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Human Resources Scheduling Based on Machines Maintenance Planning and Human Reliability Level

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ABSTRACT

In today's competitive market, quality has an important role in manufacturing system. The manufacturers attempt to maintain their production system in a proper condition to produce high quality products. One of the key factors to achieve this goal is maintenance policy. Most studies on maintenance focused on machines and less attention has been paid to human resources as the most important factor in manufacturing system. In this paper we propose a mixed integer nonlinear model to schedule the maintenance of machines and rest of human resources based on reliability factor. This model aims to minimize the cost of machines and human resources idleness and products quality cost. The performance of proposed model was examined by two instances and the obtained results indicated this model can provide efficient and effectiveness work and rest schedule for machines and human resources in manufacturing systems.

1.Introduction

The reliability is an important factor in manufacturing systems; it is vital to measure the capability of a manufacturing system and determine whether it can satisfy customers' orders or not based on the reliability of all elements involved in production system such as machines, human resources and materials. The reliability of machines has been widely studied in many papers on maintenance [1-3]. By contrast, less attention has been paid to human and material reliability as two important factors in production systems. As is evident if these three factors are not in a reliable state, the products have poor quality level and cannot satisfy the customer's expectation.

The main factor in reliable production system is integration. If we do not have reliable machines, human and material simultaneously the output of production is not proper and does not achieve the expected production profit.

Many researchers studied machines reliability and maintenance scheduling. Also there are many papers combined these matters with production scheduling and material supply. Adamyan and he [4] proposed an analysis of failure in order to estimate the reliability of machines in manufacturing system. Guan et

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al.[5] also proposed a baysian method based on first order reliability method to calculate the reliability for a production system. Regattieri et al.[6] investigated the reliability estimation based on censored data from machines performance for a manufacturing system. Thomas [7] carried out a survey about maintenance and replacement models for maintainability and reliability of multi-item elements in production systems. Marseguerra and zio [8] proposed a genetic algorithm to optimize the maintenance policy to increase the machines reliability in production systems. Sheu and Jhang [9] provided a generalized group maintenance policy for each machine in production system based on reliability that required for each machine according to their operations.

Another researchers have invested the human reliability. Human reliability comprises a wide range of topics such as human error classification, human error recognition, human error rate prediction and human error elimination [10-12].

The most papers in human reliability aim to categorize human error and determine the effect of human error on manufacturing system. It should be mentioned that nearly all papers deal with conceptual model in human reliability and less attention has been paid to mathematical model. Karaulova and Pribytkova [13] studied the human role within the overall reliability analysis but proposed generalized comments, such as better ergonomic design or improving human–machine interface. Barroso and Wilson[14] considered a manufacturing system and estimated the overall effect of human reliability. Blanks [15] indicated the necessity for improvement in reliability prediction and paying special attention to human error causes. Mosleh and Chang [16] introduced a new method for model-based human reliability analysis. They believed that every human reliability analysis should consider a model-based approach that provides explicit cognitive causal links between human behaviors and directly or indirectly measurable causal factors and failure. Kolarik et al. [17] developed a model to monitor and estimate human resources' performance with a fuzzy logic-based assessment method. Stanton and Baber [18] proposed a systematic model to estimate the rate of human error. They focused their study on man-machine system and proposed a multi-level estimation model for production systems. Marianne Döös et al. [19] studied on human errors that have accidents with an injury outcome. Their aims were to identify and describe the occurrence of risk-triggering and risk-creating human errors. Cacciabue [20] discussed the methods and techniques that are applied for including human factors considerations into risk analysis of modern plants. Liua et al. [21] proposed a human error cost estimation model to facilitate production managers with a proper tool to collect and calculate the total losses. Sträter and Bubb [22] proposed a method to describe how plant experience about human failures and human performance are used to support the process of analyzing and assessing human reliability. Some researchers considered other factors such as learning and skill in human reliability analysis for example Biskup [23] and Teyarachakul et al. [24], considered human resources reliability and studied the effects of skill and learning on human resources performance.

Although there are some papers about the machine reliability with considering human resources, but most of them considered human as a resource to improve machine reliability and did not consider the human as an important factor has special effect on reliability. Kiassat et al. [25] presented a novel method to quantify the effects of human-related factors on the risk of failure in manufacturing industries. Taylor [26] studied the human role as an important resource in maintenance of machines. He believed that maintenance resource management is the part of maintenance human factors which addresses the issues of management. Martorell et al. [27] addressed the effect of human resources and material resources (spare parts) on reliability, availability, maintenance and cost models.

The fundamental point that should be noted is that, since human and machines work together to produce products their reliability must be studied simultaneously [25]. That is to say if we have reliable machines and unreliable workers, the products will not be in a proper quality state.

To the best of author's knowledge, there are no outstanding researches in which machines reliability and human reliability have been studied simultaneously.

In this paper we study human reliability and machine reliability simultaneously. We propose a mathematical model to provide the best production scheduling and best work and rest scheduling for each worker. In the proposed model we assume that machines have a periodic maintenance plan and workers should rest based on their reliability to decrease their failure rate. If workers continue to work without any rest, their failure rate increases and this fact leads to produce poor quality products. Since the complexity of proposed model we use linearization technique and solve the linearized model by branch-and-bound method (B&B).

The rest of the paper is organized as follows: Section 2 presents the problem statement and its assumptions. Section 3 proposes the linearized model. Section 4 presents two instances with computational results to validate and verify the proposed model and finally section 5 concludes the paper.

2. Problem Statement

In this section, we formally describe the considered problem and propose a new mathematical model based on cost of machine and worker idleness and poor quality cost regarding to minimum completion time and proper reliability for workers and machines. In this model the idle time and rest time for human resources are different. If a worker rests, his failure rate decreases and his reliability increases. But if a worker is idle, his reliability does not change, since he is not in a proper condition and cannot rest perfectly. The proposed model attempts to synchronize the workers rest times with machines maintenance times and reduce the machines and workers idleness time based on their reliability. We assume that workers with low reliability value produce poor quality products and impose extra cost to the production system. In this regard we propose the best work and rest schedule for each worker. Since the proposed model is a nonlinear one, we then linearize such model in next subsection. Other assumptions made in the model are proposed in next subsection.

2-1. Assumptions

- Each machine has a specific worker.
- Operation time for each machine is known.
- Planning horizon is divided to equal unit called time position. For example each time unit may be equal to 10 or 15 minutes.
- The worker reliability increases according to the rest duration.
- The machines are not available in specific time positions for periodic maintenance.
- If each main worker reaches his necessary reliability level, he should rest to retrieve his reliability level.
- The planning horizon is equal to the required time to produce the entire products and this time is known.

2-2.Notations

2-2-1.Subscripts

i	Index for machine and its worker (i=1, 2,…I)
k	Index for time position (k=1, 2,…K)

2-2-2. Input parameters

L_i	Operation time of machine i
Rn_i	The necessary reliability level for the worker of machine i
Rp_i	The primary reliability level for worker of machine i

λ_i	The e rate for worker of machine *i*
Cm_i	The unitary cost of machine *i* idleness
Ch_i	The unitary cost of idleness for the worker of machine *i*
Cq_i	The unitary cost of poor quality for machine *i*
$X_{i,k}$	The availability of machine *i* in position *k*

2-2-3. Decision variables

$Y_{i,k}$	1 if the worker of machine *i* is available in position *k*; =0 otherwise
$Z_{i,k}$	1 if the worker of machine *i* works in position *k*; =0 otherwise
C_i	The last position number that machine *i* completes its work
$R_{i,k}$	The reliability for the worker of machine *i* in position *k*

With respect to the above notations, the mathematical model can be formulated as mentioned in next section:

2-3.The mathematical model

$$\min Z: \sum_{i=1}^{I}\sum_{k=1}^{K} X_{i,k}.(1-Y_{i,k}).Cm_i + \sum_{i=1}^{I}\sum_{k=1}^{K} Y_{i,k}.(1-Z_{i,k}).Ch_i + \sum_{i=1}^{I}\sum_{k=1}^{K}\left(1-R_{i,k}\right).Cq_i + \sum_{i=1}^{I} C_i \quad (1)$$

S.t.

$$\sum_{k=1}^{K} Z_{i,k} = L_i \quad \forall m \quad (2)$$

$$R_{i,1} = Rp_i \quad \forall i \quad (3)$$

$$R_{i,k} = e^{-\lambda_i}.Z_{i,k-1}.R_{i,k-1} + (1-Z_{i,k-1}).(1-Y_{i,k-1}).e^{\lambda_i}.R_{i,k-1} + (1-Z_{i,k-1}).Y_{i,k-1}.R_{i,k-1} \quad \forall i, \geq 2 \quad (4)$$

$$Z_{i,k} \leq Y_{i,k} \quad \forall i, \quad (5)$$

$$Z_{i,k} \leq X_{i,k} \quad \forall i, \quad (6)$$

$$Rn_i - R_{i,k} \leq 1 - Y_{i,k} \quad \forall i, \quad (7)$$

$$R_{i,k} \leq 1 \quad \forall i, \quad (8)$$

$$C_i = \max_k \left\{k.Z_{i,k}\right\} \quad \forall i; \quad (9)$$

Objective Function (1) minimizes the total cost of production that includes the machines idleness cost, workers idleness cost, quality cost and completion time cost. The first and second components show if worker rests and machine is not under maintenance action, we face with machine idleness cost, by contrast if a worker is available but does not work, we confront with worker idleness cost. The third component calculates the quality cost. A worker with greater distance from high reliability (100%) has larger quality cost since the failure probability increases when reliability of workers decreases gradually. Finally the last component makes sure that each machine completes its production function as soon as possible and does not waste time without any rational reason.

Relation (2) assures that the total working time of a worker should be equal to production time. Relation (3) shows that the first reliability value in first time position for each worker is equal to primary reliability level. Relation (4) calculates the reliability of each worker in each time position based on his work or his availability in prior time position. If the worker has already worked in previous position, his reliability level decreases. On the other hand if he is not available and rest, his reliability level increases. Finally if the worker is available and does not work, his reliability level is the same as prior reliability level. Relation (5) ensures that a worker can work when he is available and does not rest and Relation (6) assures that if a machine is not available, its worker cannot work. Relation (7) shows that if the reliability level of a worker is less than necessary reliability value, the worker should rest and cannot be available to work. Relation (8) sets a limit on reliability value. Relation (9) calculates the completion time for each machine.

The aforementioned model is almost similar to maintenance scheduling of production machine. According to [28] these models are categorized as NP-hard problem. This model not only includes constraints of maintenance model but also includes the nonlinear constraints of reliability calculation. Based on these facts this model is NP-hard, within which it is difficult to find the optimal solution accurately.

3. Linearization

Since the objective function and Constraints (4) and (9) are nonlinear, in this section an attempt is made to linearize the proposed mathematical model.

The nonlinear worker idleness cost term in the second component of objective function could be linearized with $\boldsymbol{F_{i,k} = Z_{i,k}.Y_{i,k}}$ under the following set of constraints:

$$F_{i,k} \leq Z_{i,k} + A(1 - Y_{i,k}) \qquad \forall i,k; \qquad (10)$$

$$F_{i,k} \geq Z_{i,k} - A(1 - Y_{i,k}) \qquad \forall i,k; \qquad (11)$$

$$F_{i,k} \leq Z_{i,k} \qquad \forall i,k \qquad (12)$$

$$F_{i,k} \leq Y_{i,k} \qquad \forall i; \qquad (13)$$

Also, the nonlinear terms of the fourth constraint also could be linearized via three transformations. First of all we should extend the fourth constraint as follows:

$$R_{i,k} = e^{-\lambda_i}.Z_{i,k-1}.R_{i,k-1} + (1 - Z_{i,k-1}.R_{i,k-1} - Y_{i,k-1}.R_{i,k-1} + Z_{i,k-1}.Y_{i,k-1}.R_{i,k-1}).e^{\lambda_i} + (Y_{i,k-1}.R_{i,k-1} - Z_{i,k-1}.Y_{i,k-1}.R_{i,k-1}) \qquad (14)$$

To linearize the relation (14) we should define three auxiliary and their related constraints.

The first variable is $ZR_{i,k} = Z_{i,k}.R_{i,k}$ that utilized with the following constraints.

$$ZR_{i,k} = Z_{i,k-1}.R_{i,k} \qquad \forall i,k; \qquad (15)$$

$$ZR_{i,k} \leq R_{i,k} + A(1 - Z_{i,k}) \qquad \forall i,k; \qquad (16)$$

$$ZR_{i,k} \geq R_{i,k} - A(1 - Z_{i,k}) \qquad \forall i,k; \qquad (17)$$

$$ZR_{i,k} \leq Z_{i,k} \qquad \forall i,k \qquad (18)$$

The second auxiliary variable is $YR_{ik} = Y_{i,k}.R_{i,k}$ that added to model with the following constraints

$$YR_{i,k} = Y_{i,k}.R_{i,k} \qquad \forall i,k; \qquad (19)$$

$$YR_{i,k} \le R_{i,k} + A(1 - Y_{i,k}) \qquad \forall i,k; \qquad (20)$$

$$YR_{i,k} \ge R_{i,k} - A(1 - Y_{i,k}) \qquad \forall i,k; \qquad (21)$$

$$YR_{i,k} \le Y_{i,k} \qquad \forall i,k \qquad (22)$$

The last auxiliary variable that souled be added is $FR_{i,k} = F_{i,k}.R_{i,k}$ with the following constraints.

$$FR_{i,k} = F_{i,k}.R_{i,k} \qquad \forall i,k; \qquad (23)$$

$$FR_{i,k} \le R_{i,k} + A(1 - F_{i,k}) \qquad \forall i,k; \qquad (24)$$

$$FR_{i,k} \ge R_{i,k} - A(1 - F_{i,k}) \qquad \forall i,k; \qquad (25)$$

$$FR_{i,k} \le F_{i,k} \qquad \forall i,k \qquad (26)$$

By using these three variable and their related constraints the relation (4) can be replaced by following relation.

$$R_{i,k} = e^{-\lambda_i}.ZR_{i,k-1} + (1 - ZR_{i,k-1} - YR_{i,k-1.} + FR_{i,k-1}).e^{\lambda_i} + (YR_{i,k-1} - FR_{i,k-1}) \qquad (27)$$

To linearize the Relation (9) we can reformulate this relation and replace it with relations (29-30). Based on this new formula variable Qq_{ik} is added to proposed model.

$$C_i = \max_k\{k.Z_{i,k}\} \qquad \forall i,k; \qquad (28)$$

$$C_i = Qq_{i,K} \qquad \forall i; \qquad (29)$$

$$Qq_{i,k} = Qq_{i,k-1}.\left(1 - Z_{i,k}\right) + k * Z_{i,k_{i,k}} \qquad \forall i,k; \qquad (30)$$

Since Constraint (30) is still nonlinear, so we need to introduce auxiliary variables to replace these nonlinear terms with additional constraints. The required new variables could be defined by the following equations.

$$Zqq_{i,k} = Qq_{i,k-1}.Z_{i,k} \qquad \forall i,k \ge 2 \qquad (31)$$

$$Zk_{i,k} = k.Z_{i,k} \qquad \forall i,k; \qquad (32)$$

By considering above equations, following constraints must be added to the mathematical model:

$$Zqq_{i,k} + A(Z_{i,k} - 1) \le Qq_{i,k-1} \qquad \forall i,k \ge 2; \qquad (33)$$

$$Zqq_{i,k} - A(Z_{i,k} - 1) \ge Qq_{i,k-1} \qquad \forall i,k \ge 2; \qquad (34)$$

$$Zqq_{i,k} \le A.Z_{i,k} \qquad \forall i,k; \qquad (35)$$

$$Zk_{i,k} + A(Z_{i,k} - 1) \le k \qquad \forall i,k; \qquad (36)$$

$$Zk_{i,k} - A(Z_{i,k} - 1) \ge k \qquad \forall i,k; \qquad (37)$$

$$Zk_{i,k} \le A.Z_{i,k} \qquad \forall i,k; \qquad (38)$$

According to the aforementioned constraints, the linear mathematical model is as follows:

$$\min Z: \sum_{i=1}^{I}\sum_{k=1}^{K} X_{i,k}.(1-Y_{i,k}).Cm_i + \sum_{i=1}^{I}\sum_{k=1}^{K}(1-F_{i,k}).Ch_i + \sum_{i=1}^{I}\sum_{k=1}^{K}\left(1-R_{i,k}\right).Pn_i.Cq_i + \sum_{i=1}^{I} C_i$$

Subject to Constraints (2)−(3), (5)−(8), (10)−(13), (17)−(27), (29)−(38).

4. Numerical illustration

In this section, we report computational results to evaluate the effectiveness of the proposed model. Two instances are solved by branch-and-bound (B&B) method using Gams software on a PC including Intel® Core i5 and 2 GB RAM.

Instance 1: This instance includes 2 machines, 2 workers and 21 positions time. The period of maintenance for each machine is 5 positions time and the maintenance duration for each machine is 2 positions time. The schema of machines availability is shown in Figure 1. As is evident both machine 1 and machine 2 are under periodic maintenance action in positions 6-7 and positions 13-14. That is to say, $X_{1,6} = X_{1,7} = 0$ and $X_{1,13} = X_{1,14} = 0$. This fact also holds true for the second machine.

	Position time													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Machine 1	1	1	1	1	1	0	0	1	1	1	1	1	0	0
Machine 2	1	1	1	1	1	0	0	1	1	1	1	1	0	0

Fig. 1. Schema of maintenance action for each machine

The data set related to the machine processing time and reliability level of each worker are shown in Table 1. For example, as seen in Table 1 the total processing time that machine 1 and machine 2 should be work with their workers are 5 and 10 positions time. Also the failure rate for worker of machine 1 and machine 2 are 0.05 and 0.05 per each time position

Table 1 The input data of instance 1

	Machine 1	Machine 2
L_i	5	10
Rn	0.7	0.7
Rp	0.85	0.8
λ	0.05	0.05
Cm	50	75
Ch	50	50
Cq	200	300

The results of instance1 obtained by the proposed model are elaborated in the rest of this section. The total objective function and its detail are shown in Table 2.

Table 2 The results obtained for instance 1

Objective function	Machine idleness cost	Machine idleness cost	Quality cost	Completion cost
1850	525	350	937	38

The production plan and workers' rest time are shown in Tables 3. As we described in section 2 the $Y_{i,k}$ =1 shows the availability of worker *i*. and $Z_{i,k}$ =1 shows that the worker *i* works in position *k*. based on these facts we can illustrate the result shown in Table 3. The worker of machine 1 rests in first three time positions and works in positions 4-5, 11-12 and 19. As could be seen the reliability of worker 1 is not less than necessary reliability level in any time position. Based on parameter $X_{i,k}$ for each machine the worker cannot work in positions 6-7, 13-14 and 20-21 since the machine is under periodic maintenance action.

Table 3 The workers' optimum rest and work schedule for instance 1

	Time Position	Y	Z	R		Time Position	Y	Z	R
Machine 1	1	0	0	0.85	Machine 2	1	0	0	0.8
	2	0	0	0.89		2	0	0	0.84
	3	0	0	0.94		3	0	0	0.88
	4	1	1	0.99		4	1	1	0.93
	5	1	1	0.94		5	1	1	0.88
	6	0	0	0.89		6	0	0	0.84
	7	0	0	0.94		7	0	0	0.88
	8	1	0	0.99		8	1	1	0.93
	9	1	0	0.99		9	0	0	0.88
	10	1	0	0.99		10	0	0	0.93
	11	1	1	0.99		11	1	1	0.98
	12	1	1	0.94		12	1	1	0.93
	13	0	0	0.89		13	0	0	0.88
	14	0	0	0.94		14	0	0	0.93
	15	1	0	0.99		15	1	1	0.98
	16	1	0	0.99		16	1	1	0.93
	17	1	0	0.99		17	1	1	0.88
	18	1	0	0.99		18	1	1	0.84
	19	1	1	0.99		19	1	1	0.8
	20	0	0	0.94		20	0	0	0.76
	21	0	0	0.99		21	0	0	0.8

The Figure 2 also shows the trend of reliability level for each worker of machines. It should be noted that the minimum reliability in entire positions time is larger than necessary reliability level.

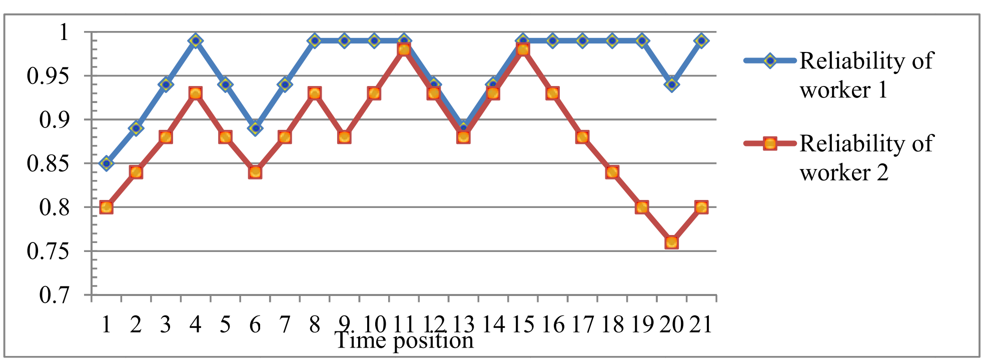

Fig. 2.The trend of reliability level for each worker in instance 1

Instance 2: the second example includes 4 machines, 4 workers and 30 positions time. The period of maintenance for each machine is 7 positions time and the maintenance duration for each machine is 2 positions time. Other parameter such as processing time and failure rates are shown in Table 4.

Table 4 The input data of instance 2

	Machine 1	Machine 2	Machine 3	Machine 4
L_i	5	10	14	12
Rn	0.7	0.75	0.67	0.65
Rp	0.85	0.8	0.85	0.82
λ	0.05	0.06	0.04	0.05
Cm	50	75	65	60
Ch	50	70	70	60
Cq	200	300	350	375

The best scheduling of work for each worker is shown in Figure 3. In this Figure number 1 indicates that the worker is not idle and works and number 0 indicates that the worker rests to retrieve his reliability level. Blank positions show the idleness of each worker.

	Time position																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Worker1	0	0	0			1	1	0	0						1	1	0	0							1	0				0
Worker2	0	0	0		1		1	0	0	1	0	1	0		1	1	0	0	1	0				1	1	0	0			1
Worker3	0	0	0	0		1	1	0	0	1	0	1	0	1	1	1	0	0	1	0	0	1	0	1	1	0	0	1	1	1
Worker4	0	0	0			1	1	0	0	1	0	1	0		1	1	0	0	1	0	1	0		1	1	0	0	1	0	1

Fig. 3. The workers' optimum rest and work schedule for instance 2

The obtained reliability by running proposed model for instance 2 are shown in Figure 4. Since the quality cost of worker 1 is less than worker 3 consequently the number of rest time for worker 1 is less than worker 3.

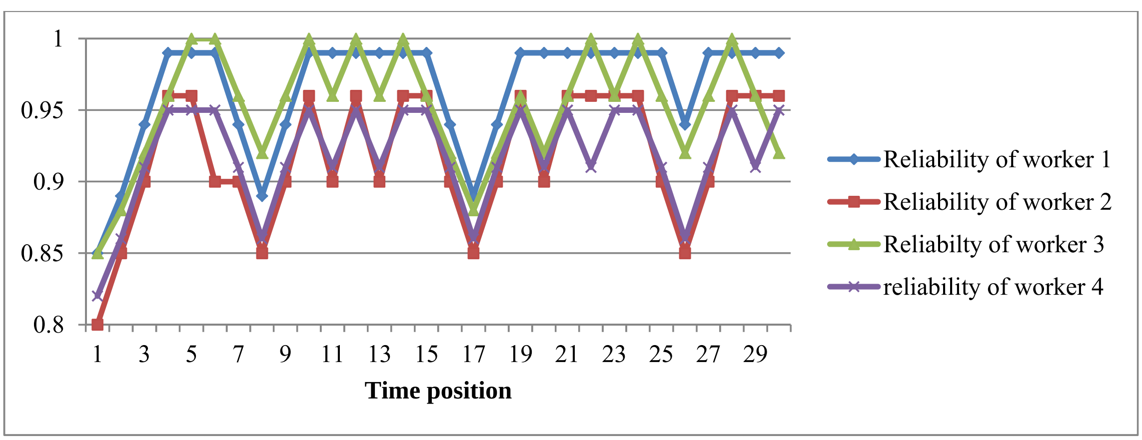

Fig. 4. The trend of reliability level for each worker in instance 2

5. Conclusions

This paper presented a novel integer nonlinear model for the human resource scheduling according to machine maintenance time and reliability level of workers. The excellent advantage of the proposed model is to calculate the cost of idleness of machines and workers and work quality of each worker.

Considering the role of human resources reliability in quality and proposing the best work and rest schedule for workers is the other advantages of the proposed model. Since the complexity of proposed model we used the linearization technique to convert it to linear form and decrease the solving time. The performance of proposed model was examined by two instances and the provided results indicated the model can obtain efficient and effective work and rest schedule for each worker.

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