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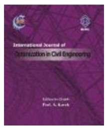

A LINEAR PROGRAMMING MODEL FOR PRODUCTION PLANNING: AN IRANIAN CASE STUDY IN CEMENT

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ABSTRACT

Production planning and inventory control efforts are known as the driving engines of manufacturing systems. The manufacturers, competing to survive in these days' competitive business environment, aim to satisfy customers' needs. This requires a precise production plan throughout the supply chain. These days, because of the increasing costs of production and distribution, especially in the cement industry, and given the importance of this industry, investors seek to reduce the production costs as much as possible, to achieve a competitive advantage. In cement industry, main focuses are converging on the alternative fuels developments, optimization of furnace fuel consumptions and sustainable and green production considerations. In this study, a mathematical model is developed to investigate the cement production plan. The objective function is to minimize the total costs of a real case of cement industry. The proposed model is applied on a case of real world application at the West Azerbaijan's Urmia Cement Company. Sensitivity analyses are carried out on the findings of the model. The proposed model has proven to be cost efficient.

Keywords: optimization; production planning; cement; optimization of cement supply chain.

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1. INTRODUCTION

In today's competitive business world, the supply chain (SC) strategy is believed to be the vital backbone of businesses [1]. Any miss placed strategy can lead to a catastrophic outcome for the SC [2]. Effective market coverage and product-accessibility at key revenue locations, depends on the effective role of the supply chain management (SCM) [3]. SCM has become an integral part of organizations in achieving the company success and consumer satisfaction, as it has the ability to increase customer service [4], reduce operating costs [5], and improve

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corporate finances [6]. But the important question is that, how these benefits can be achieved? In fact, customers expect high quality and healthy product to be delivered on time with the least possible price. For this purpose, the products should be in the right place and be provided with after-sales service. These expectations are in contrast with the business-oriented company's ultimate goal, to earn profit, and are opposing it.

SCM is mainly focused on boosting profits and market share of the SC entities and reducing the associated costs of the supply chain network (SCN). The very final purpose of a SC is to meet customer demand at the lowest cost possible, and one of its priorities is to improve delivery effectiveness from raw material suppliers to the final consumers [7]. Severe competition in today's global markets, short life-cycled products and growing consumer expectations have forced businesses to focus their attention on their SC's effectiveness [8]. In other words, SCM is referred to as a network of facilities and activities providing raw materials, their flow among facilities, manufacturing process, distribution plan and after-sale provision of the services by improving the relationships among the SC members to achieve a reliable and sustainable competitive advantage. The globalization of competition in various industries, especially cement industry, has brought up both opportunities and challenges [9]. On one hand, investors can conquer the markets by increasing cost effective production quantities. On the other hand, environmental issues along with transportation costs, create strong restrictions for investors [10, 11].

Cement is one of the most important construction materials around the world and due to the geographic frequency of its main ingredients, and the low supply price, it is produced in most of the countries around the globe. World trade in cement industry in comparison with other industries is limited, with the exception of factories located at the border [12]. This limitation is due to high transportation costs, low number of production inputs and the abundancy of these materials in different countries [13]. But cement is one of the promising industries in the economies of the countries because there is always demand for cement [14], and this demand is expected to increase with the development of construction in the region [15], especially in the developing countries. Therefore, the exact study of cement production planning and SCM considerations is essential. In this study, a dynamic mathematical model for an optimum cement production plan, is proposed and analyzed with the aim of reducing cement supply costs.

The remainder of the paper is organized as follows. In the next section, the related literature is reviewed and investigated thoroughly to point out the research gap in production planning area and clarify the contributions of the proposed model. Section 3 includes the description and formulation of the proposed model. The case study is proposed in section 4. The numerical results and illustrations are presented in Section 5. Finally, Section 6 concludes this paper and offers the possible future research directions.

2. LITERATURE REVIEW

Even though the cement production planning has a huge role in the effectiveness of cement SC, there has been few works on this issue in the last decades. Most of the research efforts have focused on supply chain network design (SCND) problem and green SC considerations [16]. But some remarkable studies have been conducted on the optimal production planning in general. The study of the production and distribution optimization has been identified as a competitive advantage in manufacturing and distribution companies in the past two decades [17]. Following, the main streams of the related literature are investigated, SCND, production planning, cement production and integrated studies.

Mula, et al. [18], investigated the body of production planning literature from 1983 to 2004. They provided a comprehensive literature review of production planning models under uncertain inventory considerations and examined all models presented for optimal production planning including conceptual, analytical models and simulation-based models. According to them, most of the mathematical-based modeling studies have considered SC topology for the production planning and transportation decision variables at the tactical decision-making level [19]. The main objective of these studies is to minimize the total cost of the SC or equivalently, to maximize the revenue of the SC by a mixed linear programming approach.

Extensive studies have been conducted on the SCND problem and inventory optimization. As authors investigated the reliability of the inventory and the lead time, only a few of them have focused on trade-offs between SCND problem costs and inventory optimization in tactical decision making level [20]. Fahimnia, et al. [21], states that the integrated production-distribution optimization modeling in both academia and practice efforts over the past two decades has gained significant profits. They provided a comprehensive review of current production-distribution planning and optimization literature. Yildirim and Kardas [22] have developed a multi-agent system (MAS) considering joint agents' efforts to achieve optimal production planning of a cement factory. Their proposed system has been actively implemented in one of Turkey's leading cement factories. The evaluation results showed that the use of the provided system saves significant costs. Hong and Li [23] evaluated the environmental impacts of sewage sludge as a secondary raw material supply in the cement industry. Their analysis confirms and validates the results, showing clinker production, energy consumption and limestone production have significant role in the development of inorganic respiration, land poisoning, global warming and non-renewable energy consumption. Similar efforts can be found in Li, et al. [24].

Asad [25] has focused on the long-term planning of cement mining operations. The production consistency depends on a sustainable supply of raw materials from limestone mines. The inventory of raw materials in limestone mines is identified as a block model and usually consists of thousands of blocks and no individual block can satisfy the expected supply alone. Therefore, the combination of different blocks with expensive additives purchased from the market is a prerequisite. According to the aforementioned procedure, the purpose of planning and timing of limestone production in cement factories is to dig the available blocks continuously to meet the quantitative and qualitative requirements of the production plan. Achieving a solution to this problem that each block defined as an integer binary variable is often a challenge in the cement industry at a reasonable time. A case study of this study was conducted on the production of an existing cement plant in the Midwest of the United States. Spyridakos, et al. [26] have studied a decision support system (DSS) inventory control system in the cement industry. Their provided system is specified to: A. Discussing the large volume of data in real time, B. Estimating the value of inventory control parameters in real time and considering all the important factors, and C. Considering inventory control efforts at tactical and strategic levels. Their proposed DSS in the cement industry has caused a blocked capital reduction up to 50% in inventory.

Salas, et al. [27] has provided a literature review of environmental impacts and life cycle assessment in the cement industry. They identified the improvement of energy efficiency, the use of alternative fuels, clinker replacement and carbon capture system (CCS) as a fundamental solution to reduce the environmental impacts of cement production. Mahdavi, et al. [28] focused on improving the quality of the cement production process by controlling process modification. Since in a cement plant, manufacturing processes are irreversible therefore, monitoring and controlling is vital factor. In the cement industry, if the production process is not controlled at each stage the final product can be damaged, and this can be enormously costly.

As aforementioned, due to the cement production process and its systematic limitations such as; irreversible production processes, cost-efficient supply availability, costly transportations etc. literature lacks to provide a simple yet effective production planning model to incorporate both logistics and production efforts. Proposed models in the related literature are mostly from the perspective of academia rather than practitioners and mutual ground is missing. The deterministic models where the supply availability is high could shed light on the decision variables optimization procedure. In this study a linear programming model is developed to fill out this gap. The numerical results and sensitivity analyses show a great promise on optimizing the production planning. Further analyses are presented in section 5.

3. PROBLEM DESCRIPTION

3.1 Cement production process

Cement is a mixture of inorganic ingredients, mainly calcium silicates and aluminates. In fact, cement is produced from clay and limestone. These raw materials are extracted from mines and powdered, then mixed with appropriate proportions. These raw materials are heated in rotary kilns up to 1400-1500 ° C and then slowly dried. Finally, they leave the furnace, called clinker furnace output. The clinker is stored in silos or transferred to the cement production area. In the cement production area, the cooled clinker is powdered and mixed with gypsum and other required ingredients. Gypsum is used to adjust the properties of cement in the construction [29].
Figure 1 shows the different stages of the cement production process.

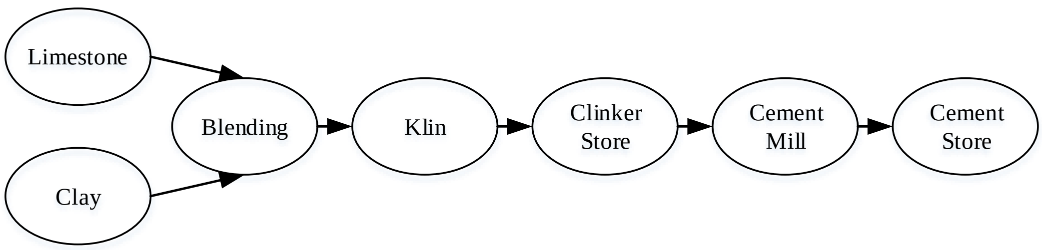

Figure 1. Cement production stages

Cement has different types and luckily, they aren’t that much different in production process. Their main difference is in the clinker additives. Following, a variety of cements are listed; (1) Portland cement type 1, (2) Pozzolan cement, (3) Acid resistant cement, (4) Blast furnace cement, (5) Colored cement, (6) Expanding cement, (7) High Alumina cement, (8) Hydrophobic cement, (9) Low heat cement, (10) Pozzolana cement, (11) Quick setting cement, (12) Rapid hardening cement, (13) Sulphate resisting cement, (14) White cement, (15) Air-entraining cement. The production process in various cement production processes is the same. In this study, a linear mathematical model is proposed for cement production planning problem. In this model, the ultimate goal is to minimize cement production costs. For this purpose, the extraction procurement costs of the raw materials, transportation and transshipment costs and inventory handling costs are taken into considerations. Following, the indices, parameters and the variables of the proposed model are introduced.

Indices and sets

i Index of raw material, $i=1,2,\dots,I$
s Index of cement type, $s=1,2,\dots,S$
t Index of time period, $t=1,2,\dots,T$
c Index of customer regions, $c=1,2,\dots,C$

Parameters

$TC1_{it}$ Shipping cost of raw material i to raw material warehouse in time period t
$TC2_{it}$ Shipping cost of raw material i to clinker plant in time period t
$TC3_{t}$ Shipping cost of clinker to clinker warehouse in time period t
$TC4_{t}$ Shipping cost of clinker to cement plant in time period t
$TC5_{sct}$ Shipping cost of cement type s to customer area c in time period t (*ton/Km*)
$TC6_{t}$ Shipping cost of pozzolan to cement plant in time period t
$CH1_{it}$ Holding cost of raw material i in time period t
$CH2_{t}$ Holding cost of clinker in time period t
$CH3_{st}$ Holding cost of cement type s in time period t
CM_{it} Cost of raw material i in time period t
CL_{t} Production cost of clinker in time period t
CS_{st} Production cost of cement type s in time period t
CP_{t} Purchase cost of Pozzolan in time period t
SC_{sct} Shortage cost of cement type s in customer area c in time period t
$CI1_{st}$ Storage capacity of cement type s in time period t
$CI2_{t}$ Clinker storage capacity in time period t
$CI3_{t}$ Raw material storage capacity in time period t
CIP_{t} Pozzolan inventory capacity in time period t
$CP1_{st}$ Production capacity of cement type s in time period t
$CP2_{t}$ Clinker production capacity in time period t
$CP3_{it}$ Extraction capacity of Raw material i in time period t
D_{cst} Demand of cement type s in customer area c in time period t
α_{s} Ratio of clinker in cement type s production
β_{t} Ratio of Limestone and Gypsum in production cement type s in time period t
γ_{s} Ratio of pozzolan in cement type s production
θ_{i} Ratio of raw material i in clinker production

Variables

MT_{it}	Quantity of extracted raw material *i* in time period *t*
KL_t	Quantity of clinker production in time period *t*
IM_{it}	Inventory of raw material *i* in time period *t*
IPZ_t	Inventory of pozzolan in time period *t*
PZ_t	Quantity of purchased pozzolan in time period *t*
IS_{st}	Inventory of cement type *s* in time period *t*
SE_{st}	Quantity of cement type *s* production in time period *t*
IK_t	Inventory of clinker in time period *t*
MK_{it}	Quantity of raw material *i* in clinker production in time period t
XL_t	Quantity of shipped clinker to clinker warehouse in time period *t*
XP_t	Quantity of shipped pozzolan to cement plant in time period *t*
XS_{st}	Quantity of shipped clinker to cement plant in time period *t*
YS_{sct}	Quantity of shipped cement type *s* to customer region *c* in time period *t*
δ_{sct}	Shortage amount of cement type *s* in customer region *c* in time period *t*
SG_{st}	Quantity of Limestone and Gypsum in cement type *s* production in time period *t*

3.2 Proposed model

3.2.1 Objective function

For the sake of clarity, the cost elements and expressions of the objective function are divided into several sub-categories, more detailed explanations are provided after introducing them.

Extraction Costs;

$$\sum_{i,t} CM_{it} MT_{it} \tag{1}$$

Shipping Costs:

$$\sum_{i,t} TC1_{it} MT_{it} \tag{2}$$

$$\sum_{i,t} TC2_{it} MK_{it} \tag{3}$$

$$\sum_{t} TC3_{t} XL_{t} \tag{4}$$

$$\sum_{s,t} TC4_{t} XS_{st} \tag{5}$$

$$\sum_{s,c,t} TC5_{sct} YS_{sct} \tag{6}$$

$$\sum_{t} TC6_{t} XP_{t} \tag{7}$$

Production and procurement associated costs;

$$\sum_{s,t} CS_{st} SE_{st} \tag{8}$$

$$\sum_{t} CL_{t} KL_{t} \tag{9}$$

$$\sum_{t} CP_t PZ_t \tag{10}$$

Inventory associated costs;

$$\sum_{i,t} CH1_{it} IM_{it} \tag{11}$$

$$\sum_{t} CH2_t IK_t \tag{12}$$

$$\sum_{s,t} CH3_{st} IS_{st} \tag{13}$$

$$\sum_{t} CHP_t IPZ_t \tag{14}$$

$$\sum_{s,c,t} SC_{st} \delta_{sct} \tag{15}$$

Equations (1) to (15) express the cost terms of the objective function. Equation (1) is cost of the raw material which is derived from the total amount of extraction of raw materials at the expense of extraction. The equations (2) to (7), are the shipping costs relate to the different levels of cement supply chain. They are representing the cost of transporting raw materials from mines to the raw materials warehouse, the cost of carrying raw materials to the clinker production department, the clinker's shipping cost to the clinker warehouse, the shipping cost of the clinker from the warehouse to the cement sector, the cost of carrying cement to customer centers at different times and the cost of transporting pozzolan from warehouse to cement section, respectively. Equations (8) and (9) are clinker and cement production costs. The expression (8) shows the cost of producing cement and (9) indicates the clinker production cost. Equation (10) is related to the purchasing cost of pozzolan. Equations (11) to (15), express the cost of inventory in the supply chain of the cement. They represent the cost of holding the materials, the clinker holding cost, the cement and pozzolan storage costs in the warehouse and the shortage cost of product in the customer areas, respectively. Following represents the total costs of the system which is the summation of the aforementioned cost expressions.

$$\begin{aligned} MinZ = & \sum_{i,t} CM_{it} MT_{it} + \sum_{i,t} TC1_{it} MT_{it} + \sum_{i,t} TC2_{it} MK_{it} \\ & + \sum_{t} TC3_t XL_t + \sum_{s,t} TC4_t XS_{st} + \sum_{s,c,t} TC5_{sct} YS_{sct} + \sum_{t} TC6_t XP_t \\ & + \sum_{s,t} CS_{st} SE_{st} + \sum_{t} CL_t KL_t + \sum_{t} CP_t PZ_t + \sum_{i,t} CH1_{it} IM_{it} \\ & + \sum_{t} CH2_t IK_t + \sum_{s,t} CH3_{st} IS_{st} + \sum_{t} CHP_t IPZ_t + \sum_{s,c,t} SC_{st} \delta_{sct} \end{aligned} \tag{16}$$

3.2.2 Constraints

In following, the constraints of the proposed model are presented. Problem's main constraints are: customer satisfaction, inventory, clinker and cement production and materials extraction capacity constraints.

$$YS_{sct} + \delta_{sct} = D_{sct} \qquad \forall s,c,t \tag{17}$$

Constraints (17) indicate the equality of demand with total quantity of transported products to the customer area and shortage quantities within each demand region for each cement type during the planning horizon. That is, the amount of cement that is transferred to each customer's area in both directions and the amount of product shortage in that area, is equal to the demand for that area.

$$KL_t = \sum_i \theta_i MK_{it} \qquad \forall t \tag{18}$$

Constraints (18) calculate the clinker production quantities, and required quantity of raw materials.

$$SE_{st} = \alpha_s XS_{st} + \beta_s SG_{st} + \gamma_s PZ_{st} \qquad \forall s,t \tag{19}$$

Constraints (19) represent the coefficient compounds of clinker, pozzolan, limestone and gypsum in cement production. In other words, these constraints calculate the quantities of raw material required for cement production in different periods.

$$IS_{st} = IS_{s(t-1)} + SE_{st} - \sum_c YS_{sct} \qquad \forall s,c,t \tag{20}$$

$$IK_t = IK_{t-1} + KL_t - XS_t \qquad \forall t \tag{21}$$

$$IPZ_t = IPZ_{t-1} + PZ_t - XP_t \qquad \forall t \tag{22}$$

$$IM_{it} = IM_{i(t-1)} + MT_{it} - MK_{it} \qquad \forall i,t \tag{23}$$

Constraints (20)-(23) are inventory control constraints of the system, controlling the flow balance in the cement SCN. Constraints (20) are the inventory balance equations for different types of cement during the planning horizon. Constraints (21) ensure that the quantities of clinker inventory in period *t* are equal to the quantities of inventory in the period *t-1*, plus the produced amount in period *t*, minus the amount of clinker that transferred to the cement sector during the period *t*. Constraints (22) state that the quantity of pozzolan in period *t* is equal to the purchased quantities in period *t*, plus inventory remaining from the period *t-1*, minus the consumed quantities during period *t*. Constraints (23) are the material flow balance constraints of raw material stock.

$$SE_{st} \le CP1_{st} \qquad \forall s,t \tag{24}$$

$$KL_t \le CP2_t \qquad \forall t \tag{25}$$

$$MT_{it} \le CP3_{it} \qquad \forall i,t \tag{26}$$

Constraints (24) and (25) are production capacity constraints, representing the amount of cement and clinker production restrictions on nominal capacity, respectively. Constraints (26) are the capacity restrictions on extractions.

$$IS_{st} \le IC1_{st} \qquad \forall s,t \tag{27}$$

$$IK_t \le IC2_t \qquad \forall t \tag{28}$$

$$\sum_i IM_{it} \le CI3_t \qquad \forall i,t \tag{29}$$

$$PZ_t \le CIP_t \qquad \forall t \tag{30}$$

Constraints (27)-(30) are the warehouse capacity restrictions. They are restricting the inventoried quantities of the cement, clinker, raw material and pozzolan respectively. These equations state that in per cases, the inventory should not exceed the warehouse capacity.

$$MT_{it}, KL_t, IM_{it}, IPZ_t, PZ_t, IS_{st}, SE_{st}, IK_t, MK_{it}, XL_t, XP_t, XS_{st}, YS_{sct}, \delta_{sct}, SG_{st} \ge 0 \qquad \forall i,s,c,t \tag{31}$$

Constraints (31) are the non-negativity restrictions of variables.

4. CASE STUDY

Urmia Cement Co. (*https://Urmiacement.co*), is a cement plant in the Urmia city, West Azerbaijan, producing different types of pozzolanic cement, type 1 cement and export cement. Due to the costly nature of the cement production and the competitive business environment in this industry, reducing the final product’s manufacturing costs with respect to the quality level of the product is very important. Therefore, the aim of the proposed model is to minimize costs and determine the optimal quantities of the cement production during the planning horizon. The following products are manufactured at the Urmia cement plant:

- Portland type 1
- Pozzolanic Portland
- PLC cement
- Portland type 1 Exports

Aforementioned products are supplied in bulk and pack. In this study, the two most seller types of cement in Urmia cement Co. are considered, non-exporter type 1 cement and pozzolanic Portland. Here, six periods in durations of six month, are taken into considerations, and the data on costs and demand for the first period are extracted from company’s report on the bourse website (http://www.codal.ir) and are estimated for the next periods. Cost parameters are evaluated based on annual profit and loss statement of the company. Capacity parameters are inquired from the company’s production plan sheets and have extended for the upcoming periods via forecasting. Estimation methods have a strong effect of the demand trends [30] and they should be applied carefully. As the main purpose of this study, which is to propose a simple yet effective model, the forecasting method is selected based on this assumption. One of the most applied methods in today’s business world is the exponential smoothing forecasting method [31]. This approach is investigated thoroughly in the literature and proved to be a cost-effective method in forecasting the production parameters and generates the most accurate signals for the under study parameter. In the following, some important data related to the case study are stated. These data refer to the coefficients of the raw materials consumed in the clinker production and the coefficients of the amount of materials consumed in the cement production. These values also came from the company's report on the bourse website. Consumer regions are considered to be 55 centers and raw materials are 5 items as indicated in

Table 2: Consumption rate of raw materials in clinker

No.	Item	Rate
1	Clay	0.1
2	Limestone	0.87
3	Iron ore	0.02
4	Silicas	0.01

and the clinker itself.

Table 1: Clinker consumption factor for cement

No.	Item	Rate
1	Bag Portland Cement type1	0.94
2	Bulk Portland Cement type1	0.94
3	Bag Pozzolan Cement	0.9
4	Bulk Pozzolan Cement	0.9

Table 2: Consumption rate of raw materials in clinker

No.	Item	Rate
1	Clay	0.1
2	Limestone	0.87
3	Iron ore	0.02
4	Silicas	0.01

Table 3: Nominal capacity of different products

No.	Item	Capacity
1	Clinker	1845000
2	Bag Portland Cement type1	95000
3	Bulk Portland Cement type1	390000
4	Bag Pozzolan Cement	585000
5	Bulk Pozzolan Cement	20000

5. NUMERICAL RESULTS AND DISCUSSION

The mathematical model presented in this study is a deterministic model which optimizes production planning decisions in a cement production industry. To justify the proposed model, it is applied in a real case in Iran. In this model, demand is considered to be a deterministic parameter and objective function is representing system’s costs, including inventory costs, production costs, and transportation costs. In this case, the maximum allowed shortage amount

is up to 35% of each time period’s demand according to management preference. Table and Table are presenting the optimal quantities of different cement types and clinker during the planning horizon. Interestingly, optimal solution suggests satisfying the 6th period’s demand from the inventory pile of previous periods and do not engage in production in the last period. In
Table , different cost expressions of the objective function are presented separately for more clarity. Inventory associated costs are the minimum cost expression while the production costs term is the most costly item of the objective function. This suggest that more investigation on the production process of the cement industry is required for noticeable improvements.

Table 5: Quantities of produced cement type s in time period t

	1	2	3	4	5	6
Bag cement type 1	106254	170418	113266	75066	100762	0
Bulk cement type 1	48411	46589	48411	24521	17966	0
Bag Pozzolan cement	7363	9808	9983	2070	574	0

Table 6: Quantities of clinker produced in time period t

Time period	1	2	3	4	5	6
clinker	300886	437432	319661	159026	184041	0

Table 7: Different optimal cost expressions values of the objective function

Cost	Value
Total production cost	4.62545E+11
Total inventory holding cost	1.550110E+9
Total transportation cost	2.51715E+11
Total shortage cost	1.15680E+11

Sensitivity analysis are done on demand and cost parameters, namely; transportation cost coefficient, shortage and material handling costs coefficients and production cost coefficient. To conduct the analysis, the aforementioned parameters are mapped into an interval of [-0.2, -0.1, -0.05, 1, +1.05, +1.1, +1.2] coefficients. The results of sensitivity analysis are illustrated in Figure 2. As expected, any increment in cost parameters will lead to a boost in objective function value. By comparing all the curves presented in Figure 2, one can find out that the objective function values are more sensitive to the demand fluctuations than the other parameters. It is worth mentioning that the demand fluctuation must not violate the capacity constraints of the proposed model. In inventory-costs curve, small fluctuations do not lead to a big change in objective function values, especially for the middle range of the test parameters. This behavior could be driven out by the low-cost raw materials of cement industries.

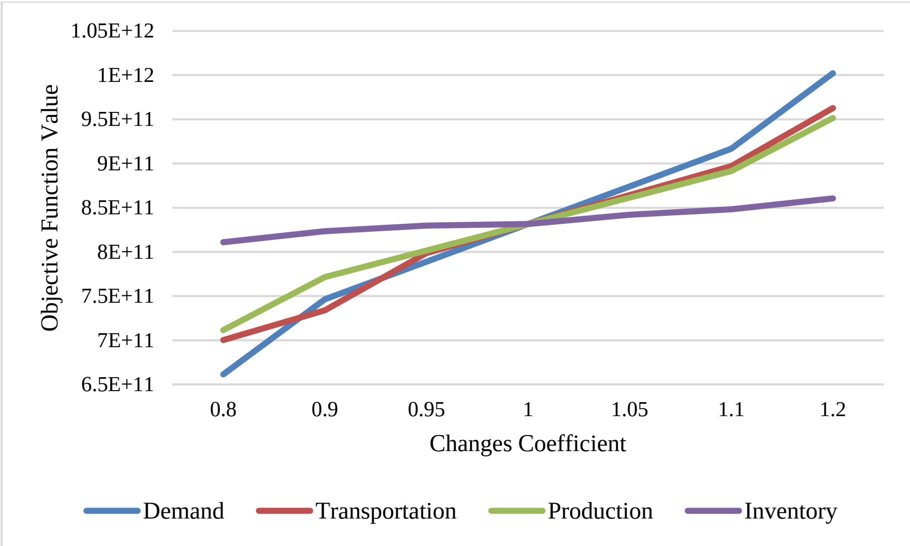

Figure 2. Optimal objective function values under different cost parameters

6. CONCLUSION

In this paper, the SC of cement from minerals to the distributors of the end product is investigated. Considering cement and clinker production process, an optimal production plan is driven out from a linear mathematical modeling approach. In the proposed model, demand is assumed to be a deterministic parameter, and transportation, inventory and production costs are taken into consideration. Sensitivity analysis is performed on cost and demand parameters. Optimal results indicate that a better production plan leads to a much better cost-effective SC. The proposed model provides managers with the optimal production plan in an environment, where the availability of the supply allows them to estimate the parameters as deterministic parameters. The parameter forecasting is argued to be a very sensitive process as it can fundamentally affect the optimal results of the model. A brief investigation on the literature has led us to apply on the mostly used methods, the exponential smoothing. The proposed model is applied in a real case study of cement industry in Iran. The obtained results show a great promise on the proposed model's effectiveness and efficiency.

The main future research avenues are unfolded into the following sub-categorizes: (a) extending the planning horizon and developing the proposed model in a strategic decision-making environment, (b) considering environmental impact of different processes and optimizing both cost and environmental objective functions by a multi-objective model, (c) considering the stochastic and uncertain nature of the real world problems and finally (d) considering potential rental warehouses to reach a trade-off between shortage costs and warehousing costs. The trade-offs in supply chain network design problems and production planning problems lead to interesting and insightful results, showing the impact of each decision variable and its associated costs on the optimal results. Another totally different possible research direction is to investigate the impact degree of uncertainty in industries where the supply is adequately available.

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