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Technical note:

Determining maintenance system requirements by viewpoint of availability and lean thinking: A MODM approach

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Abstract: Since lean concept has appeared many works have been done on decreasing or even eliminating of wastes such as extra inventory. Although these studies have not taken into account expected availability seriously. So in this paper, a Multiple Objective Decision Making (MODM) model has been developed by viewpoint of these subjects. They are decreasing wastes and increasing system availability. Wastes that have been minimized are maintenance requirements (i.e. labor, spare parts, reserve system and productive maintenance activities) and maintenance system availability that has been maximized is a function of maintenance requirements. A set of Society Anonym Iranian Production Automobile (SAIPA) data has been used to run the case study and test the effectiveness and the efficiency of the proposed model.

Keywords: *Availability; Goal programming; Lean; Multi-Objective Decision Making (MODM); Maintanance*

1. Introduction

Today maintenance has become a management issue, with its task as a contributor towards profit. This indicates the need for the maintenance operation to align with the business objectives and increase profit for the enterprise. As a contributor to current management techniques, lean thinking approaches are now more commonly used by Davies and Greenough (2003).. Timothy and Bruce Hawkins (2006) developed principles and Concepts of Lean Maintenance and Ricky Smith and Bruce Hawkins (2004) developed a Pre-Planning for Lean Maintenance.

The key question here is that is lean maintenance merely a subset of lean manufacturing? Is it a natural fall-in-behind spin off result of adopting lean manufacturing practices? Much to the chagrin of many manufacturing companies, whose attempts at implementing lean practices have failed ignominiously, lean maintenance is neither a subset nor a spin off of lean manufacturing. It is instead a prerequisite for success as a lean manufacturer (Smith, 2004). Lean maintenance, coined in the last decade of the twentieth century, seeks to eliminate all forms of waste such as extra inventory in the maintenance process (smith and Hawkins, 2004; McCarthy and Rich, 2004).

Lack of synchronization in the production system, along with inherent uncertainty in material supply and demand, makes holding inventory a necessity, yet keeping a high level of inventory is a costly exercise. It is thus no surprise to find that many managers generally regard inventories as necessary evils. Representing a significant portion of a company's assets, inventories are used to serve a variety of functions, chief among which are: (1) coordinating operations, (2) smoothing production, (3) achieving economies of scale and (4) improving customer service.

Since appearance of lean concept many researchers have studied decreasing or even eliminating inventories. Although these studies have not taken into account seriously expected availability (Jeremy, 1965; Smart, 2003), and they have been in a limited field (in other words the aim of this studies is maximum level of availability and minimum level of one item for example labor or spare parts).

Ignacio Castillo proposed an alternative multidimensional paradigm, where labor minimization and service level maximization are considered simultaneously, together with other, complementary criteria (Castillo *et al.*, 2009). So in this paper, we developed a MODM model for determining optimum level of maintenance requirements (such as labor, spare part, inspection, service and etc.). This model not only eliminates wastes in maintenance system but also satisfies maintenance availability.

In this model, we have two conflicting objectives; these objectives are to minimize wastes and increase maintenance system availability in such a way that optimum level of maintenance requirements (e.g. labor, spare parts, reserve system and productive maintenance activities) and

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expected maintenance availability are satisfied. In order to solve this MODM model we used goal programming approach. Goal programming, proposed by Charnes (Rachna Shah and Ward , 2003), is a widely used approach within the multi-criteria decision-making (MCDM). It attempts to combine the logic of optimization in mathematical programming with the decision maker's desire to satisfy several goals.

The organization of this paper is as follows. In section 2, the MODM model is formulated to determine minimum level of maintenance requirements.

The use of this model is illustrated through a problem of SIPA Company as a case study in Section 3. In section 4, we discuss some aspects of sensitivity analysis of the optimal solution based on the GP approach. Our conclusions are given in the final section.

2. Model formulation

In this section, a MODM model is formulated to determine minimum level of maintenance requirements and also satisfy maintenance availability level. The developed model in this section is constructed by two conflicting objectives minimizing maintenance requirements (i.e. labor, spare parts, reserve system, productive maintenance activities) and maximizing availability.

2.1. Notations

2.1.1. Model parameters

$MTTR_i$: Mean Time to Repair machinery i,

Ins T_i: Mean inspection time of machinery i,

Se T_i: Mean service time of machinery i,

TeT_i: Mean test & Adjustment time of machinery i,

Ins E_i: Mean inspection expenditure of machinery i,

Se E_i: Mean service expenditure of machinery i,

Spa H $Cost_{ij}$: Mean j type Spare part holding cost for machinery i,

Re H $Cost_i$: Mean reserve system holding cost for machinery i,

Re $Cost_i$: Mean reserve system price of machinery i,

M mh_i: The maximum man hour available for machinery i,

M Spaij: The maximum j type Spare part available for machinery i,

M Rei: The maximum reserve system available for machinery i,

M Insi: The maximum inspection available for machinery i,

M Sei : The maximum service available for machinery i,

M Tei : The maximum test & Adjustment available for machinery i,

M FRai: The maximum failure rate of machinery i,

Wf: Weight of goal f,

Ins F: Influence percent of inspection in failure rate (Inspection factor),

Se F: Influence percent of service in failure rate (Service factor),

Te F: Influence percent of test & Adjustment in failure rate (Test & adjust factor),

H Cost: The holding cost limitation,

Avail Goal: Desired level of 'availability goal' to be achieved,

PM Goal: Desired level of 'productive maintenance cost goal' to be achieved,

Re Goal: Desired level of 'reserve system cost goal' to be achieved.

2.1.2. Decision variables

mhi: The man hours for machinery i,

Spaij: The number of j type spare parts for machinery i,

Rei: The number of reserve systems for machinery i,

Insi: The number of inspections for machinery i,

Sei: The number of Services for machinery i,

Tei: The number of testes & Adjustments for machinery i,

F Rai: The failure rate for machinery i.

2.2. MODM model Objectives

$$max\left\{1-\prod_{i=1}^{n}(1-\left\{\begin{array}{l}\frac{A*mh(i)}{M\,mh(i)}+\\ +\frac{E*Te(i)}{M\,Te(i)}+\end{array}\right.\right.$$

$$\left.\left.\begin{array}{l}\frac{B*Re(i)}{M\,Re(i)}+\frac{C*Ins(i)}{M\,Ins(i)}+\frac{D*Se(i)}{M\,Se(i)}\\ +\sum_{j=1}^{k}\left(\frac{G*Spa(i,j)}{M\,Spa(i,j)}\right)\Big|k-\frac{F*Ra(i)}{M\,Ra(i)}\end{array}\right\}\right\}$$

$$/(A+B+C+D+E+G-f)) \quad (1)$$

$$min\left\{\sum_{i=1}^{n}(Ins\,E(i)*Ins(i)+Se\,E(i)\right.$$
$$\left.*Se(i)+Te\,E(i)*Te(i))\right\} \quad (2)$$

$$min\left\{\sum_{i=1}^{n}(Re(i)*Re\,cost(i))\right\} \quad (3)$$

Subject to:

$$\sum_{j=1}^{k}\left(\sum_{i=1}^{n}Spa(i,j)*Spa\,H\,Cost(j)\right)$$
$$+\sum_{i=1}^{n}Re(i)*Re\,H\,Cost(i)) \le H\,Cost \quad (4)$$

$$mh(i) \ge (Ins(in)*Ins\;T\;(i)+Se(i)$$
$$*\;Se\;T\;(i)+Te\;(i)*Te\;T\;(i)+Ra\;(i)$$
$$*\;MITR\;(i)) \quad (5)$$

$$FRa(i) \ge MFRa\;(i)\text{-}MFRa(i)$$
$$((Ins\;(i))/(M\;\;Ins(i)\;\;)*Ins\;F+\frac{Sr\;(i)}{M\;\;Se\;(i)}$$
$$*Se\;F+\frac{Te\;(i)}{M\;\;Te\;(i)}*Te\;F) \quad (6)$$

$$0.5 \le \frac{mh(i)}{M\;mh(i)} \le 1 \quad 0.5 \le \frac{Re(i)}{M\;Re(i)} \le 1 \quad (7)$$
$$0.5 \le \frac{Ins(i)}{M\;Ins(i)} \le 1 \quad 0.5 \le \frac{Se(i)}{M\;Se(i)} \le 1$$
$$0.5 \le \frac{Te(i)}{M\;Te(i)} \le 1 \quad 0.5 \le \frac{Spa(i,j)}{M\;Spa(i,j)} \le 1$$
$$i=1,...,n \qquad j=1,...,k$$

For solving this MODM model, we use goal programming approach; the goal programming model is presented in Section 2.3.

2.3. Goal programming model

Deviation variables of this model are as follows:

d^{+}_{Avail} Deviation of overachievement of Availability goal

d^{-}_{Avail} Deviation of underachievement of Availability goal

d^{+}_{PM} Deviation of overachievement of productive maintenance cost goal

d^{-}_{PM} Deviation of underachievement of productive maintenance cost goal

d^{+}_{Re} Deviation of overachievement of reserve system cost goal

d^{-}_{Re} Deviation of underachievement of reserve system cost goal

The goal programming model is as follow:

$$Min\,z = w_{Avail}d^{-}_{Avail} + w_{PM}d^{+}_{PM} + w_{Re}d^{+}_{Re} \quad (8)$$

$$1-\prod_{i=1}^{n}(1-\left\{\begin{array}{l}\frac{A*mh(i)}{Mmh(i)}+\frac{B*Re(i)}{M\;Re(i)}+\\ +\frac{E*Te(i)}{MTe(i)}+\end{array}\right.$$

$$\left.\begin{array}{l}\frac{C*Ins(i)}{Mns(i)}+\frac{D*Se(i)}{MSe(i)}\\ \sum_{j=1}^{k}(\frac{G*Spa(i,j)}{MSpa(i,j)}\Big|k-\frac{F*Ra(i)}{MRa(i)}\end{array}\right\}/$$

$$(A+B+C+D+E+G-f\;))+d^{-}_{Aval}+$$

$$d^{+}_{Aval} = Aval\,Goal \quad (9)$$

$$\sum_{i=1}^{n}(Ins\ E(i)*Ins(i)+Se\ E(i)*Se(i) \quad (10)$$
$$+ Te\ E(i)*Te(i)) - d_{PM}^{+} + d_{PM}^{-} = PM\ Goal$$

$$\sum_{i=1}^{n}(Re(i)*ReCost(i)) - d_{Re}^{+} + d_{Re}^{-} = ReGoal \quad (11)$$

Subject to:

$$\sum_{j=1}^{k}(\sum_{i=1}^{n} Spa(i,j)*SpaHCost(j))$$
$$+\sum_{i=1}^{n} Re(i)*Re\ HCost(i) \le HCost \quad (12)$$

$$mh(i) \ge (Ins(i)*InsT(i)+Se(i)*SeT(i)$$
$$+Te(i)*TeT(i)+Ra(i)*MTTR(i)) \quad (13)$$

$$Ra(i) \ge M\ Ra(i) - M\ Ra(i)(\frac{Ins(i)}{M\ Ins(i)} *$$
$$InsF + \frac{Se(i)}{M\ Se(i)} * SeF + \frac{Te(i)}{M\ Te(i)} * TeF \quad (14)$$

$$0.5 \le \frac{mh(i)}{M\ mh(i)} \le 1 \quad 0.5 \le \frac{Re(i)}{M\ Re(i)} \le 1 \quad (15)$$
$$0.5 \le \frac{Ins(i)}{M\ Ins(i)} \le 1 \quad 0.5 \le \frac{Se(i)}{M\ Se(i)} \le 1$$
$$0.5 \le \frac{Te(i)}{M\ Te(i)} \le 1 \quad 0.5 \le \frac{Spa(i)}{M\ Spa(i)} \le 1$$
$$i = 1,...,n \qquad j = 1,...,k$$

Goal constraints and objective function are described in section 2.3.1 and constraints are described in section

2.3.1. Objective function and Goal constraints

The aim of this model is to find optimal levels of maintenance requirements that satisfy requirements availability. To achieve this aim, three goals are considered in this model.

The objective function of this model is formulated in expression (8).

Goal 1: Availability goal

$$\frac{A*mh(i)}{Mmh(i)} + \frac{B*Re(i)}{M\ Re(i)} + \frac{C*Ins(i)}{MIns}$$
$$+ \frac{D*Se(i)}{MSe(i)} + \frac{E*Te(i)}{MTe(i)}$$
$$+ \sum_{j=1}^{k} \left(\frac{G*Spa(i,j)}{MSpa(i,j)} \right) / k - \frac{F*Ra(i)}{M\ FRa(i)}$$
$$= Avail(i) \quad (16)$$

$$Avails(i) = Avail(i)/(A+B+C+D+E+G-F)$$
$$i = 1,...,N \quad (17)$$

$$1 - \prod_{i=1}^{n}(1 - Avails(i)) + d_{Avail}^{-} - d_{Avail}^{+}$$
$$= AvailGoal \quad (18)$$

Availability goal (i.e. expression (9)) is shown in three parts (i.e. expressions (16), (17) and (18)) to describe it better; Expression (16) is requirements availability of any machinery which is a function of man hour, reserve system inventory, spare parts inventory, inspection, service, test and adjustment. Each of these items (i.e. man hour, reserve system inventory and etc) has a different influence on availability. Hence A، B،C ،D ،E ،F and G parameters are introduced to show influence percent of each requirement on availability; For example influence percent of labor (mh) is higher than Inspection. Expression (17) transforms availability scale from interval [0,A+B+C+D+E+G-F] into interval [0,1]. The left side of expression (18) is availability of all machineries (i=1,…,n). This expression assumes that requirements of any machinery is useable in other machineries (in other words machines have parallel structure from requirements viewpoint because in parallel structure any machinery can be replaced by the others). Thus the total availability will be $(1 - \prod_{i=1}^{n}(1 - Avails(i)))$ according to the parallel structure. Otherwise if machineries have series structure from requirements viewpoint (i.e. requirements of any machineries is not useable in other machineries), $(\prod_{i=1}^{n} Avails(i))$ can be replaced by $(1 - \prod_{i=1}^{n}(1 - Avails(i)))$.

Goal 2: Productive maintenance cost goal

$$\sum_{i=1}^{n}(Ins\ E(i)* Ins(i) + Se\ E(i)* Se(i) +$$

$$Te\ E(i)* Te(i)) - d^{+}_{PM} + d^{-}_{PM} = PM\ Goal \quad (10)$$

Productive maintenance cost consists of inspection, service and test and adjustment costs. The first component in expression (10) (i.e. $InsE(i)*Ins(i)$) is total machinery inspection cost.

The second component (i.e. $SeE(i)*Se(i)$) is total machinery service cost. The third component (i.e. $TeE(i)*Te(i)$) is total machinery test & adjustment cost.

Goal 3: Reserve system cost goal

$$\sum_{i=1}^{n}(Re(i)* Re\,Cost(i)) - d^{+}_{Re} + d^{-}_{Re}$$
$$= Re\ Goal \quad (11)$$

Reserve system cost for all machineries (i= 1,…,n) is expressed in expression (11).

2.3.2. Constraints

The objective function formulated in Section 2.3.1 is restricted by four sets of constraints. These constraints are holding cost constraint, available man hour for maintenance activities (i.e. inspection, test and adjustments, service and repair machineries) constraint, the relationship between failure rate and productive maintenance activities, lower and upper level of decision variables.

Constraint 1: Holding cost constraint

$$\sum_{j=1}^{k}(\sum_{i=1}^{n} Spa(i , j)* SpaHCost(j))$$
$$+\sum_{i=1}^{n} Re(i)* Re\,HCost(i) \le HCost \quad (12)$$

Constraint (12) limits the total holding cost. The holding costs consist of spare parts holding cost and reserve systems holding cost.

Constraint 2: Available man hour for maintenance activities

$$mh(i) \ge (Ins(i)* InsT(i) + Se(i)* SeT(i)$$
$$+ Te(i)* TeT(i) + F\,Ra(i)* MTTR(i)) \quad (13)$$

Right side of expression (13) is the total time for maintenance activities. These times consist of two parts. First part is productive maintenance time (i.e. $Ins(i)*InsT(i)+Se(i)*SeT(i)+Te(i)*TeT(i)$) and the second one (i.e. $F\,Ra(i)* MTTR(i)$) is emergency maintenance time. This constraint ensures that the available man hour for any machinery is greater than / equal to the total time assigned for maintenance activities.

Constraint 3: The relationship between failure rate and PM activities

$$F\,Ra(i) \ge M\ F\,Ra(i) - M\ FRa(i)(\frac{Ins(i)}{M\ Ins(i)}$$
$$* InsF + \frac{Se(i)}{M\ Se(i)} * SeF + \frac{Te(i)}{M\,Te(i)} * TeF \quad (14)$$

Expression (14) shows reverse relationship among failure rate and productive maintenance activities (inspection, service and test & adjustment). Ins F, Se F and Te F parameters are influence percent of each productive maintenance activities on failure rate.

Constraint 4: Lower and upper level of decision variables

All constraints in expression (15) show lower and upper limit of maintenance requirements. Upper limit of all of them is 1 according to explanation 2.3.1 and lower limits depend on maintenance system and management policy.

$$0.5 \le \frac{mh(i)}{M\ mh(i)} \le 1 \quad 0.5 \le \frac{Re(i)}{M\ Re(i)} \le 1 \quad (15)$$

$$0.5 \le \frac{Ins(i)}{M\ Ins(i)} \le 1 \quad 0.5 \le \frac{Se(i)}{M\ Se(i)} \le 1$$

$$0.5 \le \frac{Te(i)}{M\ Te(i)} \le 1 \quad 0.5 \le \frac{Spa(i)}{M\ Spa(i)} \le 1$$

$$i = 1,\dots,n \qquad j = 1,\dots,k$$

3. Implementing the model

In this section, flexibility of the proposed MODM model in determining maintenance system requirements is illustrated through a data set provided by the Rio robot part of SAIPA Corporation in Iran. A 1-year planning horizon (from 21 March 2006 to 20 March 2007) is supposed. Because of little importance of reserve systems in the applied example (i.e Rio robot part of SAIPA) the decision variable Re is not included in the case study model. The goal constraints and model constraints have was described in sections 2.3.1 and 2.3.2.

The cost data were approximated by consulting with company's management and experts since there were no exact data. In order to solve the optimization problem LINGO (version 8, license usage of commercial) software was used by a Dell computer with CPU 2 GHz and 1 GB of ram.

3.1. Identifying characteristics of SAIPA Corporation

SAIPA Corporation is one of the major industries in Iran. It has three main sections for common products. These sections are painting, automobile body and assemble. Except of these sections there is a central part for Rio products. As mentioned above this central part itself has three main sections. This model could be applied in any place engaging in maintenance problem.

3.2. Model inputs

Robot part of Rio has 22 machineries, $i = 1,\ldots,22$, each machinery has 11 different types of spare parts, $j = 1,\ldots,11$. The list of all reported faults in the planning horizon is given in Table 1. From this table, MTTR parameter will be computed by equation (16) and is given in Table 2.

MTTR (i) = (Repair Time for machinery i / Fault reported number for machinery i (16)

Table 2 shows inspection, service and test and adjustments expenditure as well as their accomplishment mean times. It also consist maximum available levels of mh and FRa for all machineries.

According to this table, inspection, service and test & adjustments were done twelve times a year. Maximum consumption factors of spare parts for all machineries are given in Table 3.

In the goal programming model formulation, the aspiration level for each goal has to be defined.

After consulting the company's management, the target value of 'Productive Maintenance cost goal' PM Goal is 7777.78 \$; the target value of 'Availability goal' Avail Goal is 0.8; the spare parts holding cost is 555.56 \$; Se F, Ins F, Te F respectively are 0.4, 0.3, 0.3; the value of A, C, D, E, F, G parameters (i.e. percent effect of each requirements in availability) respectively are 0.3, 0.1, 0.1, 0.1, 0.2, 0.2; weight of all deviation variables are 1.

3.2.Model outputs

Obtained value of 'objective function' is 0; the rest of results are shown in Tables 1, 2 and 3. Values of the deviation variables are given in Table 1; mh, Ins, Se and test and adjustment Optimum values for all machineries are provided in Table 2 and spare parts optimum values for all machineries are given in Table 3.

In order to compare assigned requirements to the machineries (i.e. man hour, spare parts, inspection, service and test & adjustment) with model outputs, Figures 1 through 5 are given.

Figure 1, shows that model outputs for man hour
Figure 1, shows that model outputs for man hour
approximately are the same as available maximum level; it means that man hour assignment in SIPA Corporation is optimum while Figures 2, 3 and 4 show that inspection, service and test and adjustment activities are not necessary for twelve times a year for all the machineries; these activities are just essential for machineries that have high failure rate and much mean time to repair.

Finally according to figure 5, approximately 50 percent of spare part inventory is sufficient for achieving availability goal and the rest are remained as MODA in system.

By results of this model, we ensure that them not only are optimum level of maintenance requirements (such as man hour, inspection, service and etc.) but also satisfy availability goal and other goals.

maximum and optimum values figures for maintenance requirements

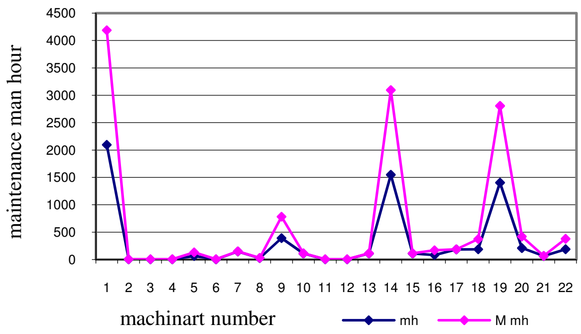

Figure 1: Max and optimum man hour.

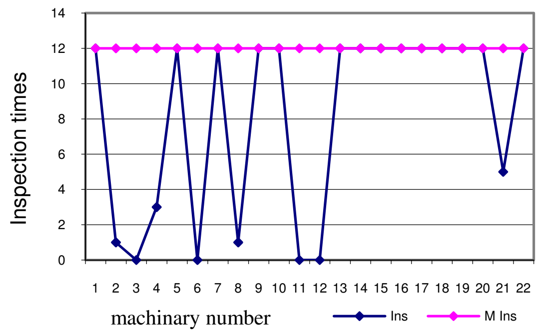

Figure 2: Max and optimum inspection.

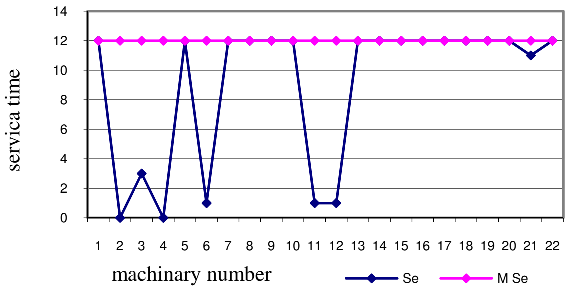

Figure 3: Max and optimum service.

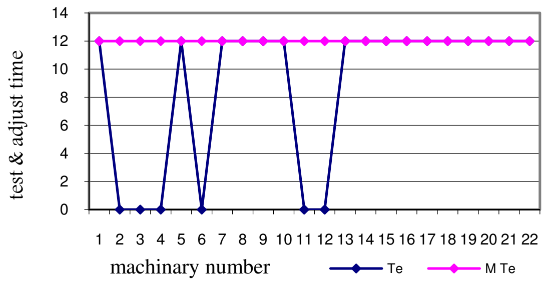

Figure 4: Max and optimum test and adjust.

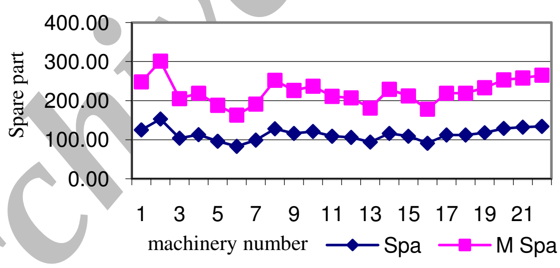

Figure 5: Max and optimum spare part.

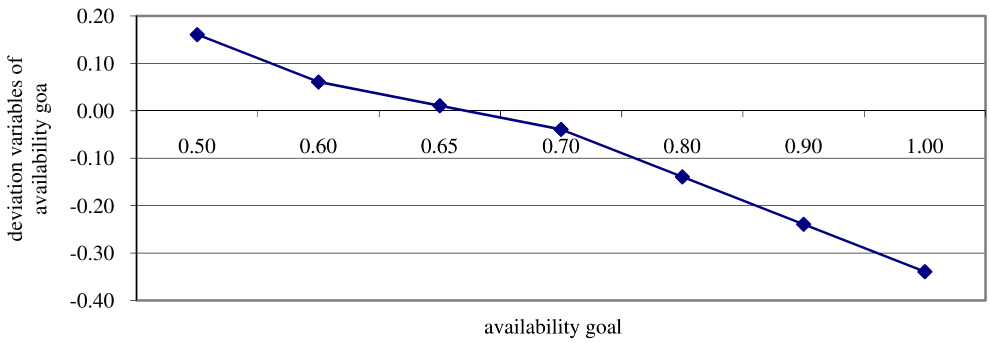

Figure 6: deviation variables changes versus availability goal.

Table 1: All faults list reported at horizon planning.

Date of fault reported	Machinery number (i)	Machinery name	Serviceman numbers	Repair Time (minute)
2006/06/07	1	Welding robot	2	20
2006/06/20	1	Welding robot	1	4
2006/07/09	1	Welding robot	1	5
2006/06/28	5	Welding robot	1	5
2006/06/19	5	Welding robot	3	10
2006/11/11	7	Welding robot	2	5
2006/11/11	7	Welding robot	2	10
2006/01/17	8	Welding robot	1	3
2006/05/17	9	Welding robot	5	75
2006/08/13	9	Welding robot	1	9
2006/05/24	10	Welding robot	1	6
2006/06/06	10	Welding robot	2	6
2006/08/01	13	Welding robot	1	12
2006/06/01	14	Welding robot	3	315
2006/06/03	14	Welding robot	2	40
2006/07/18	14	Welding robot	2	10
2006/08/06	14	Welding robot	3	18
2006/05/15	15	Welding robot	3	7
2006/06/28	15	Welding robot	2	5
2006/08/06	16	Welding robot	1	5
2007/02/14	16	Welding robot	3	12
2006/08/24	17	Welding robot	1	5
2006/08/29	17	Welding robot	3	14
2006/05/18	18	Welding robot	2	40
2006/05/03	19	Welding robot	2	300
2006/05/22	19	Welding robot	3	15
2006/10/08	19	Welding robot	3	11
2006/10/08	19	Welding robot	2	5
2006/12/16	19	Welding robot	1	5
2006/08/03	20	Welding robot	1	10
2006/08/06	20	Welding robot	1	8
2006/08/23	20	Welding robot	1	10
2006/09/26	20	Welding robot	1	13
2006/10/10	20	Welding robot	2	5
2006/06/22	21	Welding robot	2	10
2006/07/25	21	Welding robot	1	8
2006/08/02	21	Welding robot	1	7
2006/08/06	21	Welding robot	1	10
2006/08/13	21	Welding robot	1	8
2006/08/20	21	Welding robot	1	10
2006/09/28	21	Welding robot	1	5
2006/10/05	21	Welding robot	3	5
2006/10/05	21	Welding robot	3	7
2006/11/12	21	Welding robot	1	5
2006/11/23	21	Welding robot	2	3
2007/01/15	21	Welding robot	1	5
2006/06/20	22	Welding robot	1	10
2006/09/04	22	Welding robot	1	12
2006/09/21	22	Welding robot	1	10
2006/10/04	22	Welding robot	2	7
2006/10/07	22	Welding robot	3	11

Table 2: Expenditure, time and maximum levels of model variables.

machinery	Model parameters											
	Ins E($)	Se E($)	Te E ($)	Ins T (hour)	Se T (hour)	Te T (hour)	M mh	M Ins	M Se	M Te	MTTR	MF Ra
1	2.8	10	2.8	2	2	1	4187	12	12	12	30	30
2	5.5	6.7	5.5	2	2	2	5	12	12	12	1	1
3	11.1	10	11.1	2	1	2	5	12	12	12	1	1
4	5.5	6.7	5.5	1	2	2	5	12	12	12	1	1
5	2.8	3.3	2.8	1	1	1	130	12	12	12	7	4
6	2.8	6.7	2.8	2	2	1	5	12	12	12	1	1
7	5.5	6.7	5.5	2	2	2	149	12	12	12	8	4
8	11.1	10	11.1	1	1	1	28	12	12	12	3	2
9	5.5	6.7	5.5	1	2	2	782	12	12	12	42	4
10	2.8	3.3	2.8	2	1	1	112	12	12	12	6	4
11	2.8	6.7	2.8	1	2	1	5	12	12	12	1	1
12	5.5	6.7	5.5	2	2	2	5	12	12	12	1	1
13	11.1	10	11.1	1	1	1	112	12	12	12	12	2
14	5.5	6.7	5.5	1	2	1	3094	12	12	12	95	7
15	2.8	3.3	2.8	2	1	1	112	12	12	12	6	4
16	2.8	6.7	2.8	1	2	1	167	12	12	12	9	4
17	5.5	6.7	5.5	2	2	2	186	12	12	12	10	4
18	11.1	10	11.1	2	1	1	372	12	12	12	40	2
19	11.1	10	11.1	2	2	1	2806	12	12	12	67	9
20	8.3	10	8.9	1	3	1	419	12	12	12	10	9
21	11.1	13.3	11.1	3	2	2	65	12	12	12	7	2
22	11.1	16.7	11.1	2	3	2	377	12	12	12	9	9

Table 3: maximum use factors of spare parts for all machineries.

Machinery	Type of Spare parts										
	bolt	key	O-ring	pin	Cable & Scket	battery	cutter	fuse	cable	Cable for robot	Grease nipple
1	100	2	11	80	17	4	4	4	10	2	14
2	130	4	7	120	20	1	1	1	4	1	12
3	50	6	9	100	15	2	2	2	6	3	10
4	80	7	10	90	15	1	1	1	7	2	5
5	70	6	13	60	15	4	3	4	4	4	5
6	70	1	14	50	10	2	3	1	2	2	8
7	100	1	14	40	13	1	3	2	9	1	7
8	100	1	15	90	14	4	4	4	8	3	9
9	79	1	18	80	15	1	2	1	10	4	15
10	90	2	19	80	15	4	4	1	6	1	15
11	80	3	10	80	15	3	4	1	5	1	9
12	80	1	13	70	16	4	4	2	7	1	9
13	80	3	13	40	20	3	1	1	7	3	10
14	110	1	14	50	20	2	4	4	8	1	15
15	120	1	17	40	13	2	1	1	5	2	10
16	89	3	18	30	14	4	2	4	3	1	10
17	90	2	18	70	13	1	2	3	8	3	9
18	90	2	19	70	15	3	3	4	4	1	8
19	100	2	10	80	15	4	4	3	6	1	8
20	110	3	20	80	16	2	1	3	9	2	7
21	120	2	10	90	13	2	1	1	9	1	9
22	120	4	16	90	12	1	3	2	10	1	6
Spa HCost ($)	0.11	0.22	0.17	0.11	0.17	0.22	0.22	0.22	0.22	0.22	0.17

Table 4: model sensitivity analysis.

Objective Coefficient Ranges			
Variable	Current Coefficient	Allowable Increase	Allowable Decrease
d^{+}_{Avail}	0	INFINITY	INFINITY
d^{+}_{PM}	1	INFINITY	INFINITY
d^{-}_{Avail}	1	27.2	27.2
d^{-}_{PM}	0	INFINITY	INFINITY
Right Hand Side Ranges			
Constraint number	Current RHS($)	Allowable Increase	Allowable Decrease($)
(10)	7777.78	0	0
(12)	555.56	0	0

4. Model sensitivity analysis

Sensitivity analysis for sensitive parameters (i.e.coefficient of deviation variables in objective function and right hand side of expressions (10) and (12)) is shown in Table 7. In addition to sensitivity analyses which are given in Table 4, Fig. 6 shows deviation variable change versus availability goal.

According to Fig. 6 in a point between interval [0.65, 0.7], value of deviations variable are zero; this indicates that availability goal was not deviated in this point.

5. Conclusion

In this paper, A MODM model was proposed to deal with the determination of maintenance requirements problem in SIPA Company in Iran. This model had three objectives. They were availability, productive maintenance cost and reserve system cost. One of the objectives was to minimize wastes and the other one was to maximize or satisfy expected availability which is in conflict with the former objective. Hence, we proposed goal programming model for decision-making aid, a real case in an existing Iranian automobile manufacturing company was studied and some useful findings were observed. Output of the proposed model was optimum level of maintenance require-ments which satisfies expected availability.

Lean maintenance seeks to eliminate all forms of waste such as extra inventory in the maintenance process without taking into account seriously availability. Thus a MODM model proposed to consider this two subjects simultaneously (i.e. eliminating or decreasing wastes and considering availability). Nearly three examples were run and the achieved results illustrate effectiveness and efficiency of the proposed model.

However, there is still much room for improvement and investigation for this model with regard to its application to real-world situations. Real data from other manufacturing companies should be used to validate the model.

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