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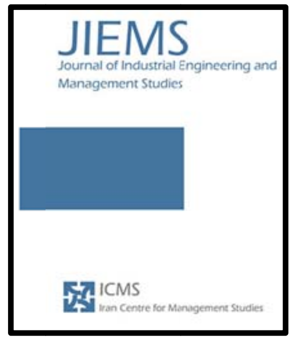

Determination of optimum of production rate of network failure-prone manufacturing systems with perishable items using discrete event simulation and Taguchi design of experiment

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Abstract

This paper, considers Network Failure Manufacturing System (NFPMS) and production control policy of unreliable multi-machines, multi-products with perishable items. The production control policy is based on the Hedging Point Policy (HPP). The important point in the simulation of this system is assumed that the customers who receive perishable item are placed in priority queue of the customers who are faced with shortage. The main goal of this paper is determining of optimal production rates that minimizes average total cost consist of shortage, production, holding and perishable costs. Because of uncertainly and complexity of this system, simulation optimization of this system using ARENA software has been done. A numerical example will show the efficiency of the proposed approach.

Keywords: FPMS; Perishable items; Simulation modeling; production planning; Taguchi design of experiment.

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1. Introduction

Production planning is a vital activity in any manufacturing system, and naturally implies assigning the available resources to the required operations the processes of production planning are the most complex (Saidi-Mehrabad et al., 2013). The goal of production planning is thus to make planning decisions optimizing the trade-off between economic objectives such as cost minimization or maximization of contribution to profit and the less tangible objective of customer satisfaction. To achieve this goal, manufacturing planning systems are becoming more and more sophisticated in order to increase both the productivity and the flexibility of the production operations (Pochet & Wolsey, 2006). Because of this complexity, different types of event-oriented models have been independently developed as separate production planning problems for facing the uncertainties of the considered sub-classes of manufacturing systems (Kenne et al., 2007) that Failure-Prone

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Manufacturing Systems (FPMS) are among them. In the real world, analysis of these type of systems are so complex that we can solve their problems only by simulation. In all of the former multi-machine FPMS, only machines in series or in parallel are considered (sajadi, 2011). Older and Souri (1980) have been formulated of Failure-prone manufacturing systems as a stochastic optimal control problem and then Kimemia (1982) and Kimemia & Greshwen (1983) expanded it. In FPMS production is strictly forward-flowing and discrete. the optimal control policy of FPMS has a special structure called the hedging point policy (HPP) (Rishel,1975). In such a policy, an optimal inventory level is maintained when excess production capacity is available in order to hedge against future capacity shortage caused by machine failures. If the current inventory level exceeds the optimal inventory level, the machine should not produce at all; if it is less, it should produce at the maximum rate. If the inventory level is exactly equal to the optimal level, the machine should produce just enough to meet demand (sajadi, 2011). The structure of the optimal inventory policy can be approximated by the HPP (Kenne & Gharbi, 1999) and (Gharbi & Kenne, 2000). The production/inventory control policy, which is based on the hedging point policy, consists in building and maintaining a safety stock of finished products in order to respond to demand and to avoid shortages during maintenance actions (Gharbi et al., 2011). The optimal flow control for a one-machine, two-product manufacturing system subject to random failures and repairs can be found in Kenne and Gharbi (2004). They first showed that the hedging point policy is optimal for constant demand rates and exponential failure and repair time distributions of the machine. Next, they extended the hedging point policy to non-exponential failure and repair time distributions models. The structure of the hedging point policy is parameterized by two factors representing the thresholds of involved products. With such a policy, simulation experiments are coupled with experimental design and response surface methodology to estimate the optimal control policy. Results showed that the hedging point policy is also applicable to a wide variety of complex problems where analytical solutions may not be easily obtained. Chen et al. (2007) presented a two-level hedging point policy for controlling a manufacturing system with time-delay, demand uncertainty and extra capacity. The mathematical model for its production control problem is established, with the objective of minimizing the mean costs for Work-In-Process (WIP) inventory and occupation of extra production capacity. To solve the problem, a two level HPP was proposed. By analyzing the probability distribution of system states, optimal values of the two hedging levels were obtained. Finally, numerical experiments were done to verify the effectiveness of the control policy and the optimality of the hedging levels. The Gharbi”s article (Gharbi et al., 2011) considered a joint preventive maintenance (PM) and production/inventory control policy of an unreliable single machine, mono-product manufacturing cell with stochastic non-negligible corrective and preventive delays. The main objective of this paper is to determine the joint optimal policy that minimizes the overall cost, which is composed of corrective and preventive maintenance costs as well as inventory holding and backlog costs. The main objective of this paper is to determine the joint optimal policy that minimizes the overall cost, which is composed of corrective and preventive maintenance costs as well as inventory holding and backlog costs. Dye and Lee (2012) presented an inventory model for deteriorating items under stock-dependent demand and controllable deterioration rate. The objective is to find the optimal replenishment and preservation technology investment strategies while maximizing the total profit per unit time.

In this paper, we study a multi-machines, multi products system with relationship constraints between them. Each intermediate machine produces one kind of product. Final machine produces the final commodity to meet the constant demand rate facing the system. The stochastic nature of the system is due to machines that are subject to random breakdowns and repairs. Time between failures (TBF) and time to repairs (TTR) are assumed to be exponentially distributed with different parameters. When a machine is operational, its demand is met from the safety stock of the intermediate buffers that precede it. Demand for the final commodity is met from the final buffer or backlogged. However, when the backlog amount exceeds a given amount, demand is lost.

Intermediate WIP cannot be backlogged, and when demand for an intermediate product cannot be met, the machine that requires this product is starved (Sajadi, 2011). It is assumed that the final product is allowed to be time-dependent decay. Also, when-ever a machine is breaking down during production; maintenance operations will be performed to restore the machine to its initial operational mode after repair. It is supposed that production run isn't aborted when a breakdown occurs.

In this paper, Network Failure Prone Manufacturing Systems (NFPMS) with perishable items are analyzed by simulation, and then design of experiment with Taguchi test is done. Finally, the best scenario is chosen for determine of optimum value of production rate.

2. Notations and Problem Statement

As showed in figure 1, the network systems consist of *n* machines that in each stage of production, is produced one kind of product. The first stage of commodity is used in second and third stage of commodity production, and so continues until produce of final product. There is a warehouse between tow machines. In this system, demand rate is constant and known. In final stage of production, both backlog and lost sales is allowed and the final product has expire date and if it isn't used until expiration date, is considered of perishable item.

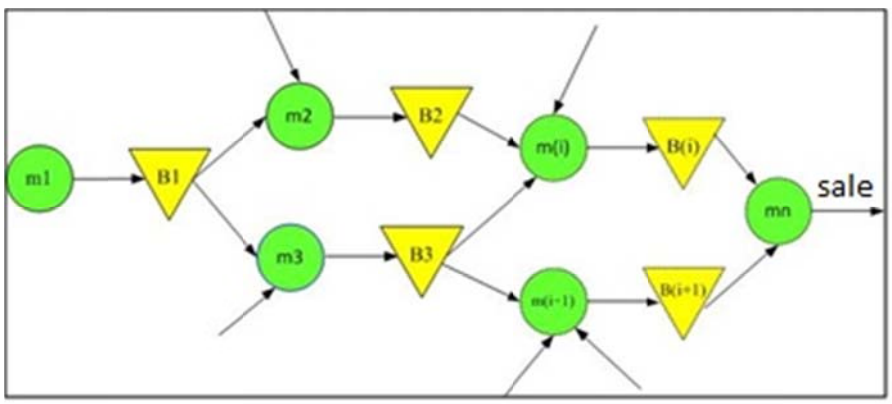

Figure 1: Network failure prone manufacturing system

Through this paper, we use the following notations and abbreviations:

NFPMS: Network Failure Prone Manufacturing System
TBF: Time Between Failures
TTR: Time to repair
HPP: Hedging Point Policy
M_i: Machine *i*
B_i: Buffer belong to machine *i*
n: Number of machines or products
d: Constant demand rate for final commodity
h_i: Inventory holding cost per unit of time for product *i*, (i=1, ..., *n*)
$\hat{\pi}_i$: Shortage cost per unit of unmet demand for production *i*, (i = *n*)
C_p: Perishable cost per unit of time for perishable production i, (i = *n*)
$u_i(t)$: Production rate of machine *i*, (i=1, ..., *n*)
$U(t)$: Control policy vector
$x_i(t)$: Inventory level/backlog for buffer *i* at time *t*
Z_i : Inventory threshold level parameter of buffer *i*
K: Threshold of lost sales for final commodity
$K(t)$: expected long run average cost (Inventory/Backlog) function

l_{ij} : Number of items of product *i* that is consumed by machine *j* to produce one unit of product *j*, (*i* < *j*)
$\lambda^i_{\alpha\beta}$: Transition rate of machine *i* from state *α* to *β*
$P(t)$: Number of perishable production *i*, (*i* = *n*)
$\zeta_i(t)$: Stochastic Markov process of the machine *i* at time *t*
At the time of being active, products are produced with $U_i(t)$ rate. After each production part, there is a warehouse that extra inventory can be stored in it; it causes that at the time-to failure during a production run, production of product isn't stopped. When machine M_i starts to produce, the products of stage M_{i-1} is used with U_i rate at the time interval $t_i = X_i / U_i$. At the time of τi, machine M_i produces product *i*, so immediately accessible inventory levels will be added for using in the stage (*i* + 1) (Fatemi-Ghomi, 2009) with *L (i*+1*) (i)* number of products produced by machine *i*. Each machine has a maximum production rate $u_i^{\max}$ with

$$u_i^{max}(t) > \sum_{i<j} l_{ij}\, u_j^{max} \qquad i \neq n \tag{1}$$

$$u_n^{max}(t) > d \tag{2}$$

2.1. Equations related to state of machine

Let $x_i(t)$ be inventory level of product *i* and let variable $\zeta_i(t)$ as state of machine *i* at time t, then

$$\zeta_i(t) = \begin{cases} 0 & if\ machine\ i\ is\ under\ maintanance\ operation \\ 1 & if\ machine\ i\ is\ busy\ or\ idle \end{cases} \tag{3}$$

Also if $\lambda^i_{\alpha\beta}$ be the transition rate of machine *i* frome state *α* to *β* that is assumed constant and $B = \{0,1\}$ then

$$\lambda^i_{\alpha\beta} \geq 0\ ,\ \ \lambda^i_{\alpha\beta} = -\sum_\beta \lambda^i_{\alpha\beta}\ ,\ \ \alpha \neq \beta\ \epsilon\ B \tag{4}$$

$$\lim_{\delta t \to 0} \frac{O(\delta t)}{\delta t} = 0$$

(5)

$$P(\zeta_i(t+\delta t) = \beta | \zeta_i(t) = \alpha) = \begin{cases} \lambda^i_{\alpha\beta}\, \delta t + O(\delta t) & if\ \alpha \neq \beta \\ 1 + \lambda^i_{\alpha\beta}\, \delta t + O(\delta t) & if\ \alpha = \beta \end{cases} \tag{6}$$

As the inventory level reaches a maximum limit of Z* at ($t_i\tau +_i$), production stops. This optimum level could be considered as a decision variable of failure prone manufacturing systems instead of production rate. In the other words, decision variable of failure prone manufacturing systems is determined according to this optimal level. When breakdown occurs (after this time), product is used with *d* rate, so inventory level is decreased. It may also inventory level of final machine be finished, in this case shortage (backlog and lost sales) occurs.

2.2. Equations related to inventory level

Let x_i^0 as initial inventory level then equation related to inventory level of final product according to perishable items can be described as:

$$x_i(t) = \int \left(u_i(t) - \sum_{j>i} l_{ij}\, u_j(t)\right) dt \quad x_i(0) = x_i^0 \quad 1 \leq i < n \quad x_i(t){:}\, integer \tag{7}$$

$$x_n(t) = \int \left[u_n(t) - d\left(x_n(t)\right) - P(t)\right]\, dt \quad x_n(0) = x_n^0 \tag{8}$$

$$d\left(x_n(t)\right) = \begin{cases} d & x_n(t) \geq -K \\ 0 & otherwise \end{cases} \tag{9}$$

The constraints of inventory levels of intermediate machines and final machine is represented as:

$$-K \leq x_n(t) \leq Z_n$$

$$0 \leq x_i(t) \leq Z_i \qquad i \neq n \tag{10}$$

Ensuring that the production rate does not exceed a given value u_i^{max} when the machine *i* is operational, is described by the following equation:

$$u_i(t) = \begin{cases} 0 & if\ \zeta_i(t) = 0 \\ [0\ , u_i^{max}] & if\ \zeta_i(t) = 1 \end{cases} \tag{11}$$

2.3. Equations related to feasible control policy

If we describe $U(t)$ as control policy vector of $u_i(t)$, then the set of feasible control policy of process $k(\alpha)$ is represented as:

$$k(\alpha) = \{U(t)\ \epsilon\ R^n \quad 0 \le u_i(t) \le u_i^{max} \quad 1 \le i \le n\} \tag{12}$$

Another objective function of FPMS with perishable items is given as following equation:

$$J(\alpha, x, u, P) = \{\lim_{T\to\infty} \frac{1}{T}\ E \int_0^T \left[h_i\ x_i^+(t) + \hat{\pi}_i\ x_i^-(t) + C_p\ P(t)\right] dt \quad | X(0) = X_0\ , \quad \zeta(0) = 1\} \tag{13}$$

And

$$x_i^+(t) = Max(x_i(t), 0)$$

$$x_i^-(t) = Max(-x_i(t), 0)$$

So we define optimum value of objective function as $\nu(\alpha, x)$

$$\nu(\alpha, x) = \min_{u\ \in\ k(\alpha)} J(\alpha, x, u, P) \tag{14}$$

3. Control Policy

Because of complexity of these systems, hedging point policy is utilized as control policy. In this paper, the control policy that is presented in Xie"s article (Xie, 1989) to a network of FPMS with multiple non-identical machines and connections between them is generalized.

$$u_{i\ne n}(t) = \begin{cases} 0 & x_i(t) > Z_i^* \\ u_i^{max} & x_i(t) + u_i^{max} < Z_i^* \\ [Z_i - x_i(t)] & \text{otherwise} \end{cases} \tag{15}$$

$$u_{i=n}(t) = \begin{cases} 0 & x_i(t) - d > Z_i^* \\ u_i^{max} & x_i(t) + u_i^{max} - d < Z_i^* \\ [Z_i - (x_i(t) - d)] & \text{otherwise} \end{cases} \tag{16}$$

Production rate of each machine is related to Z_i^* that is as optimal inventory threshold level of each machine, so Z_i^* is defined as decision variable (Sajadi, 2011).

4. Research framework

4.1. A simulation model in Network FPMS

Simulation model in Network Failure Prone Manufacture Systems is used to learn optimum production level of each machine, and to obtain data to plug into ARENA14.0 in order to simulate production and satisfy demand systems in 10 replications that each replication takes over 960 minutes. We consider a NFPMS system with four machines. In this part of paper, Figure 2 illustrates the simulation modeling of production of final machine. Parts are generated on a constant inter-arrival rate of $1/mpr_i$ hours. Then the variables are defined such as: production machine rates, holding and shortage inventory costs, production coefficient, demand rate, etc., to their initial values.

After that the state of machine and inventory level of previous production are checked by first Decide Module decides whether machine 4 is busy, idle or not. By the next three Decide Modules, we check number of parts of previous products that is consumed by machine 4 to produce one unit of product4..

Then control policy is defined by Decide Module that is defined in Section 3. After production, product is stocked in warehouse, if the product isn"t use until it"s expire date, it is considered as perishable item and it is unusable, otherwise it is usable. Simulation modeling of previous machines is the same as simulation of final machine. But in previous machine shortage and perishable items aren"t allowed. Producing of final product loop is related to Demand and shortage loop. As showed in Figure 3, customers inter the system with $1/d_n$ rate, then a signal is sent to Producing of final product loop, and the customers have to wait for product. It may the customers receive perishable items, so is defined a share queue that the customers who receive perishable item (red shape) are placed in priority queue of the customers who are faced with shortage (green shape).

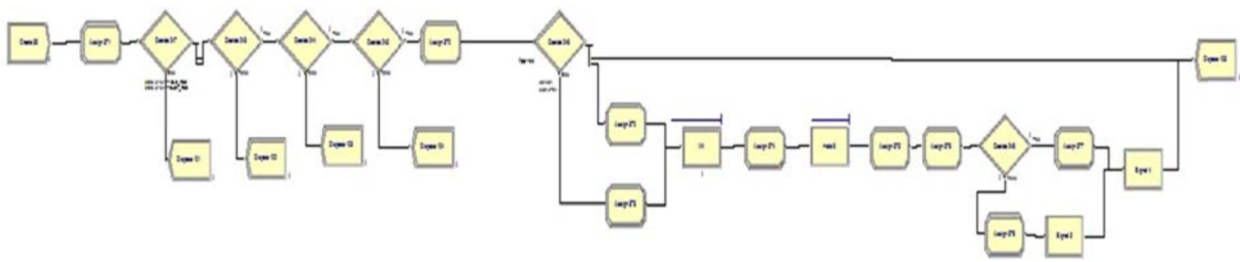

Figure 2: Simulation modeling of final machine

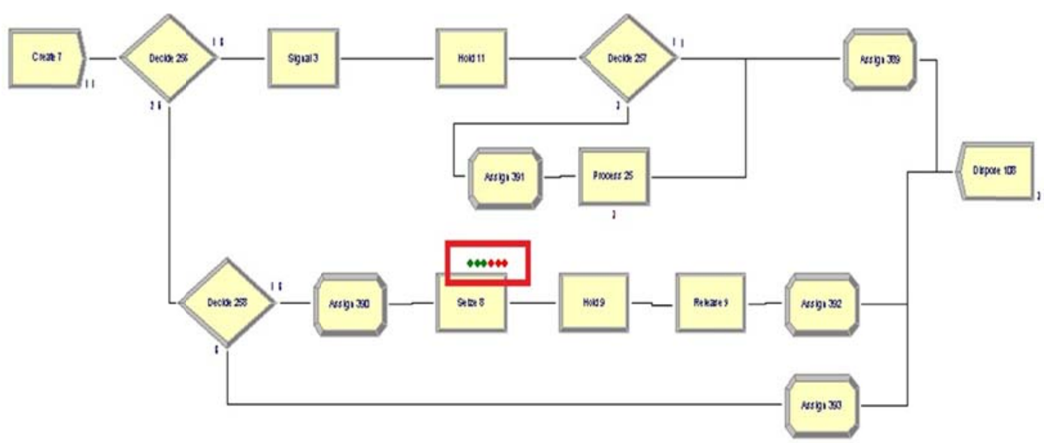

Figure 3: Simulation modeling of Demand and Shortage

- The customer that receive perishable items
- Backlog shortage

4.2. Numerical example

For numerical example in the simulation modeling of this system, we define variables (production machine rates, holding and shortage inventory cost, production coefficient, demand rate, etc.) with initial values.

Production rate of each machine is defined as Mpr_1=51, Mpr_2=19, Mpr_3=9, Mpr_4=8 that parts inter to system. Although, production coefficient is as $l_{12} = 1, l_{13} = 2, l_{14} = 2, l_{24} = 1, l_{23} = 2, l_{34} = 1$.

Demand of final machine is: $Demand_4 = 6$

The factors are illustrated with Zi that is $Z_1 = 100, Z_2 = 65, Z_3 = 12, Z_4 = 7$. The control policy of intermediate machine and final machine is defined as eq.(15) and eq.(16). Although, x_i that is defined as inventory level at time t is valued as followed: $x_1 = 100, x_2 = 65, x_3 = 12, x_4 = 0$.

Expire date of final product is 2.5 hours, so if product isn't used until 2.5 hours, that product is unusable and it's perishable product. Unit holding cost of each product is valued as $h_1 = 1, h_2 =$

$3, h_3 = 6, h_4 = 10$ curency. Unit perishable cost for final product is 27 currencies. And unit backlog cost is 30 currencies.
Finally, running of simulation of this system, average total cost by eq.(13) is calculated.

4.3. Taguchi technique

Taguchi optimization is an experimental optimization technique that uses the standard orthogonal arrays for forming the matrix of experiments. By using this matrix it will help us to get maximum information from minimum number of experiments and also the best level of each parameter can be found. In data analysis, signal-to-noise (S/N) ratios are used to calculate the response (Murugesan et al., 2014). There are three types of performance characteristics used for analyzing S/N lower the better, higher the better and nominal the better. The goal of this study is to minimize Average total cost. Therefore the lower-the-better is used as shown in Eq. (17):

$$\eta = {}^{S}/_{N_s} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (17)$$

Where y_i is the observed data at the i^{th} experiment and n is the number of observations of the experiment (Mandal et al., 2011).

4.4. Taguchi – design of experiments

For the computational purpose, four factors at three levels are considered for the Taguchi method that shown in table 1. In this case, the neighborhood radius threshold level ($Z_i \pm 1$) is considered. So the decision variables are significant in the distance. In this study, with a sensitivity analysis on the radius of the neighborhood, the search area is considered to be mentioned.

Table 1: Inventory threshold level parameters and their levels

	Z_1	Z_2	Z_3	Z_4
Level 1	99	64	11	6
Level 2	100	65	12	7
Level 3	101	66	13	8

In this analysis, number of factors is 4 and number of levels is 3. The standard orthogonal arrays available are L9 and L27. According to the Taguchi design concept, L9 orthogonal array is chosen for our computations and the structure of the array is shown in Table 2.

Table 2: Experimental layout using an L9 orthogonal array

Experiment number	Inventory threshold level parameters			
	Z_1	Z_2	Z_3	Z_4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Each computational trial is performed as per standard L9 array table. The optimization of the observed values is determined by using the signal-to-noise (S/N) ratios. Table 3 shows experimental result for Inventory threshold and S/N ratio.

Table 3: Experimental results for Inventory threshold and S/N ratio

Experiment number	**Inventory threshold level parameters**	**Average total cost**	**(S/N) ratio**

	Z_1	Z_2	Z_3	Z_4		
1	99	64	11	6	612.87	-55.7474
2	99	65	12	7	620.09	-55.8491
3	99	66	13	8	625.24	-55.9209
4	100	64	12	8	618.47	-55.8264
5	100	65	13	6	625.66	-55.9268
6	100	66	11	7	617.07	-55.8067
7	101	64	13	7	624.03	-55.9041
8	101	65	11	8	617.37	-55.8109
9	101	66	12	6	622.56	-55.8836

In the Taguchi method, all the S/N ratio values are calculated based on the concept of higher the better. This figure (Figure 4) shows that slope of factor Z_3 is highest, so it has the greatest impact on reducing costs that this figure is given from Minitab software.

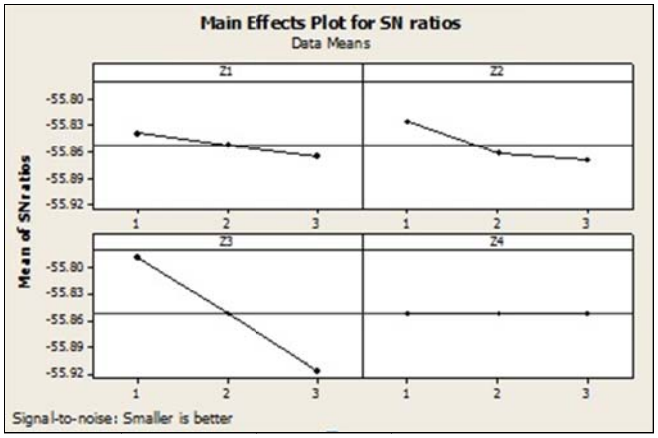

Figure 4. Main effects plot for S/N ratios

From the rate of S/N in Table3, the best composition factors for the average total cost are determined by the highest levels. So, the best configuration for it is: be Z11 (Z1 at level 1), Z21 (Z2 at level 1), Z31 (Z3 at level 1), Z41 (Z4 at level 1). According to the optimal solution from a numerical example obtained and due to the equations (15) and (16), control policy (optimal rate of production) for machines, are introduced as follows:

$$u_{i=1}(t) = \begin{cases} 0 & x_1(t) > 100 \\ 51 & x_1(t) + 51 < 100 \\ [100 - x_1(t)] & \text{otherwise} \end{cases}$$

$$u_{i=2}(t) = \begin{cases} 0 & x_2(t) > 65 \\ 19 & x_2(t) + 19 < 65 \\ [65 - x_2(t)] & \text{otherwise} \end{cases}$$

$$u_{i=3}(t) = \begin{cases} 0 & x_i(t) > 12 \\ 9 & x_3(t) + 9 < 12 \\ [12 - x_3(t)] & \text{otherwise} \end{cases}$$

$$u_{i=4}(t) = \begin{cases} 0 & x_4(t) - 6 > 7 \\ 8 & x_4(t) + 8 - 6 < 7 \\ [7 - (x_4(t) - 6)] & \text{otherwise} \end{cases}$$

5. Analysis of Variance

In this section, the effect of each factor on cost reduction is examined using analysis of variance. The following formulae have been used to calculate the sum of squares (SS), variance and degree of freedom (Sivasakthivel et al. 2014):

$$SS = \frac{1}{2}\{(sum\ of\ \frac{S}{N}\ ratio\ level\ I\ )^2 + (\ sum\ of\ \frac{S}{N} ratio\ level\ II\ )^2 + (\ sum\ of\ \frac{S}{N} ratio\ level\ III\ )^2 - C.F\} \quad (18)$$

$$Correction\ Factor\ (C.F) = \frac{(sum\ of \frac{S}{N})^2}{N} \quad (19)$$

Where N is the total number of experiments (N = 9)

$$\text{Degree of freedom} = \text{Level} - 1 \quad (20)$$

$$Variance = \frac{SS}{DOF} \quad (21)$$

The results of analysis variance are shown in table.4.

Table 4: ANOVA for Inventory threshold

Factors	Degree of freedom	Sum of squares	Variance	% Contribution
Z_1	2	0.047	0.0235	0.072
Z_2	2	0.086	0.043	0.131
Z_3	2	0.52	0.26	0.797
Z_4	2	0.000	0	0
Error	0			
Total	8	0.653		100

According to following table, Z3 factor has the greatest impact on reducing costs.

6. Sensitivity Analysis

Sensitivity analysis is a method for predicting changes in the output of the model, with changing of inputs. In this study, a sensitivity analysis is done on the deterioration time and failure rate.

6.1. Sensitivity analysis on expire date

In this study, if the final product in final buffer isn"t used within a specified period, it is deterioration items and unusable. Deterioration cost per unit of item is constant but deterioration rate depend on time. To doing sensitivity analyzes on this parameter, expire date of final products is increased and then decreased by one unit of time and results obtained as follow.

Table 5: Sensitivity analysis on expire date

Variation of expire date	Expire date per unit of time	The average total cost	The average holding cost	The average shortage cost	The average deterioration cost
Decrease by one unit	2	634.5542	245.352	89.2721	**299.9301**
Main scenario	3	612.87	270.78	78.0549	**264.0351**
Increase by one unit	4	577.3216	304.7568	60.127	**212.4378**

Table 5 shows effect of this time on the average cost of the system. Comparison of result with optimal scenario, increasing of deterioration time causes to increase holding cost and decrease shortages costs and number of deterioration items.

6.2. Sensitivity analysis on failure rate

In this study, failure of machines follows exponential distribution. Also, it is assumed that the failure of machines doesn't depend on the records of maintenance and downtime. To evaluate the effect of tis parameter on the average cost, as shown in Table 6, different values for the mean time between two failures for each machine is tested.

Table 6: Sensitivity analysis on failure rate

Variation of failure rate	The average total cost	The average holding cost	The average shortage cost	The average deterioration cost
50 % reduction	539.0637	227.8354	95.3758	**215.8525**
50 % increase	651.4297	298.671	53.6724	**299.0863**

Reduction time between failures, reduce the buffer inventory at and probability of deterioration. Inventories meet the demand, so holding cost is decreased. Increasing number of failure of machine, increase the probability of shortages, so shortage cost is increased too.

7. Taguchi method – analysis of the S/N ratio for Average total cost

The main objective of the Taguchi experiment is to optimize the factors. The four factors in this paper are: Z_1, Z_2, Z_3, and Z_4. Each factor has three levels that are given in Table 1. The layout of L9 Orthogonal Array (OA) is presented in Table 2. The values of levels of the above four factors for calculating the Zi for all the 9 trial runs and the Zi values calculated using these data for average total cost, so they are shown in table 3. Although, The S/N ratio values of average total cost are calculated using the higher the better concept. The calculated signal-to-noise ratio values for average total cost are given in Table 3 too. The average responses for S/N ratios for each level of factors for average total cost are shown in plots in Fig. 4 respectively. From the S/N ratio Tables 3 and Fig. 4, the best set of combination factors for average total cost can be determined by selecting the level with the highest value for each factor. Thus, the best combination of the operating factors are found to be Z_{11} (Z_1 at level 1), Z_{21} (Z_2 at level 1), Z_{31} (Z_3 at level 1), Z_{41} (Z_4 at level 1).

8. Conclusions

In this paper, optimizing of production rate was done using simulation in a Network Failure Prone Manufacturing System. Desired system was a multi-machines, multi products system that demand for final product is assumed constant and known. Breakdown of machines was stochastic. In final stage of production, backlog and lost sales shortages was allowed, also final product had expire date. The important point in the simulation of this system is assumed that the customers who receive perishable item are placed in priority queue of the customers who are faced with shortage. The main purpose of this paper was minimizing of average total costs that included shortage, production, holding and perishable costs based on production rate in the infinite planning horizon. Because of uncertainly and complexity of these systems, we used simulation modeling with ARENA. Then, Taguchi method is used for determining of threshold level of inventory and consequently, optimal production rate is specified.

To determine of optimal production rate in NFPMS, we used HPP policy. HPP is an optimal control policy in NFPMS. Because of uncertainly conditions and complexity of these systems, simulation of system do to HPP to estimate of total cost was done. Then using Taghuchi design of experiment in Minitab Software, best combination of production rate that is as decision variables, was determined.

In this paper, 4 decision variables (factors) Z1, Z2, Z3 and Z4 in 3 levels were considered and 9 various combinations of these were designed using Minitab Software that each combination is a scenario. Then total cost in simulating model was estimated do to these combinations, and the best scenario in order to S/N ratio was in firs combination that total cost is minimized. Du to the values of S / N of each factor, we can see that the third factor (Z3) has greatest impact on reducing costs. Of course, the results of analysis of variance that were done to determine the importance of each factor, illustrate this. Following the above, sensitivity analysis of two parameters on the failure rate of machines and expire date of final products have been performed.

In future studies, we can assume that backlog and lost sales shortages is allowed in various stage of production. Also demand can be considered stochastic. Repair costs can be calculated. We can use meta-heuristic algorithms and Opt Quest in Arena Software to determine optimal production rate, and compare the result.

References

1. Akella, R. Kumar, PR. 1986. " Optimal control of production rate in a failure prone manufacturing system, IEEE Transactions on Automatic Control, 31: 116–126.
2. Chen, Y.H. Tam, SC., Chen, W.L., Zheng, H.Y., 1996. "Application of Taguchi method in the optimization of laser micro-engraving of photo masks", Int J Mater Prod Technol, 11: 333–344.
3. Fatemi Ghomi, M., 2010. "Production Planning and Inventory Control", 7th ed. Tehran, Iran.
4. Gharbi, A. Kenne´, JP., 2000. "Production and preventive maintenance rates control for a manufacturing system: an experimental design approach", International Journal of Production Economics, 65: 275–287.
5. Kenne´, JP. Gharbi, A. 1999. "Experimental design in production and maintenance control problem of a single machine, single product manufacturing system", International Journal of Production Research, 37: 621–637.
6. Kenne´, JP. Gharbi, A., 2000. "Production planning problem in manufacturing systems with general failure and repair time distributions", Production Planning & Control, 6: 581–588.
7. Kenne JP, Gharbi A, Beit M ., 2007. "Age-dependent production planning and maintenance strategies in unreliable manufacturing systems with lost sale". Eur J Oper Res, 178: 408–420
8. Kimemia, JG., 1982. "Hierarchical control of production in flexible manufacturing systems", PhD thesis, Massachusetts Institute of Technology, Dept. of Electrical Engineering and Computer Science.
9. Kimemia, JG. Gershwin, SB., 1983. "An algorithm for the computer control of production in felxible manufacturing system", IIE Trans 15: 353–362
10. Mandal, N. Doloi, B. Mondal, B. Das, R., 2011. "Optimization of flank wear using Zirconia Toughened Alumina (ZTA) cutting tool: Taguchi method and Regression analysis", Measurement, 44: 2149–2155.
11. Older, GJ. Suri, R., 1980. "Time operational part-routing in manufacturing system with failure prone machines In: Proc. 19th conf. decis. Control, Albuquerque, NW.
12. Ping Lee ,Yu., Yuan Dye, C., 2012 "An inventory model for deteriorating items under stock-dependent demand and controllable deterioration rate", Computers & Industrial Engineering, 63: 474–482.
13. Pochet Y, Wolsey LA; 2006. "Production planning by mixed integer programming". Secaucus, NJ, USA: Springer-Verlag New York, Inc; ISBN 978-0387299594, 500.
14. Rishel, R., 1975. "Control of systems with jump Markov disturbances", IEEE Trans Automat Contr 20: 241–244.
15. Saidi-Mehrabad, M. Paydar, M.M. Aalaei, A., 2013 "Production planning and worker training in dynamic manufacturing systems", Journal of Manufacturing Systems, 32: 308– 314.
16. Sajadi, S.M., 2011" Determination of production rate of network failure prone manufacturing system with constant demand", PhD thesis, Amirkabir university, Dept. of Industrial Engineering.
17. Sajadi, S.M. Seyed Esfahani, M.M. So¨ rensen, K., 2011" Production control in a failure-prone manufacturing network using discrete event simulation and automated response surface methodology , Int J Adv Manuf Technol 53: 35–46.
18. Sivasakthivel, T. Murugesan, K. Thomas, H.R., 2014 "Optimization of operating parameters of ground source heat pump system for space heating and cooling by Taguchi method and utility concept",Applied Energy, 116: 76–85.
19. Xie, X.; 1989 "Optimal control in a failure prone manufacturing system", Automatic Control, IEEE, 31: 116-126.