *i*
a_n	Manpower needed to produce product *n*.	C_t	Energy cost in period *t*.
F	Firing cost	P_t^{MAX}	Maximum energy consumption in period *t*.
HC	Hiring cost	e_n	Energy consumption for producing each unit of product *n*.
K	Maximum production capacity		

The decision variables are defined as follows:

X_{nt} Amount of product type *n* produced in period *t*.
XQ_{nkt} Number of units of product type *n* shipped from supplier *k* in period *t*.
YQ_{nit} Number of units of product type *n* shipped to customer *i* in period *t*.
B_{nit} Shortage of product *n* of customer *i* in period *t*.
L_t Number of workers available in period *t*.
F_t Number of workers fired in period *t*.
H_t Number of workers hired in period *t*.
I_{nt} Inventory level of product type *n* in period *t*.
Y_{nt} Binary variable that determines whether product type *n* is produced in period *t* or not.

The objective function given in Equation (1) maximizes profit which is sales revenue less the total costs. The later encompasses the cost elements of labor, production, energy, inventory holding, purchasing, and shortage costs.

$$\text{Maximize } Z = \sum_{n,i,t} P_{ni} \cdot YQ_{nit} - \sum_t W \cdot L_t - \sum_t FC \cdot F_t - \sum_t HC \cdot H_t - \sum_{n,t} CI \cdot I_{nt} - \sum_{n,t} PC \cdot Y_{nt} - \sum_{n,t} C_n \cdot X_{nt} - \sum_{n,k,t} CM_{nk} \cdot XQ_{nkt} - \sum_{n,i,t} \pi_{ni} \cdot B_{nit} - \sum_{n,t} e_n \cdot c_t . X_{nt} \quad (1)$$

Equations (2) to (14) lists all constraints considered in the model. Equation (2) states that any unmet demand in period *t*, which is the sum of current period demand plus any backordered quantities from previous period, is backordered. An inventory balance constraint for each product *n* in each period *t* is described in Equation (3); it ensures that the quantity of each product *n* shipped to all customers in period *t* is satisfied via the on hand inventory and the production quantity in period *t*.
The workforce capacity constraint is expressed in Equation (4); where, the manpower needed to produce any amount of product type *n* produced in period *t* should not exceed the workforce capacity in the same period *t*. While, Equation (5) ensures that the workforce level in each period *t* must be equal to the workforce level in the previous period *t*-1 plus the number of workers hired minus the number of workers fired in period *t*.
Supplier capacity, inventory storage capacity, and production capacity constraints are given in Equations (6), (7), and (8); respectively. Inclusion of the binary decision variable in Equation (8) guarantees that the capacity will be equal to zero if it is decided not to produce a specific product *n* in period *t*. Furthermore, production amount of any product *n* in any period *t* should not exceed the raw material received from the supplier for the needed for that product in that period; this is indicated by the constraint in Equation (9).
Equation (10) is a balancing constraint that ensures that units of product *n* shipped from the factory in period *t* should not exceed the amount of units produced of the same product in the same period.
The energy constraint is presented in Equation (11), where the actual energy consumed in production of product *n* in period *t* is restricted to the maximum allowed/available energy in the same period *t*.
Non-negativity, integrality and binary constraints are expressed in Equations (12), (13), and (14), respectively.

$$YQ_{nit} - D_{nit} - B_{ni(t-1)} + B_{nit} = 0 \quad \forall\, n, i, t \quad (2)$$

$$I_{n(t-1)} + X_{nt} - \sum_i YQ_{nit} = I_{nt} \quad \forall\, n, t \quad (3)$$

$$\sum_n a_n . X_{nt} \leq L_t \quad \forall\, t \quad (4)$$

$$L_t = L_{(t-1)} + H_t - F_t \quad \forall\, t \quad (5)$$

$$XQ_{nkt} \leq CS_{nk} \qquad \forall\, n,k,t \tag{6}$$

$$\sum_n I_{nt} \leq CP \qquad \forall\, t \tag{7}$$

$$\sum_n X_{nt} \leq K \cdot Y_{nt} \qquad \forall\, t \tag{8}$$

$$X_{nt} \leq \sum_k XQ_{nkt} \qquad \forall\, n,t \tag{9}$$

$$\sum_i YQ_{nit} \leq X_{nt} \qquad \forall\; n,t \tag{10}$$

$$\sum_n e_n \cdot X_{nt} \leq p_t^{Max} \qquad \forall\, t \tag{11}$$

$$I_{nt}, XQ_{nkt}, YQ_{nit}, X_{nt} \geq 0 \tag{12}$$

$$L_t,\; H_t,\; F_t \quad integer \tag{13}$$

$$Y_{nt} \in \{0,1\} \tag{14}$$

4. Case Study

The case study investigated in this work is a manufacturer of porcelain tableware in Egypt. The factory is mainly export-oriented and does also serve local market. It produces a variety of high quality tableware. The factory includes four production lines depending on the type of forming operations applied. This case study is restricted to the press production line, which contributes 30% of the total production. The average daily capacity of this line is 60 tons of production per day.

The operations of the press production are mapped in Figure 1. Raw materials are received from warehouse and prepared by crushing, screening and mixing. Parts are then formed by press machines and shipped to bisque fire kilns. At this stage the parts are heated to low temperatures to evaporate volatile contaminates. Parts are then inspected and are either forwarded to glazing stage or sent back to be crushed and reformed. Glazed parts are forwarded to glaze kilns, where they are heated to high temperatures (greater than 1,200 degree Celsius) until the required density is attained. Parts are then allowed to cool, and thus the porcelain parts are created. These are inspected and are either sent to the decoration stage to apply a decal or packaged to and sent to storage to be sold by item at a lower price. After adding the decal, the parts enter a final decoration kiln. Final inspection follows. Conforming parts are packaged in sets or individually according to product type, and then sent to storage. While, defective products are also packaged and sent to storage; as these items are also sold; however, at a lower price in local market.

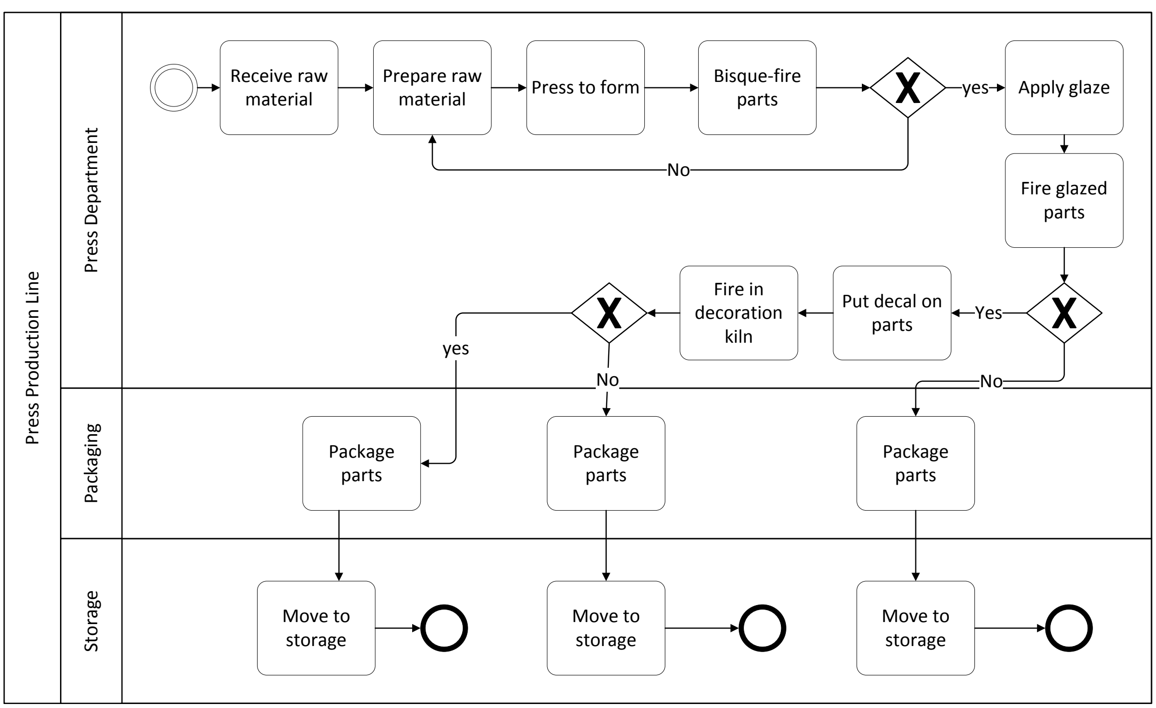

Figure 1. BPMN for the ceramic tableware manufacturing process

For the press production line, electricity consumption amounts to approximately 2,000 kWh per day. Two types of energy are used, electrical energy and natural gas. A product family consisting of 10 products is used in defining the aggregate production plan. The total demand of all 10 products and the maximum energy consumption for each month is given in Table 2. The maximum production energy is set at 150% of the actual energy consumption.

Table 2. Monthly demand and electricity availability

Time (months)	1	2	3	4	5	6
Demand (units)	506,400	396,900	507,300	381,000	280,700	399,900
P_t^{MAX} (kWh)	28,864,800	22,623,300	28,916,100	21,717,000	15,999,900	22,794,300

The different input parameters are declared in Table 3. These represent the different cost elements, workforce level, production capacity level, and energy requirements.

Table 3. Model input parameters

Parameter	**Value**	**Parameter**	**Value**
CR_n (EGP/unit)	1.47	L_0 (Worker)	90
CI_n (EGP/unit)	1.91	M (units)	500,000
PC_n (EGP/unit	2.23	a_n(worker/unit)	3.6×10^{-5}
P_{ni} (EGP/unit)	6.23	b_0 (units)	0
π_{ni} (EGP/unit)	12	I_0 (units)	0
CM_{nk} (EGP/unit)	1.46	e_n (kWh/unit)	1.35
W (EGP)	1,640	c_t (EGP/ kWh)	0.48
CP (units)	3,090,250	FC (EGP/unit)	25,000
CS_{nk} (units)	3,708,300	HC (EGP/unit)	1,500

Over the past ten years electricity prices in Egypt has been subject to increases due to varying subsidy levels offered by the government. Figure 2 presents the electricity prices per kWh over the last 10 years. It can be observed how the rate of increase is higher over the past three years. Future increase in electricity prices is foreseen due to the economic reform undertaken by the Egyptian government. The Ministry of Electricity and Energy is planning to reduce the amount of subsidy currently provided. There is a plan to eliminate subsidy in the next three years.
Because of the current calls for energy savings and the frequent changes in electricity prices, the management wants to address the production planning problem with consideration of energy consumption. The management is further interested in determining the effect of changing the electricity prices. Currently, the factory is charged a constant electricity price of 0.48 EGP/kWh.

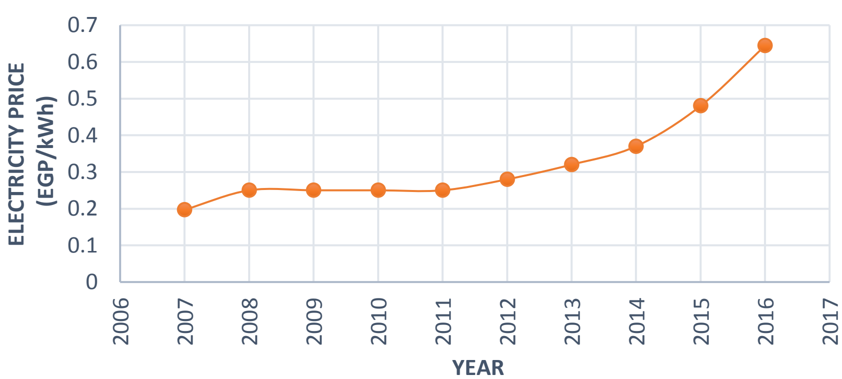

Figure 2**.** Electricity prices in Egypt over the last 10 years

5. Results and Discussion

The model has been solved using Lingo 16 and the results are presented in Table 4. The results are the monthly production quantity (X_{nt}), amount received from suppliers (XQ_{nkt}), amount shipped to customer (YQ_{nit}), shortage quantities (B_{nit}), and inventory level (I_{nt}). It is noted that the quantities are backordered in periods 1 and 3 only, and that no quantities are held in inventory in any period.

Table 4. Model results

t (month)	1	2	3	4	5	6
X_{nt} (units)	500,000	403,300	500,000	388,300	280,700	399,900
XQ_{nkt} (units)	500,000	403,300	500,000	388,300	280,700	399,900
YQ_{nit} (units)	500,000	403,300	500,000	388,300	280,700	399,900
B_{nit} (units)	6,400	0	7,300	0	0	0
I_{nt} (units)	0	0	0	0	0	0

The total cost and its elements obtained from the model are compared to the actual costs in **Error! Reference source not found.**. Total cost is broken down to five cost elements: labor, inventory, production, shortage, and energy costs. It is clear that the model results in decreased total costs. Total cost breakdown reveals that the model has a positive effect on inventory and shortage costs. The shortage cost has fallen from 4.22 (million EGP) in the actual case to 0.16 (million EGP) by the model. This represents a reduction of 96.2% in shortage cost. Both production and energy costs are higher in the model, since more quantities are produced causing a decrease in shortage costs and hence in total costs. The increase in production and energy cost present 15.84% and 15.94%, respectively. The highest cost element is production cost followed by energy cost and contribute to 73.2% and 16.2% of total costs; respectively. As to labor costs no difference is noticed between the model and actual case. Total costs have decreased by 23.2% by applying the model. Thus, the application of the model is beneficial in terms of cost reduction and customer demand fulfillment. The latter is manifested by the considerable decrease in shortage cost.

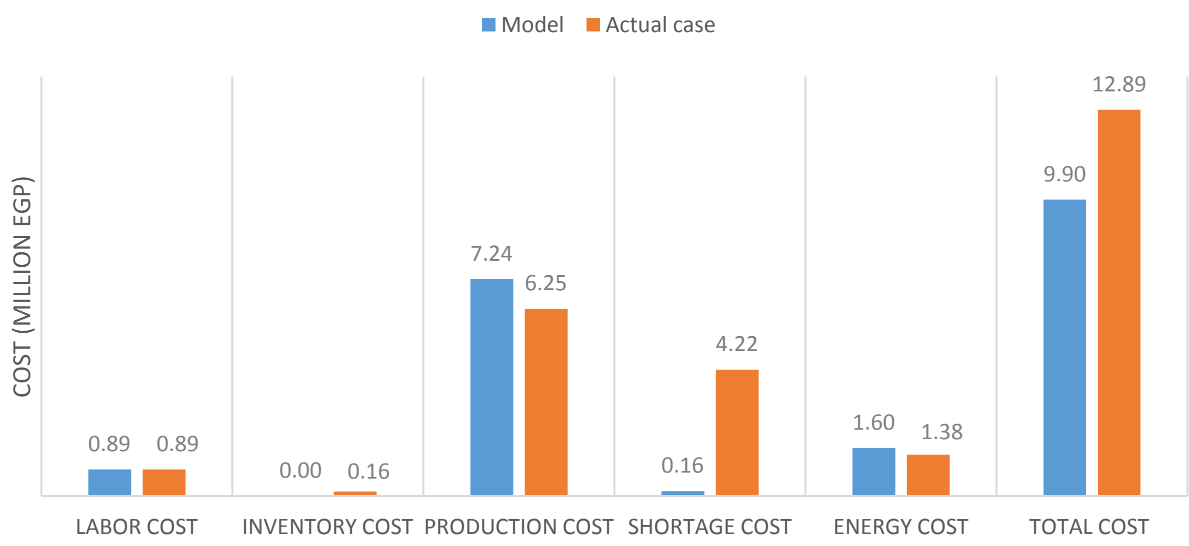

Figure 3. Comparison between total costs and its elements for the actual case and model results

The model has been run with the same cost data and different electricity prices to investigate how the production decisions are affected by changes in energy cost. The electricity prices used in this analysis started from 0.48 (EGP/kWh),which has been used in the model and were escalated till 2.8 (EGP/kWh). Both costs and profit have been monitored. Results of the runs are shown in Figure 4.

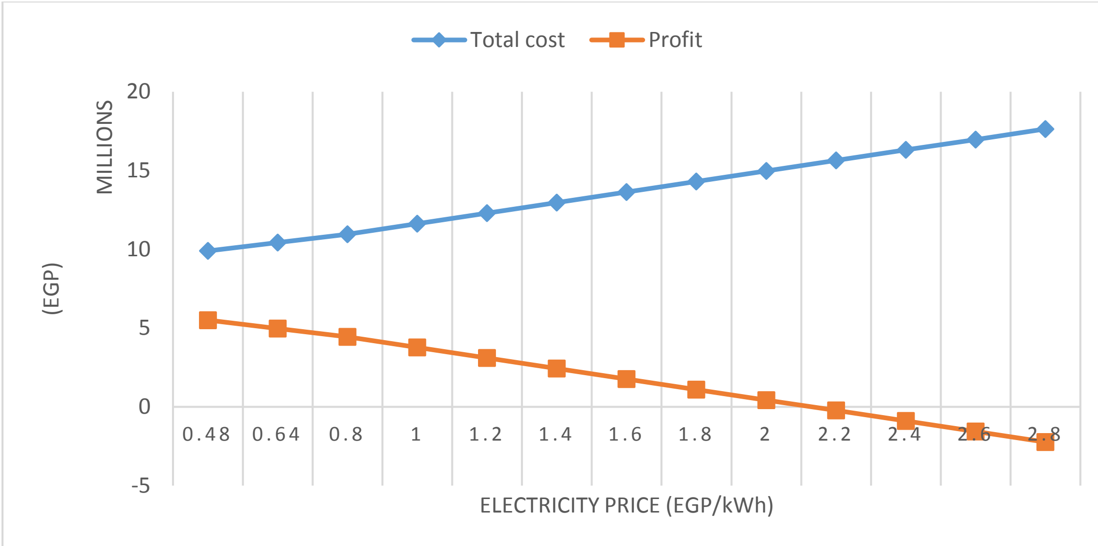

Figure 4. Relationship between total cost, profit and price energy.

It can be observed that the increase in electricity price causes an increase in total costs and consequently a decrease in profit. Unless selling price per unit of product is increased, which cannot be easily attained given the fact that the factory is export-oriented as mentioned earlier, at an electricity price of 2.2 EGP/kWh, losses will occur.
Hence, it is infeasible to obtain profit for increased electricity prices. Management should consider electricity saving measures to hedge against increase in electricity price. An investigation of the economic feasibility of the use of other renewable energy resources to provide the necessary energy demand is also recommended.

6. Conclusions and Future Work

The purpose of this paper is to formulate an MILP aggregate production planning model that explicitly factors energy in terms of electricity costs in the objective function and in the constraints and to apply the developed model to a real-life problem of a porcelain tableware manufacturer in Egypt. The developed model maximizes the profit over the planning horizon and considers different cost elements, which are production cost, inventory cost, and labor cost in the objective function in addition to the energy cost. The model has been solved via Lingo and an optimal solution has been obtained. Based on the analysis of the results, the model revealed that it outperforms current management planning practices in terms of cost and demand fulfillment. The model reduced the total costs by 23.2% and improved demand fulfillment by 96.2% as indicated by the shortage cost. It was also clear that the energy cost element plays a considerable role, as it constitutes 17% of the total production cost. Given the importance of the industry and its high energy consumption, the modeling of energy consumption explicitly and involving it in the decision making process is vital.
Furthermore, the increase of electricity prices, affects the profitability of the company. If a specific profit margin is targeted, the management may determine the threshold of electricity price that will satisfy the aspired profit. For the company to deal with the increase in electricity price and to maintain its profitability other energy resources should be considered and their economic feasibility investigated.
The application of this model in a multi-product environment, the consideration of uncertainty of demand, and the inclusion of other energy sources are suggested areas for extending this work.

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Biography

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