LINEAR MODEL OF MAINTENANCE PLANNING BASED ON FAILURE TREND OF EQUIPMENTS IN EXCEL

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Abstract
Database of failures and maintenance of equipments offers not only their statistical analysis but also time schedule of maintenance that respects registered failures in latest periods. In this paper, we are trying to define this problem as a task of linear programming which is soluble by Solver, supplement of Excel MS Office. We assume that the effect of maintenance is expressed with a delay and it is dependent on the development of trend of failure rate in the latest two periods. The proposed solution is demonstrated on real examples of failures of machines in 2010-2013 periods.

Key words
Maintenance, Excel, supplement Solver

Introduction

The availability of Excel [1] with its tools designed for a relatively easy selection of data from a failure table of machines led us to select the following three types of data (YEAR, MONTH, LOSS). From 324 selected entries there were 236 with label LOSS= fault and 88 with label LOSS= maintenance.

FAILURES	1	2	3	4	5	6	7	8	9	10	11	12
2010	2	1	3	3	8	4	1	2	3	8	6	3
2011	16	7	9	7	3	12	4	4	4	12	6	3
2012	7	6	4	10	2	5	6	13	7	7	5	0
2013	9	3	3	11	7							

Tab. 1 The numbers of failures registered during 41 months

Tab.1 corresponds to Fig.1, where there is no significant seasonal character of trend frequency failures.

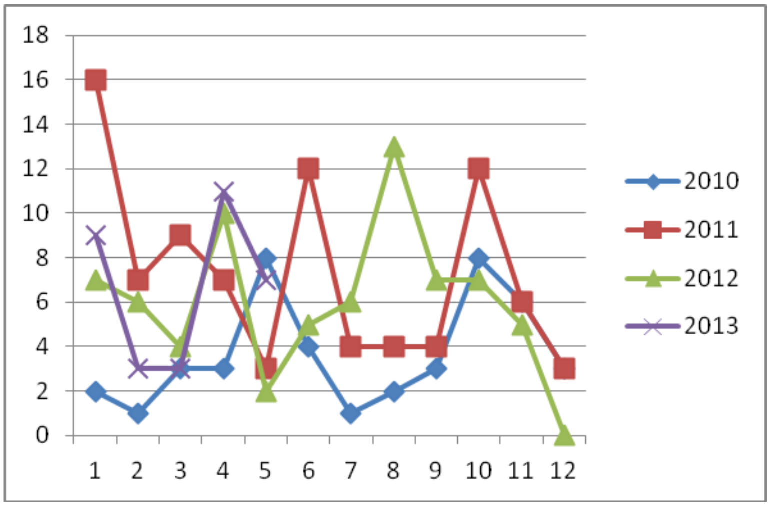


Fig.1 Trend of frequency failures during 41 months

Similar situation occurs with the numbers of the identified maintenance cases in the given period.

MAINTENANCE	1	2	3	4	5	6	7	8	9	10	11	12
2010	3	4	6	2	3	2	0	1	1	5	2	2
2011	5	5	2	5	1	2	0	0	0	1	2	2
2012	1	0	6	3	2	1	1	3	2	5	1	1
2013	0	1	1	3	1							

Tab.2 Numbers of maintenance registered in the period of 41 months

In Tab.2 corresponding Fig.2, we can observe seasonal character of maintenance development. If we combine the graphs to one, we will get frequency development of the registered failures and maintenances in Fig.3

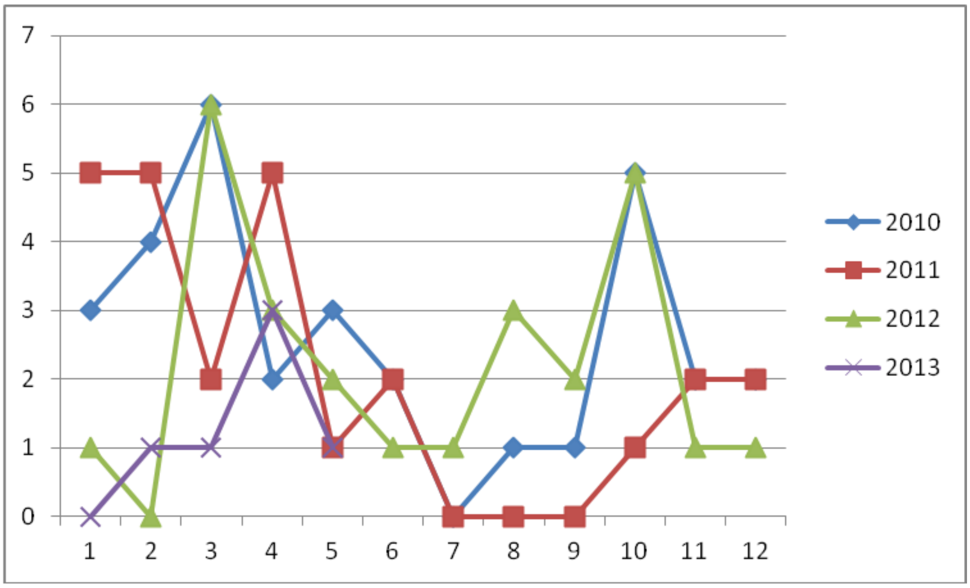


Fig.2 Trend of frequency maintenance during 41 months

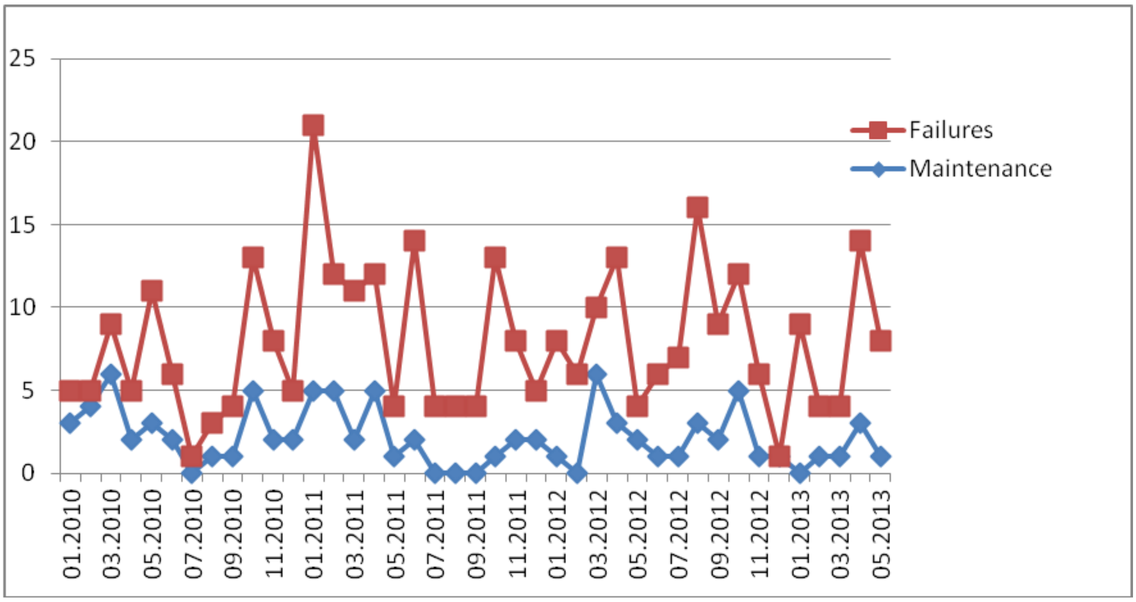


Fig.3 Development of the number of failures and maintenance during 41 months

We can see in Fig. 3 that number of maintenance in each month is trying to copy the proportional numbers of failures. This corresponds to the rule: „If we register increased number of failures in any month, we will conduct increased number of maintenance works too.“ From experience we know that the effect of maintenance is normally expressed with delay in other periods and by reduced number of failures. Futhermore, we will show how to schedule number of maintenance in each month so that their effect was the greatest according to current total number of maintenance.

2. Linear programming model

Let *pi* failures be identified during *n* periods and *ui* maintenance *(i=1,2,…,n)* implemented. We are looking for such plan of maintenance schedules *xi*, where the coefficient of efficiency of the maintenance schedules *y* is maximal.

Integers *xi* are variables in this model that indicates the number of planned maintenance schedules in the *i*-th period. Coefficient of maintenance efficiency *y* indicates the percentage of the number of failures that must be covered by maintenance work.

We get the following linear programming task:

(1) $y \rightarrow max$
(2) $\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} u_i = 0$
(3) $(p_i - p_{i-1})y \leq x_{i+1}$ i=2,3,…,n
(4) $x_i - p_i y \geq 0$ i=1,2,…,n
(5) $x_i \geq 0, whole$ i=1,2,..,n
(6) $0 \leq y \leq 1$

The objective function (1) maximizes coefficient of the maintenance efficiency. Limitation (2) requires the same total number of maintenance schedules as it was set in the monitored the period. Inequality (3) ensures the effectiveness of maintenance growth in the following period of positive growth of number of failures in last periods. Inequality (4) estimates a minimum efficiency of maintenance. Integers of number of searched maintenance is guaranteed by the condition (5). Condition (6) limits for the effectiveness of maintenance from 0% to 100%.

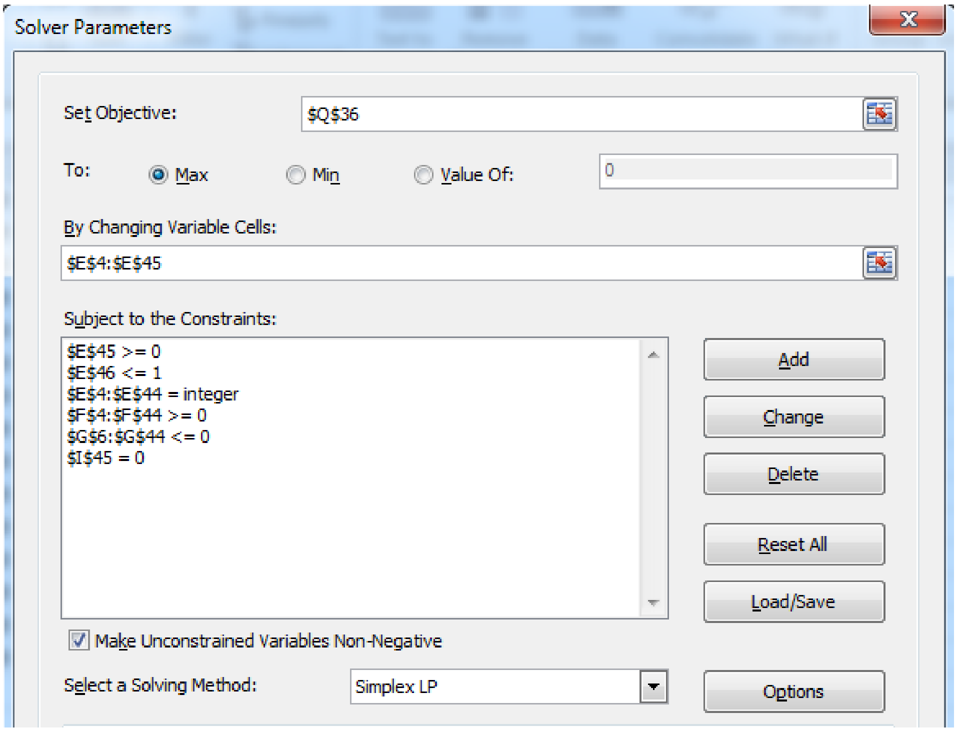
3. Illustrative example in Excel

We can use supplement Solver in menu Data [2] for solution of this model. At first we need to prepare appropriate formulas in the cells. We have the part of Excel table with input data in columns C and D on Fig 4. There will be calculated searched solution into the selected red column.

	A	B	C	D	E
1					(5)
2		_i	p_i	u_i	x_i
3	month/year	Periods	Failures	Maintenances	Maintenances plan
4	01.2010	1	2	3	
5	02.2010	2	1	4	
6	03.2010	3	3	6	
7	04.2010	4	3	2	
8	05.2010	5	8	3	
9	06.2010	6	4	2	
10	07.2010	7	1	0	
11	08.2010	8	2	1	
12	09.2010	9	3	1	
13	10.2010	10	8	5	
14	11.2010	11	6	2	
15	12.2010	12	3	2	
16	01.2011	13	16	5	
17	02.2011	14	7	5	
18	03.2011	15	9	2	
19	04.2011	16	7	5	
20	05.2011	17	3	1	
21	06.2011	18	12	2	
22	07.2011	19	4	0	

Fig.4 Input data on number of registered failures and maintenance

Critical cells are formulas [3] for right sides of constraints (3) and (4) In cells G6 = E45 * (C5-C4) - E6 and E4 - F4 = C4 * E45, which are necessary to be copied accordingly. Other constraints of model are defined similarly. Now we can run Solver and define the required parameters in it. As it can be seen it is enough to fill table Tab 3. and press option Solve.



Tab.3 Solving the model using Solver

We have solution in the column E of table on Fig 5. Effectiveness of calculated maintenance plan is only 25%. This means that only 25% of growth trend of failures number was effectively used to calculate the number of maintenance. Better result would have been received by higher number of planned maintenance.

22	07.2011	19	4	0	3	2.000	-0.750
23	08.2011	20	4	0	1	0.000	-3.000
24	09.2011	21	4	0	1	0.000	-1.000
25	10.2011	22	12	1	3	0.000	-3.000
26	11.2011	23	6	2	2	0.500	0.000
27	12.2011	24	3	2	1	0.250	-2.500
28	01.2012	25	7	1	2	0.250	-2.750
29	02.2012	26	6	0	2	0.500	-1.000
30	03.2012	27	4	6	1	0.000	-1.250
31	04.2012	28	10	3	3	0.500	-3.500
32	05.2012	29	2	2	2	1.500	-0.500
33	06.2012	30	5	1	2	0.750	-4.000
34	07.2012	31	6	1	2	0.500	-1.250
35	08.2012	32	13	3	4	0.750	-3.750
36	09.2012	33	7	2	2	0.250	-0.250
37	10.2012	34	7	5	2	0.250	-3.500
38	11.2012	35	5	1	2	0.750	-2.000
39	12.2012	36	0	1	0	0.000	-0.500
40	01.2013	37	9	0	3	0.750	-4.250
41	02.2013	38	3	1	3	2.250	-0.750
42	03.2013	39	3	1	1	0.250	-2.500
43	04.2013	40	11	3	3	0.250	-3.000
44	05.2013	41	7	1	8	6.250	-6.000
45				y	0.25	(1)	

Fig.5 Solving of linear programming task

We have the overall plan of maintenances in Fig.6. We can see that the planned number of maintenance, that we calculated by our linear model, follows the trend of failures more accurately in last periods.

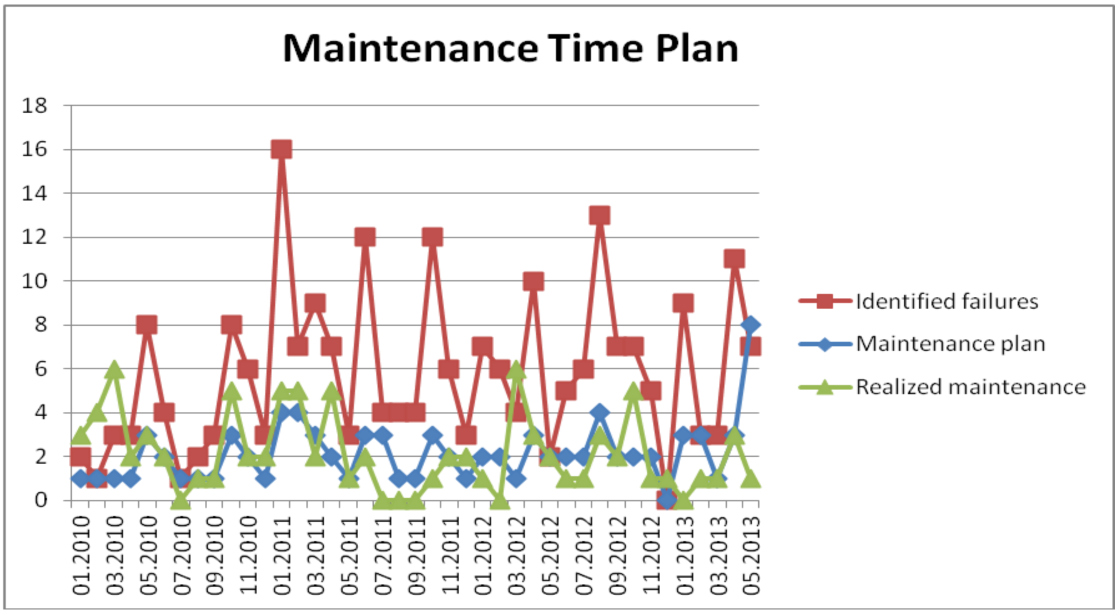


Fig.6 Comparison of registered and calculated maintenance

Summary
We have shown in the presented linear model that if we have only the parameters of number failures and registered maintenances, we will not need more efficient planning terms for the maintenance specialized software. Solver of linear programming in Excel allows its optimal scheduling. We believe that if we knew additional parameters, eg. average maintenance costs respectively removal of failures or the total financial resources, the model would also allow other economic generalizations.

The contribution has been elaborated within the task solution:
"E-learning of robotics with the implementation of virtual laboratory with remote control of real facilities on based Internet"

References

[1] HARMON, M.: Step-By-Step Optimization With Excel Solver - the Excel Statistical Master (Excel Master Series) [Kindle Edition], Amazon Digital Services, Inc. ASIN: B005O2F0FE, 2011
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