Decision support system designed to optimize maintenance and operation processes in petrochemical industry based On Markov Decision Approach

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Abstract— **The focus of this article is on designing a decision support system, which optimizes maintenance and operation processes in petrochemical industries based on Markov decision process. Since a consistent process is located at the end of processes range, these industries' machines form a continuous chain, and the resulting flow on them always continue from the feed to the final product. Flaws result in equipment failure, hiatus in production, and even decrease of product quality and in practice any case of production stopping costs a lot to resume.**

This research has been conducted to analyze the effects of changes resulting from high demand of market on equipment. The new formula calculates relations between maintenance and repair controls clearly with regard to the weight of lack of production in case of equipment failure in different production conditions in a continuous system based on Markov decision process. This model optimizes a set of maintenance controls of different production conditions in each period, and in this way optimized values of condition, control, and optimized policy of control are obtained. This model has been performed in 12 to 72 month periods. Having chosen the optimized policy of control and obtaining the sample number of surveyed statistical population, the indicators have been measured for six months both before and after performing the optimized policy of control where the overall effectiveness of system increased to 87 from 82.7, and positive and acceptable changes were seen.

Index Terms— **Decision Support System, Maintenance, Markov Decision Approach, Optimization, Overall Systems Effectiveness**

I. INTRODUCTION

In the third millennium, different companies and organizations face numerous challenges to have a successful presence in the business world, and these challenges are sometimes conflicting. Meanwhile, one of the most fundamental factors of changing the return on asset is the Equipment plays an undeniable role in qualities of products, and a production of high quality is one of the major objectives of any system [2]. We consider a petrochemical factory with a high number of equipment, devices, and machines which all contribute to the production process. Since planning for conducting maintenance operation of equipment is done periodically, production process is affected, and even could stop during conduction [3], [4]. Otherwise, sudden failure of equipment may cut production systems. Sometimes, High rate of production because of high demand, leads to imposing more pressure on production systems which itself expedite the failure of systems [5]. The motivation for doing so is resulted from the need for development of optimized policies of maintenance, and operation for time-continuous systems, so that a correct and accurate method could be designed for supporting the production [6]. This can be possible by developing the concept of effectiveness using the Markov decision process according to the weight of lack of production in case of equipment failure in continuous systems [7] – [11]. Overall equipment efficiency (OEE) in Total Productive Maintenance (TPM) can be defined based on Tkachima's Definition (1998) as following [12]:

OEE = availability × production rate× quality rate (1).

Therefore, based on the given definition in (1), and because of the studied equipment being hidden, Overall System Effectiveness (OSE) is the integrated availability, the capability of production, and quality measurement of all equipment calculated by (2): OSE=$\prod_{i=1}^{i=n} OEE_i$ (2)

The rest of this article is organized as following. The subject has been reviewed in the first two sections. In the third section, the issue has been presented in detail and the problem is expressed by theoretical backgrounds of Markov decision process, considering the lack of production in case of equipment failure in continuous systems, and a mathematical model to maximize the Overall System Effectiveness. In section four, the calculation method based on the defined process in section three has been offered. Also, a numerical example of application is shown, and in section six the conclusion of this article is done.

II. REVIEW OF SUBJECT

In this article, support system is designed to optimize maintenance and operation processes in petrochemical industries based on Markov decision process, considering the lack production in case of equipment failure. The final decision is, then, taken by calculating operating costs depending on different states along which the operation time, risk due to the equipment age and irregular inspection, and replacements are considered depending on time and operating costs. In another research by Koochaki, Javid et al. (2013) about the impacts of maintenance based on equipment conditions for workforce planning and maintenance [13], the maintenance policy is used to predict a failure event

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according to the circumstances of each part, and therefore, it tries to prevent any unwanted failure, and unnecessary maintenance and repair activities from happening. The two factors of Condition Based Monitoring (CBD) or Age Based Replace (ABR) have been considered both in parallel and series multi-component systems regardless of staff limitation and with internal staff of the unit, or with external maintenance and repair staff with their attendance time. AlDurgam, Mohammad et al. (2012), carried out a study titled common policies of optimal operation, maintenance and repairs to maximize overall equipment efficiency [14], and performed it in one of the refinery units. This model optimizes maintenance and repair operation, and production rate for each period. The decision maker (controller) can choose the optimal policy using the space vector of system state (belief state). Zhang Zaifang et al (2010) carried out a research on conceptual design of production and maintenance. They investigated the increasing importance of services such as maintenance to a manufactured product, and their role in improvement of customer satisfaction and promotion of consistent consumption [15]. Another research was done by Murat Kurt et al (2010) about the optimal maintenance of a critical Markov system with incomplete limited repairs. They considered a problem in a critical periodically inspected system using time-discrete Markov process with limitation on number of repairs before replacements to achieve the optimal maintenance [16]. After each inspection, the decision maker should decide whether a replacement should be done to repair the system or the equipment could be used until the next inspection, and introduce the optimal structure and policy. In 2009, a research was done by Radouane Laggounea et al about preventive maintenance planning for multi-component system with not-negligible replacement times. The impacts of maintenance time on the desirable policy have been shown clearly by numeral results in an oil refinery [17].

In this paper, maintenance, as well as production operation and the relations between them have been modeled by the optimal value of state and control in systems. In addition to differences in production states, other differences in control activities of this process have been considered, and control models have been categorized based on target function. The target is to minimize the total cost of maintenance controls in different states of production.

III. SIGNS AND SYMBOLS OF PROBLEM

The marks used in this paper are shown in A. and the problem is described in Section B.

A. *Symbols used in the paper*

S: All states of system facilities

S_t: System state at time t

P [s_t , s_{t+1}]: Transition probability from states s_t to s_{t+1}

P: Transition matrix State S

U: Maintenance activities

U_t: Control element of U, u_0 (no maintenance) to u_n (replacement)

P(u): Possibility of U control

$P^u_{ss'}$: Change state of s to s' with the control u

M: Matrix of the cost of production in the equipment failure

M_w: non-production equipment costs in the event of failure of W.

P [u_i|s]: states transition probability when ui control runs.

$g_u(s_t,s_{t+1})$: Change the state of t to t + 1 the cost control when u apply.

π(s,u): Select a control policy u in state s.

g^{π}_{s}: The cost of policy π when state s choice

$j^{\pi}(s)$: Return value function, the policy π is the expected return starting from states S.

$Q^{\pi}(s,u)$: The control value, the expected return of the S mode with the control policy u is π.

$j^{*}(s)$: Minimum function return values for all policies

$Q^{*}(s,u)$: Minimum value for all policies is the function control.

γ : Discount factor and a maximum is one

$\pi^{*}(s,u)$: The best control policy u in state s

B. *Problem expression*

The decision support system is designed to optimize the maintenance and operation processes, and to integrate the production, taking into account the equipment failure effects on Markov decision process based-production volume, and then, the production and maintenance data are collected according to localization of Markov decision process. Finally, the optimal values of production state and of maintenance control are calculated, and the optimal policy is then chosen, using the created modern approach. Using the maintenance data of six years ending 2013, the model has programmed each group of equipment used in petrochemical companies in a way that the changes in production rate have the least impact on quality and the extent of equipment depreciation, which in turn increases the overall system effectiveness. The Markov decision process model consists of a set of different operation states S, a set of possible maintenance actions U, weights of various equipment MW, and the real cost of G(S, U) function [18] – [25].

This research tries to find the real cost of G(S, A) function with regard to repairing groups in the maintenance system, and production through modeling different combination scenarios and operating actions. Then, using Markov decision process, the optimal control policy is obtained based on the minimum forced cost [26] – [41].

IV. PROBLEM CALCULATIONS

The defined objective of problem is to find the optimal control policy of maintenance for production systems, while the weight of the used equipment set are variable.

In the problem, the activity s is defined as the function π, where π is the policy of decision maker for a state where S has been chosen.

The objective has been to choose the policy π, when the accumulation function sums of stochastic costs were at their minimum.

The sum of expected costs over a six-year period is defined as (3):

$\sum_{W=1}^{W=5}\sum_{t=1}^{t=7} M_w \gamma^t g_{u_t}(s_t, s_{t+1})$ where $u_t = \pi(s_t)$ (3)

γ is the discounting factor with a maximum of one (0≤γ≤1); M_w is the weight of any equipment; and $g_{u_t}(s_t, s_{t+1})$is the cost imposed upon system when control u is performed, and the transition from t to t=1 take places.

A. *Production states*

The production states of system are shown as set S, which includes all states.

The initial state in Markov decision process is defined as s, and the alternative state as s'. Then, the transition state is assumed as following:

$P_{ss'} = P\,[s_t, s_{t+1}]$

B. *Control states*

States of system maintenance (control) is defined as follows.

$U_{\text{Maintenance Actions}} = \{u0, u1, u2, u3, u\,4, \ldots\}$

C. *The cost of production of each type of equipment failure.*

Lost production costs of manufacturing facilities during different conditions in the matrix M are shown.

$$M=\begin{bmatrix} M11 & \cdots & M15 \\ \vdots & \ddots & \vdots \\ M51 & \cdots & M55 \end{bmatrix}$$

D. *the status of the maintenance control*

Figure (1) states the overall system different from controls are shown.

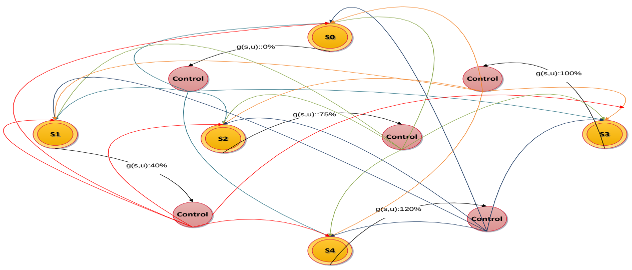

Figure 1: show the different positions of the controller

E. *Calculation of the probability of changing the state by control of the policy π*

Policy change control condition of equation (4) is obtained. $P^{\pi}_{s,s'} = \sum_{u\in U}\pi(s,u)P^{u}_{s,s'}$ (4)

F. *Calculation of cost control by policy π*

The cost of changing the control mode of relation (5) is obtained. $g^{\pi}_{s} = \sum_{u\in U}\pi(s,u)g^{u}_{s}$ (5)

G. *Calculation of the state value function and the control value function*

State value function of a Markov Decision Process MDP policy π is the expected return starting from state S, that the relation (6) is obtained.

$j^{\pi}(s) = E_{\pi}[j_t \mid s_t = s\ ]$ (6)

Control value function of a Markov decision process is expected to return to the start of the S state control policy u is π. From equation (7) is obtained.

$Q^{\pi}(s,u) = E_{\pi}[j_t \mid j_t = s,\ u_t = u]$ (7)

H. *Bellman Expected equation*

Bellman equation for the value function state expected to affect the cost of lost production due to downtime of equipment, the relation (8) is defined.

$j^{\pi}(s) = E_{\pi}[m_{t+1}g_{t+1} + \gamma\, j^{\pi}(s_{t+1}) \mid s_t = s]$ (8)

Bellman equation for the value function to control the impact of the expected cost of lost production due to downtime of equipment, the relation (9) is defined.

$$Q^{\pi}(s,u) = E_{\pi}[m_{t+1}g_{t+1} + \gamma\, Q^{\pi}(s_{t+1},u_{t+1}) \mid s_t = s, u_t = u\ ]$$
(9)

Figure (2) represents the expected Bellman equation for the value of the control u control the state s to state s' to change its state when the policy π is chosen.

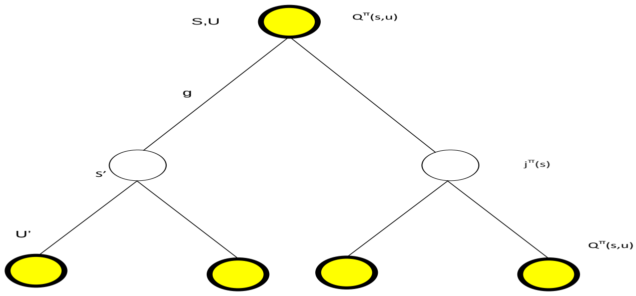

Figure 2: Bellman equation for the expected value of the state s to state s' with the control u and the choice of policy π

Equation (10) Bellman equation for the value of state s is expected, when the state s to s' is done with the policy π.

$j^{\pi}(s) = \sum_{u\in U}\pi(s,u)\ (M_s G^{u}_{s} + \gamma \sum_{s'\in S}\rho^{u}_{ss'}\ j^{\pi}(s'))$
(10)

Equation (11) is expected Bellman equation, u is the control value when the state s to s' is done with the policy π.

$Q^{\pi}(s,u) =$
$M_s G^{u}_{s} + \gamma \sum_{s'\in S}\rho^{u}_{ss'} \sum_{u'\in U}\pi(s',u')\, Q^{\pi}(s',u')$ (11)

According to equation (10) the expected Bellman equation can be summarized as equation (12) should be used.

$j^{\pi} = M^{\pi}G^{\pi} + \gamma\,\rho^{\pi}j^{\pi}$ (12)

After obtaining the relation (12), the expected Bellman equation of state value by equation (13) is obtained for the various policies.

$j^{\pi} = (I + \gamma\,\rho^{\pi})^{-1}\,M^{\pi}G^{\pi}$ (13)

IV.IX. Calculate the optimal policy

The optimal policy is the minimum control value in the production states obtained through (14).

$$\pi^*(s,u) = \begin{cases} 1 \text{ if } u = \operatorname{argmin}_{a\in A} Q^*(s,u) \\ 0 \quad \text{otherwise} \end{cases}$$
(14)

The obtained policy is the definite optimal policy based on Markov decision process.

V. Numerical Computation Problem

A. *Frequency of changes in year*

Frequency of changes in production conditions in Table (1) is displayed.

Table 1: Cumulative Frequency Percent of Total Change

State Change	No	State Change	No	State Change	No
from 0 to 0	0	from 40 to 0	0	from 75 to 0	0
from 0 to 40	0	from 40 to 40	0	from 75 to 40	1
from 0 to 75	1	from 40 to 75	2	from 75 to 75	6
from 0 to 100	0	from 40 to 100	0	from 75 to 100	1
from 0 to 120	0	from 40 to 120	0	from 75 to 120	0
Sum	1	Sum	2	Sum	8

B. *Frequency of equipment failures*

In Table (2) the number of defects in the study is shown.

Table 2: the number of defects in equipment

Categories	1387	1388	1389	1390	1391	1392
Ordinary	38	189	202	208	404	389
Important	25	220	280	467	450	602
The average	22	201	189	564	347	386
Important	1	3	2	6	4	2
Very important	0	0	0	0	1	0
unique	0	0	0	0	0	0

C. *The weight of each type of equipment*

The cost of production of each type of equipment downtime percentages imposed by the production of matrix M is shown.

$$M = \begin{bmatrix} 0\% & 0\% & 0\% & 0\% & 0\% \\ 0\% & 0\% & 0\% & 0\% & 0\% \\ 0\% & 0\% & 0\% & 15\% & 35\% \\ 0\% & 0\% & 20\% & 45\% & 65\% \\ 0\% & 15\% & 50\% & 75\% & 95\% \end{bmatrix}$$

D. *change between different states of the system*

State transition matrix in Table (3) is displayed.

Table 3: State-transition matrix

$P_{12} =$

	0	40	75	100	120
0	0%	0%	0%	0%	0%
40	0%	0%	14%	0%	100%
75	100%	100%	72%	100%	0%
100	0%	0%	14%	0%	0%
120	0%	0%	0%	0%	0%

E. *change production modes with different control*

$P^0_{75,100}=P(0)\times P(75,100)=4.61\% \times 100\%=4.61\%$

F. *Calculate the state value function*

The calculation according to equation (11) in state matrix valued function value is calculated with a discount rate.

$$j^{\pi}=\begin{bmatrix} (0.0) \\ (0.00069) \\ 0.22915 \\ 0.92205 \\ 1.87444 \end{bmatrix} \$$$

G. *Calculate the function value control*

Control value with a discount rate according to equation (11) in Table (4) is displayed.

Table 4: Calculate the value of control

Q(s,u)	u=0	u=1	u=2	u=3
s=0	0.00000	0.00000	0.00000	0.00000
s=1	0.08795	0.00876	0.00698	0.00068
s=2	0.24428	0.02433	0.01940	0.00189
s=3	0.77847	0.07755	0.06181	0.00601
s=4	1.57948	0.15734	0.12542	0.01220

Q(s,u)	u=4	u=5	u=6
s=0	0.00000	0.00000	0.00000
s=1	0.00000	0.00000	0.00000
s=2	0.00000	0.00000	0.00000
s=3	0.00000	0.00000	0.00000
s=4	0.00000	0.00000	0.00000

H. *selection of the optimal control policy*

According to (14), and calculated that the optimal control policy is selected.

So in general, for $\gamma = 1$, Q (s, u3) = 679193, third time horizon optimal control options and policy choices are counted.

$\pi^* (s, 3)=1$

VI. Conclusion

In this paper, a model was designed to choose the optimal control policy provided that the activities of maintenance and production decisions in the context of Markov decision process depend on each other, and the impact of lack of production volume is considered, when the equipment fails in the production support system.

The optimal control policy has been chosen and implemented using the calculations of the fifth section over a specific period. Then, sampling of equipment was done according to the studied statistical population to measure the overall system effectiveness where indicators of reliability, failure rate of equipment, mean time between two failures, and, at the end overall system effectiveness were calculated over a six-month period both before and after the implementation of the optimal policy. The aforementioned indicators have been shown in Table 5, and positive and acceptable effects could be seen there.

Table 5: comparing indicators before and after implementation of the optimal policy

Kind of Indicator	Before the run	After the run
Reliability	78.09%	89.99%
Failure rate	0.45%	0.01%
Mean time between failures	0.64 day	3.83 day
OSE	82.7%	87%

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