A Daily Production Planning Model Considering Flexibility of the Production Line under Uncertainty

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Abstract. Due to the change of production processes from mass production mode to mass customization mode, increasing customer knowledge, and the rapid development of communication technology, manufacturing organizations are under increasing pressure from dynamic changes in the business environment. For example, continuous product changes and unexpected changes in demand patterns; therefore, organizations do their best to be more responsive to their customers by having a flexible production plan and taking into account the latest changes and fluctuations in demand. In this paper, using the mathematical model presented and minimizing the company's costs, we try to obtain the appropriate time and the appropriate amount of production for each product. The presented model considers production capacity constraints, maximum production variety, as well as maintenance and setup times. The problem has been implemented in general algebraic modelling system software according to the home appliance industry's conditions and information. Finally, the analysis of change in production line flexibility, change in the minimum allowable production of each product, and change in production capacity are examined.

Keywords: Scheduling and production planning, Uncertainty, Mixed integer linear programming, Home appliance industry

1 Introduction

Population growth and community development have increased the use of home appliances. Today, the home appliance industry is linked by industries such as steel, copper, petrochemicals, etc. through the supply chain. For this reason, this industry can be called a kind of accelerator of economic development in the world [1]. The home appliance industry is one of the most important domestic industries in the country, covering a wide range of companies and domestic factories directly and indirectly. The home appliance industry is the second largest employment industry in the country after the automotive industry. This is due to various reasons, including the existence of significant demand in the domestic market and the appropriate market in neighboring countries. Planning to increase productivity is an issue that will increase competitiveness and will affect both quality and price. Simultaneously, following people's tastes and offering a variety of goods in the home appliance sector can increase the competitiveness of these industries. Currently, we see that foreign products are more successful in attracting customers than domestic goods for many reasons. These reasons include the wrong culture of society, better quality of foreign products, lack of technology and innovation in domestic goods production, higher prices of domestic goods than similar foreign goods, etc. [2, 25, 32].

Mass personalization requires a flexible assembly line that increases variability without compromising on quality. There may be situations where manufacturers want to increase system flexibility. One of the main ways to improve the flexibility of production is to use a flexible manufacturing system (FMS). Flexible production is the creation of a system that can adapt to change [3]. They can respond to the need for change and transformation towards flexibility and productivity increase at different levels. According to the activity model shown in Fig. 1, process development involves the production process's main framework, which has specific inputs and outputs. Flexibility development and innovation engagement are considered as attributes of the development, whereas investment costs and labor requirements are considered as constraints. The outputs from a process system development comprise the products, information as knowledge (knowhow), and productivity rise [4].

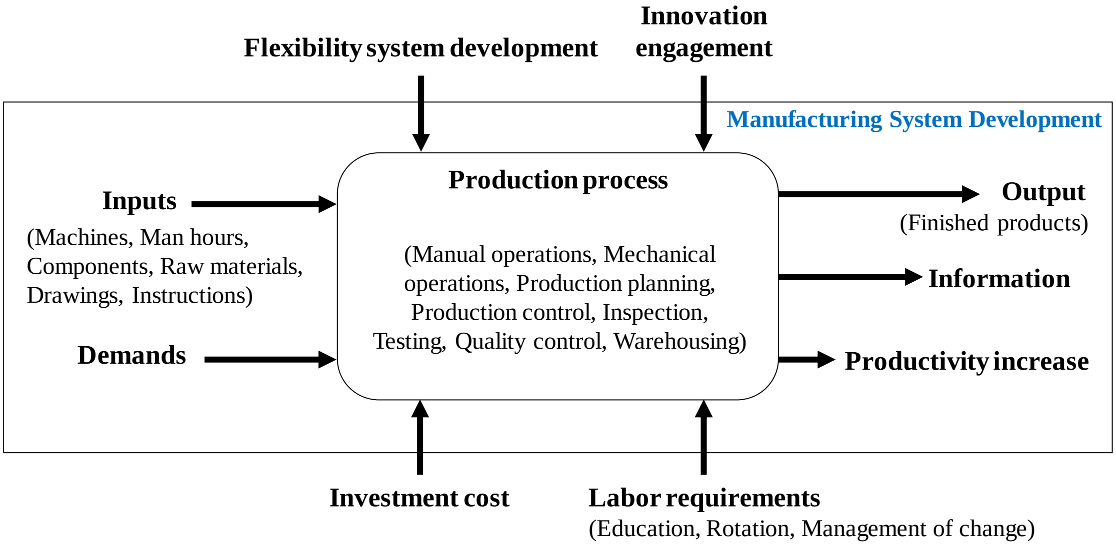

Fig. 1. Activity model of production process development [4]

Production planning includes planning for production units and the amount of their production in a company. Production planning in organizations is of particular importance. Lot sizing is one of the most important production planning problems. The goal of lot-sizing is to determine the optimal production amount by balancing the tradeoffs between production, inventory, backorder, and setup costs [5]. This subject has been studied extensively in the literature. Mula et al. [6] reviewed some of the existing literature on production planning under uncertainty. Wagner and Within [7] published on lot-sizing and scheduling problems in 1958 and this has been one of the most interesting topics for researchers ever since. Mohammadi et al. [8] investigated a lot-sizing problem in capacitated pure flow shops with sequence-dependent setups and proposed a new method to solve it. Meyr & Mann [9] in order to reduce total costs, present a solution heuristic to the general lot-sizing and scheduling problem for parallel production lines. Masmoudi et al. [10] proposed mixed linear programming models, both linear and non-linear, with the aim of minimizing production costs for a lot sizing problem in flow shop systems with respect to energy. Hu and Hu [11] proposed a two-stage stochastic programming model for lot-sizing and scheduling under uncertainty. Gayruad et al. [12] considered the production planning problem with financial constraints. Assuming that the manufacturer is not able to finance all operating costs, they proposed a model in which the optimal production policy can be implemented despite these limitations. Sanjari-Parizi and Bashirzadeh [13] studied a lot sizing problem for a cutting machine according to the possibility of adjusting the cutting speed and with maintenance time and sequence-dependent setup times. Ríos-Solís et al. [14] studied a lot-sizing and scheduling problem to maximize assembled products' profit over several periods. Barzangi et al. [15] studied the production planning in different situations. They studied the integrated process planning and scheduling problem. Gao et al. [16] investigated lot sizing and maintenance simultaneously for a production system subject to two failure modes while previous studies usually are typically restricted to one failure mode. Mohammadi et al. [17] presented a mixed integer linear model which addressed lot sizing and scheduling problem with complex setups. They developed two types of lot sizing aggregated and disaggregated for the problem to evaluate and compare the computational efficiency of them under deterministic and stochastic demands.

In many studies in this field, only the model has been presented, and no attempt has been made to improve the industry. However, in this study, we try to implement the model presented in the home appliance industry. In addition to paying attention to sequence-dependent setup and preventive maintenance, this study also considers the flexibility of the production line. In this paper, the “flexibility of the production line” means maximum production variety in a period. In the proposed model, demand, setup time and maintenance time are considered fuzzy to bring the situation closer to reality.

The paper is organized as follows. In section 2, the problem statement is elucidated, and the problem is formulated. Also, the non-fuzzy model is presented. The numerical experiments are reported in section 3, and finally, section 4 concludes the paper and outlines further research directions.

2 Problem Description

Gustavsson [18] stated that the relationship between productivity and flexibility has not been given much attention in the literature, leading to the common belief that there is a negative trade-off between productivity and flexibility. Flexibility can create more production opportunities and higher productivity. This research aims to minimize the total costs, considering the flexibility of the production line. Due to the flexibility of the production line, the number of planning periods is obtained, so that it is equal to:

$$\text{Number of planning periods} = \left\lfloor \frac{\text{number of products}}{\text{production line flexibility}} \right\rfloor + 1 \quad (1)$$

So that, $\lfloor x \rfloor = max\{n \in Z | n \leq x\}$, and this indicates the minimum number of time periods to produce all the products. The demand for each product is predicted according to the latest demand for the product and is considered fuzzy. At the end of each period, if the amount of the products exceeds the demand, an inventory cost *(h_j)* for product j occurs. Otherwise, the backlog for product j *(b_j)* is allowed for the unsatisfied demand. Also, sequence-dependent setup cost is considered in the objective function. Each product can be produced in all periods and the flexibility of the production line in each period is specified. Also, setup times and maintenance times are considered fuzzy, which reduces the maximum daily production capacity. Given the existence of possible and necessary orders that are not foreseen in advance, a certain percentage of the daily production capacity has been set aside for such orders. Parameters and decision variables used throughout the paper are summarized as follow:

Sets

J	The set of products indexed by $j \in \{1, 2, \ldots, J\}$
T	The set of planning periods indexed by $t \in \{1, 2, \ldots, T\}$

Parameters

h_j	Inventory holding cost per unit of product *j* per period
b_j	Backlog cost per unit of product *j* per period
$sc_{jj'}$	Setup cost of switching from product *j* to j' ($j' \neq j$)
$\tilde{d}_{jt}$	The demand for product *j* at the end of period *t*; it is considered a triangular fuzzy number, *TFN* (d_1,d_2,d_3).
$\widetilde{mt}$	Maintenance time; it is considered a triangular fuzzy number, *TFN* (mt_1,mt_2,mt_3).
min_j	Minimum authorized production for product *j* if produced
M	A sufficiently large and positive number
f	The degree of flexibility of the production line (maximum variety of production) in a period
pc_j	Production cost per unit of product *j*
$\widetilde{st}$	Setup time; it is considered a triangular fuzzy number, *TFN* (st_1,st_2,st_3).
re	The amount of production that is reduced per unit time spent on setup or maintenance from the production capacity of the period
β	Percentage of capacity that is set aside for contingency orders in each period
$MaxP$	Maximum production capacity in each period

Decision variables

Q_{jt}	Quantity of product *j* produced in period *t*
$Y_{jj't}$	1 if change-over from product *j* to j' happens in period *t* and 0 otherwise
L_{jt}	The backlog of product *j* at period *t*
I_{jt}	The inventory of product *j* at the end of period *t*
X_{jt}	1 if product *j* is produced in period *t* and 0 otherwise

2.1 Basic Assumptions

The following basic assumptions are made without causing harm to the practical meaning of the model.

- Several products can be produced in each period, but the ceiling of production diversity is specified in the period.
- Setups must be completed within a period.
- Setup time for all products is the same and in the form of a triangular fuzzy number.
- Production speed is constant and does not differ for different products.
- Inventory holding costs are calculated based on end-of-period inventory.
- Products are produced in different machines with the same general production structure.
- At the end of each period, the product line will be cleared and all settings will be disabled, so we need to new setup to start the next period, this means that the last setup in the previous period cannot cover the first step in the next period.

- Setting up for a particular product creates a setup time, which reduces the maximum possible production in each period; in other words, if the number of setups increases in a period, production capacity decreases in that period.
- It is also assumed that the first setup was free of charge in any period, and its time has been considered in the capacity of the production in any period.
- There is an initial inventory for some products, which is obtained based on company information.

2.2 Model Formulation

$$Min \quad \sum_{t=1}^{T}\sum_{j=1}^{J}\left(h_j I_{jt} + b_j L_{jt}\right) + \sum_{t=1}^{T}\sum_{j=1}^{J} pc_j\, Q_{jt} + \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{j'=1}^{J} sc_{jj'}\, Y_{jj't} \tag{2}$$

s.t.

$$I_{jt} - L_{jt} = I_{j,t-1} - L_{j,t-1} + Q_{jt} - \tilde{d}_{jt} \qquad ;\forall\, j, \forall\, t \tag{3}$$

$$\sum_{j=1}^{J} Q_{jt} \le (1-\beta)MaxP - \left(\left(\sum_{j=1}^{J} X_{jt} - 1\right)\widetilde{st} + \widetilde{mt}\right) * re \qquad ;\forall\, t \tag{4}$$

$$\sum_{t=1}^{T} Q_{jt} \ge L_{j0} - I_{j0} + \sum_{t=1}^{T} \tilde{d}_{jt} \qquad ;\forall\, j \tag{5}$$

$$\sum_{j=1}^{J} X_{jt} \le f \qquad ;\forall\, t \tag{6}$$

$$X_{jt}\, min_j \le Q_{jt} \qquad ;\forall\, j, \forall\, t \tag{7}$$

$$Q_{jt} \le M\, X_{jt} \qquad ;\forall\, j, \forall\, t \tag{8}$$

$$\sum_{j=1}^{J}\sum_{j'=1}^{J} Y_{jj't} \ge \sum_{j=1}^{J} X_{jt} - 1 \qquad ;\forall\, t \tag{9}$$

$$\sum_{j'=1}^{J} Y_{jj't} \le X_{jt} \qquad ;\forall\, j, \forall\, t \tag{10}$$

$$\sum_{j'=1}^{J} Y_{j'jt} \le X_{jt} \qquad ;\forall\, j, \forall\, t \tag{11}$$

$$Y_{j'jt} + Y_{jj't} \le 1 \qquad ;\forall\, j, \forall\, j', \forall\, t \tag{12}$$

$$Y_{jjt} = 0 \qquad ;\forall\, j, \forall\, t \tag{13}$$

$$I_{j0} \text{ and } L_{j0} = \textit{According to the company information} \qquad ;\forall\, j \tag{14}$$

$$X_{jt}, Y_{jj't} \in \{0,1\} \qquad ;\forall\, j, \forall\, j', \forall\, t \tag{15}$$

$$I_{jt}, L_{jt}, Q_{jt} \ge 0 \qquad ;\forall\, j, \forall\, t \tag{16}$$

The objective function (2) aims to minimize the total operating costs, which include inventory/backlog costs, setup costs, and production costs. Constraint (3) is inventory balance constraint. Constraint (4) examines that in each period, the total number of products produced is less than the production capacity (maximum possible for production); due to the time spent on preventive maintenance and setup, the maximum possible production in each period is reduced. The initial setup time is not considered at the beginning of the period, and it is assumed that the production line's capacity is calculated with an initial setup. Constraint (5) indicates that each product's demand during the planning periods is met by production and initial inventory in the zero period. Constraint (6) examines that in each period the product variety does not exceed the maximum allowable (*f*). Constraint (7) indicates the minimum quantity of production for each product in each period if produced. Constraint (8) ensures that whenever $Q_{jt} > 0$, the indicator variable X_{jt} is automatically set to 1. Constraints (9), (10), (11), (12) determine the sequence of products. Since change-over can never happen from one product to itself, decision variable Y_{jjt} is always 0, which is restricted in constraint (13). Constraint (14) gives the values of inventory and backlog in period

0. Note that period 0 is a dummy period, so the inventory/backlog at the end of period 0 is the actual input into the model. Constraints (15) and (16) represent the type of variables.

2.3 Non-fuzzy Model

The proposed model becomes non-fuzzy according to the mathematical programming methods and based on the credibility measure. To do this, we need both optimistic and pessimistic values as critical values. If ξ is a fuzzy variable and $\alpha \in (0,1]$, the optimistic and pessimistic values for the variable ξ at the α level are defined as follows (see [19, 24, 26-31, 33]).

$$\xi_{sup}(\alpha) = sup\{r|Cr(\xi \geq r) \geq \alpha\} \tag{17}$$

$$\xi_{inf}(\alpha) = inf\{r|Cr(\xi \leq r) \geq \alpha\} \tag{18}$$

In this paper, the variable ξ is considered as a triangular fuzzy number for example, $\xi = (a_1, a_2, a_3)$. And it is assumed that $\alpha \geq 0.5$, so optimistic and pessimistic values are obtained as follows (see [20]).

$$\xi_{sup}(\alpha) = (2\alpha - 1)a_1 + (2 - 2\alpha)a_2 \tag{19}$$

$$\xi_{inf}(\alpha) = (2 - 2\alpha)a_2 + (2\alpha - 1)a_3 \tag{20}$$

Due to optimistic and pessimistic values, the problem constraints that include fuzzy parameters become non-fuzzy. If r is a definite value in the constraint, the following two equations are used to make the constraint non-fuzzy:

$$Cr(\xi \geq r) \geq \alpha \quad \Leftrightarrow \quad r \leq \xi_{sup}(\alpha) \tag{21}$$

$$Cr(\xi \leq r) \geq \alpha \quad \Leftrightarrow \quad r \geq \xi_{inf}(\alpha) \tag{22}$$

In the proposed model, constraints 1, 2 and 3 have fuzzy parameters that become non-fuzzy according to the relationships mentioned above:

$$I_{jt} - L_{jt} \geq I_{j(t-1)} - L_{j(t-1)} + Q_{jt} - \left[(2\alpha - 1)d_{jt1} + (2 - 2\alpha)d_{jt2}\right] \qquad \forall j, t \tag{23}$$

$$I_{jt} - L_{jt} \leq I_{j(t-1)} - L_{j(t-1)} + Q_{jt} - \left[(2 - 2\alpha)d_{jt2} + (2\alpha - 1)d_{jt3}\right] \qquad \forall j, t \tag{24}$$

$$\sum_{j=1}^{J} Q_{jt} \leq (1 - \beta) * MaxP - \Big[\Big(\sum_{j=1}^{J} X_{jt} - 1\Big) * [(2 - 2\alpha)st_2 + (2\alpha - 1)st_3] + [(2 - 2\alpha)mt_2 + (2\alpha - 1)mt_3] \Big] * re \qquad \forall t \tag{25}$$

$$\sum_{t=1}^{T} Q_{jt} \geq \sum_{t=1}^{T} (2 - 2\alpha)d_{jt2} + (2\alpha - 1)d_{jt3} + \sum_{t=1}^{T} ss_{jt} - I_{j0} - L_{j0} \qquad \forall j \tag{26}$$

3 Numerical Experiment

The proposed model is evaluated according to the information of one of the active companies in home appliance production in Iran. According to the reviews of the company's production line and the collection of the required information, 10 models of plate stoves produced by this company are planned for production in this paper. The mathematical programming formulation has been modeled within the general algebraic modelling system (GAMS) environment and solved by CPLEX solver. Table 1 shows the specifications of products. Sequence-dependent setup cost is considered. The α value (used in non-fuzzy modeling) is set to 0.7, and other problem information is shown in Table 2. According to the presented model and the available company information after the model implementation in GAMS, the optimal quantity of production for each product is in accordance with Table 3.

Table 1. Specifications of products.

Product	$\tilde{d}_{jt}$, *TFN (d_1,d_2,d_3) ∀ all periods*	pc_j	h_j	b_j	min_j	I_0	L_0
Product 1	(44-71-93)	1729000	880	1820	30	120	0
Product 2	(30-42-59)	1675000	880	1820	30	20	0
Product 3	(11-27-38)	1742000	880	1820	30	60	0
Product 4	(4-6-12)	1516000	880	1820	30	2	0
Product 5	(5-7-16)	1556000	640	1400	30	0	8
Product 6	(9-13-17)	1729000	880	1820	30	0	11
Product 7	(3-9-13)	1742000	880	1820	30	5	0
Product 8	(9-14-26)	1729000	880	1820	30	0	2
Product 9	(1-3-7)	857000	440	900	30	0	7
Product 10	(10-17-26)	1782000	880	1820	30	0	12

Table 2. Other problem information.

$\widetilde{st}$	$\widetilde{mt}$	*MaxP*	*r*	*β*	*f: The degree of flexibility*
TFN(5,9,11)	TFN(9,12,21)	260	0.5417	0.05	3

Table 3. The optimal quantity of production for each product in each period.

Period	*Product produced (optimal quantity of production)*	*Production sequence*
Period 1	Product 2 (122), Product 4 (32), Product 9 (30)	9 ⇒ 2 ⇒ 4
Period 2	Product 2 (54), Product 8 (78), Product 10 (95)	8⇒ 10 ⇒ 2
Period 3	Product 1 (81), Product 3 (66), Product 5 (51)	1 ⇒ 3 ⇒ 5
Period 4	Product 1 (119), Product 6 (70), Product 7 (38)	6 ⇒ 1 ⇒ 7

3.1 Evaluation

In this paper, the "flexibility of the production line" means maximum production variety in a period. Increasing the flexibility of the production line makes the production system more agile and it makes the company react faster and better to market changes. Based on Grubbström and Olhager's research [21] on production systems, the input operation flexibility is related to the time required to change the mix of production factors over time and to the time required to change the attributes of the production factors over time; for example the reduction of machinery change-over time as well as the education and training of the workforce to be able to achieve that time. Among the solutions that can increase the flexibility of the production line are:

- Reducing setup time.
- Reducing waste time and machines idle time.
- Using group technology in designing parts used in products (homogenization and unification of raw materials).
- Communicating with reputable suppliers for timely supply of raw materials.
- Reducing the minimum allowable production for products.
- Moving to JIT production system.
- Use of advanced manufacturing technologies.

In this case study the flexibility of the production line is 3, now considering the change in this value, the objective function value is shown in Fig. 2. Also, Fig. 3 shows the objective function value with respect to change in the minimum allowable production for products (min_j). Finally, with respect to the change in the daily capacity of the production line according to Figure 4, the value of the objective function is estimated.

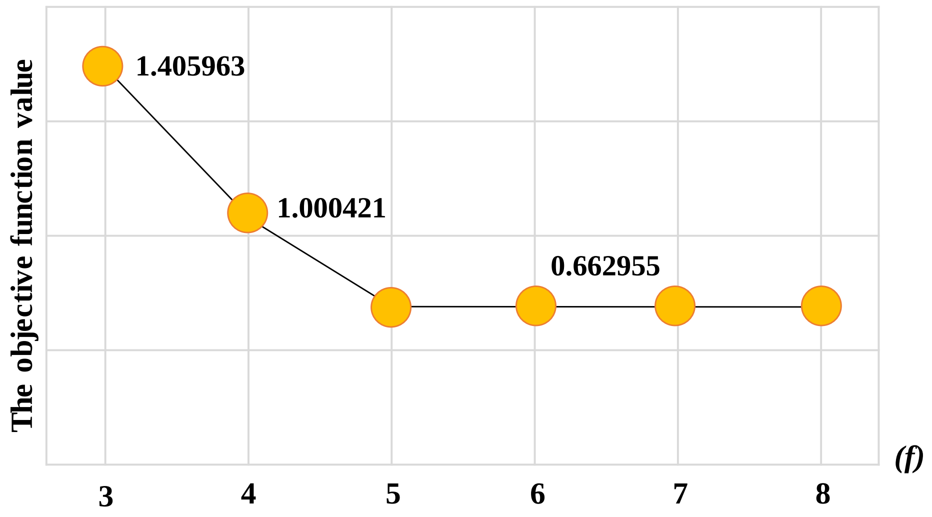

Fig. 2. The objective function value with respect to flexibility of the production line

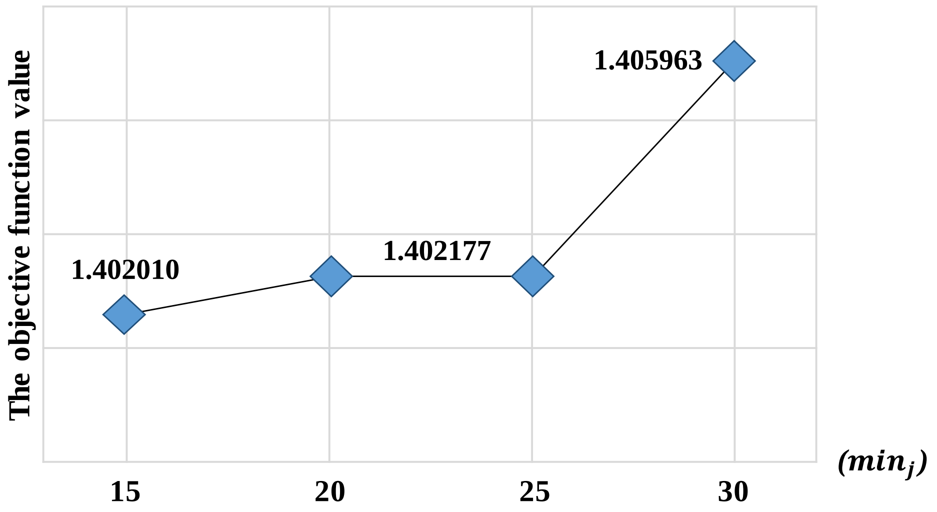

Fig. 3. The objective function value with respect to minimum allowable production

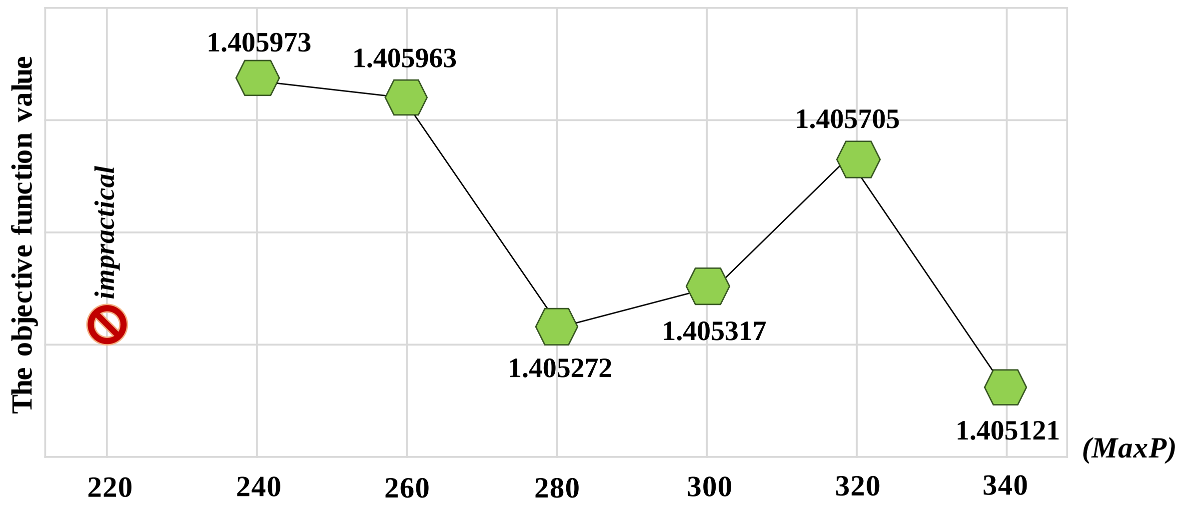

Fig. 4. The objective function value with respect to capacity of the production line

According to Figure 4, the best production line capacity is recorded for 280 and 340 values. As mentioned earlier, the value of *re* is equal to: the amount of production that is reduced per unit time spent on setup or maintenance from the production capacity of the period, this means that the amount of *re* will increase as the capacity of the production line increases. As a result, setup and maintenance costs increase due to increased time value. This is also the reason for the fluctuations in the chart above, because in some capacities, despite the increase compared to the previous value, it is not possible to plan in a way that reduces the total costs. Therefore, the value of the objective function increases (such as capacity 320 versus capacity 300), on the other hand, in some capacities, it is possible to plan in such a way that the total costs will be significantly reduced (such as capacity 280 versus capacity 260).

4 Conclusions and Future Research

According to Chryssolouris [22], the perception is growing that flexibility can be cost-effective as well. On the other hand, Meyer et al. [23] stated that a company must focus on other primary competitive priorities such as quality, lead times and cost before focusing on flexibility. In this paper, using the mathematical model presented, we try to obtain the appropriate time and the appropriate amount of production. The flexibility of the production line (maximum production variety) is one of the topics addressed in this article. Finally, according to the information of a home appliance company in Iran and under fuzzy conditions, production planning of a number of products has been obtained using GAMS software. Also, the analysis of the answers according to the changes of different parameters is examined and the solutions to increase the flexibility in the production systems are studied.

For future research, it is recommended to use the learning effects and human errors at setup and the structure of the problem can be examined in a multi-tier supply chain. The model can also be tested for large-scale examples with the help of metaheuristic algorithms.

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