Model of Maintenance Planning Based on Trend of Machines Failures with Two Priorities

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Abstract

In this article we are discussing the suggestion of planning maintenance in such situation that we have failures in database of failures and maintenance registered also according to type of failure—priority or non-priority. We are assuming that maintenance must be mainly oriented on avoiding major failures of machines. The effect of maintenance manifests with delay and is dependent on development of failures. We express this problem as linear programming task that is solvable with Solver-extension of application Excel. We demonstrate the suggested solution on example of failures of machines between years 2010 and 2012.

Keywords

Microsoft Excel, Supplement Solver, Maintenance Planning, Priority and Non-Priority Failures, Linear Programming

1. Introduction

In the paper [1] we discussed the possibility of using a linear model of maintenance planning, which was based on the trend of failures. This model was designed and solved in Excel. Computer experiments showed that there was a need to deal with planned preventive maintenance and also priority of failure. We often register failures on the basis of character—priority resp. non-priority failure in the database of failures. We assume that main-

tenance must be oriented mainly to prevent priority failures of machines. Effect of maintenance manifests with a delay and it is dependent on trend of development failure in the last two periods.

Excel and its supplement Solver present also suitable tools for solving our problem in this case. Range of the problem allows its solution in real time. We will demonstrate our solution on illustrated example with these following parameters: we have 285 records of machine failures, of which 203 records are records about the way of machine failure. We need triplet of data (YEAR, MONTH, and LOSS) to create the input data, similarly as in the model [1]. Moreover, we need to specify whether the records deal with failure (priority, non-priority) or maintenance.

But specifying priority of failures may be a problem. One of the possibilities is to create a frequency table from failure code list, which represents the number of occurrences of the considered failure in watched period. Then we can sort this table in descending order and declare the first x failures as a priority. This approach has a logical reasoning as we preferably try to look after those machines that show increased rate of failure [2] [3].

We've created a table of frequencies of failures in single months and in years 2010-2012 and based on it we have created graphs of the development of priority failures (**Figure 1**) and non-priority failures (**Figure 2**) and of development of preventive maintenance (**Figure 3**) that is realized.

By summarizing the above mentioned frequencies we get a table that allows us to determine the exact number of maintenance which is done in each month and their impacts on the identified priority and non-priority failures. We have part of the data in table (**Table 1**).

More informative than the table is the following chart of development of failures and maintenance. We see that preventive maintenance avoids failures relatively poorly and certainly not prioritized ones (**Figure 4**).
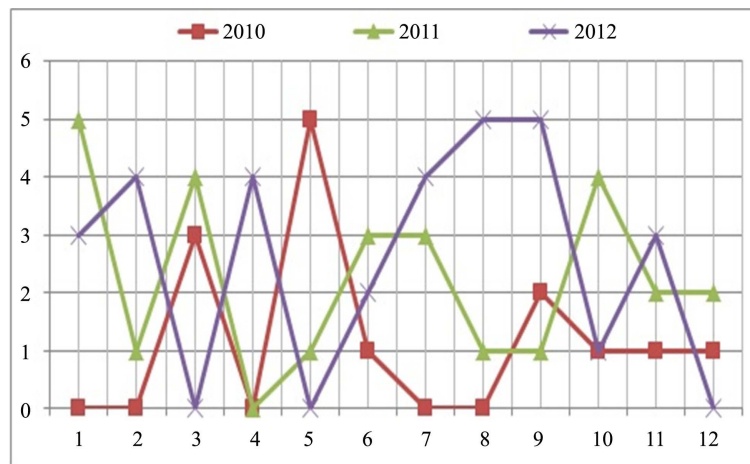

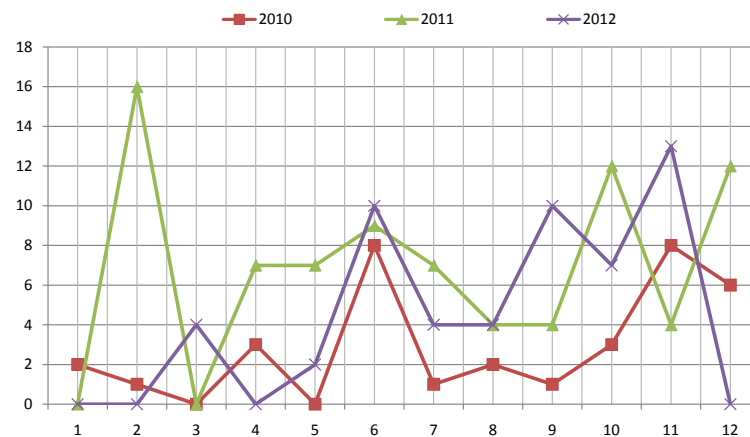**Figure 1.** Development of priority failures.

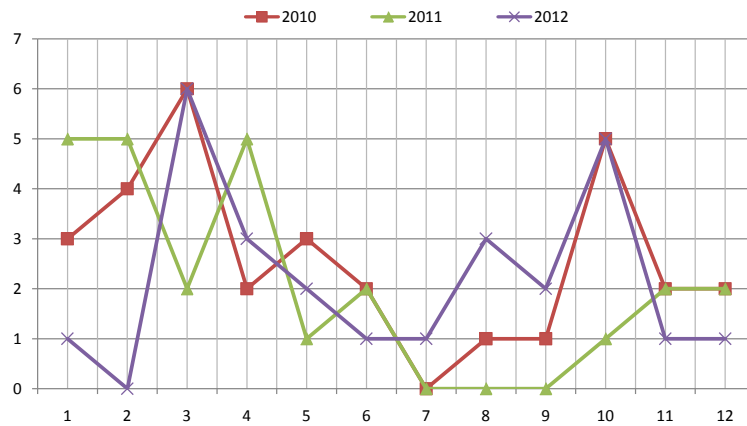**Figure 2.** Development of non-priority failures.
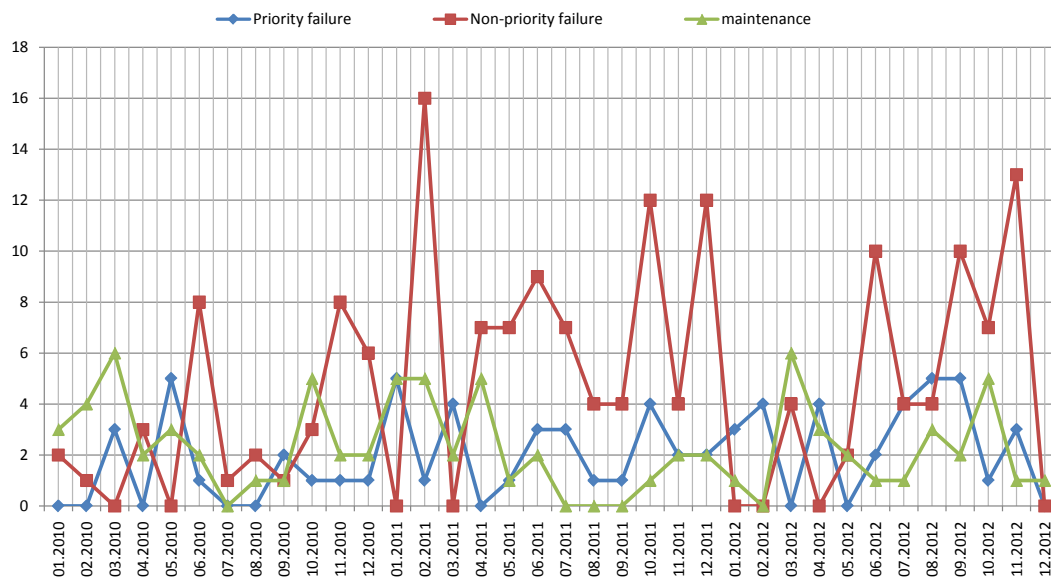
Figure 3. Development of maintenance.

Figure 4. Graphs of total number of failures and maintenance schedules.

2. Linear Programming Model

The following model tries to remove the above present disadvantage. Let pi_1 priority failures and pi_0 non-priority failure be identified during *n*-periods and it u_i maintenance schedules ($i = 1, 2, \cdots, n$) was realized. It is assumed that the period consists of *t* cycles *i.e.* $n = r \times t$.

We are looking for such plan of maintenance schedules x_i, where the sum of coefficient of efficiency from maintenance priority machines y_i and coefficient of efficiency from maintenance from non-priority machines is maximal [4]-[6].

Variables are integer values x_i in this model, that indicate the number of planned maintenance in the *i*-th period, which reflects preference of maintenance cause of priority failure. Coefficient of maintenance efficiency y_1 can be interpreted as a percentage from the number of failures, that have to be covered by priority maintenance in that same month.

We are getting to the following task of linear programming:

$$y_0 + y_1 \Rightarrow \text{maximum} \tag{1}$$

$$\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} u_i \leq t \tag{2}$$

Table 1. Total number of failures and maintenance schedules.

Total number of failures and maintenance schedules					
Year/month	Year	Month	Priority failure	Non-priority failure	Maintenance
01.2010	2010	1	0	2	3
02.2010	2010	2	0	1	4
03.2010	2010	3	3	0	6
04.2010	2010	4	0	3	2
05.2010	2010	5	5	0	3
06.2010	2010	6	1	8	2
07.2010	2010	7	0	1	0
08.2010	2010	8	0	2	1
09.2010	2010	9	2	1	1
10.2010	2010	10	1	3	5
11.2010	2010	11	1	8	2
12.2010	2010	12	1	6	2
01.2011	2011	1	5	0	5
02.2011	2011	2	1	16	5
03.2011	2011	3	4	0	2
04.2011	2011	4	0	7	5

$$x_i + x_{i+1} - p_{i+1,0} * y_0 \geq 0 \quad \text{for all } i = 1, 2, \cdots, n-1 \tag{3}$$

$$x_i - p_{i,1} * y_1 \geq 0 \quad \text{for all } i = 1, 2, \cdots, n \tag{4}$$

$$x_i = x_{(i+r)} \quad \text{for all } i = 1, 2, \cdots, n-r \tag{5}$$

$$x_i \Rightarrow \text{integer} \quad \text{for all } i = 1, 2, \cdots, n \tag{6}$$

$$y_0, y_1 \geq 0 \tag{7}$$

The target function "Equation (1)" maximizes total coefficient of maintenance efficiency. Restrictive condition "Equation (2)" ensures that the number of preventive maintenance in the cycle is greater than the number of already performed maintenance. Restriction "Equation (3)" ensures that the number of non-priority failures in the current period will be covered by efficiency taken from preventive maintenance in the previous and current periods. Restriction "Equation (4)" provides the same coverage of non-priority failures only at the current period. Cycles in periods are formulated by restriction "Equation (5)" Conditions "Equation (6)" and "Equation (7)"are forced by character of variables [7]-[9].

Before using the Excel Solver it is necessary to define the cells of the worksheet on the basis of conditions "Equation (1)"-"Equation (7)"of the model (**Table 2**).

Results of this solution are shown in (**Figure 5**).

We are getting $y_0 = 0.31$ and $y_1 = 0.50$ which leads to an overall average efficiency of 40.62%.

3. Summary

Computer experiment with the presented model "Equation (1)"-"Equation (7)" has shown its applicability to real data. Solver of linear programming in Excel allows optimal scheduling of preventive maintenance that will be used for the benefit of preventing the priority failures as much as possible. Moreover it offers also a quantita-
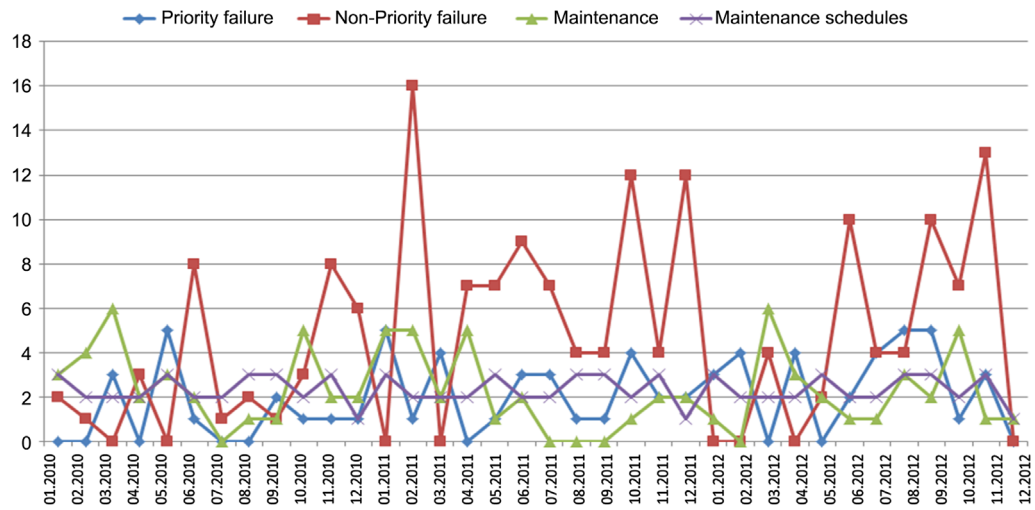
Figure 5. Graph after optimization.

Table 2. Optimization in excel.

	_i	p_i1	p_i0	u_i	x_i
Month/year	**Period**	**Priority**	**Non-priority**	**Maintenance**	**Maintenance schedules**
01.2010	1	0	2	3	3,00
02.2010	2	0	1	4	2,00
03.2010	3	3	0	6	2,00
04.2010	4	0	3	2	2,00
05.2010	5	5	0	3	3,00
06.2010	6	1	8	2	2,00
07.2010	7	0	1	0	2,00
08.2010	8	0	2	1	3,00
09.2010	9	2	1	1	3,00
10.2010	10	1	3	5	2,00
11.2010	11	1	8	2	3,00
12.2010	12	1	6	2	1,00
01.2011	13	5	0	5	3,00
02.2011	14	1	16	5	2,00
03.2011	15	4	0	2	2,00
04.2011	16	0	7	5	2,00
05.2011	17	1	7	1	3,00
06.2011	18	3	9	2	2,00
07.2011	19	3	7	0	2,00
08.2011	20	1	4	0	3,00
09.2011	21	1	4	0	3,00
10.2011	22	4	12	1	2,00
11.2011	23	2	4	2	3,00
12.2011	24	2	12	2	1,00

tive computing the effectiveness of these maintenances. We believe that if we will know also other parameters, for example average expense for maintenance, removal priority resp. non-priority failures or total financial source we will be able to generalize this more in the economic aspect. We will see limitations of the presented model in larger size of data that Excel can no longer process. Then it is appropriate to use other software to optimize, for example Gurobi optimization. For practical use of our proposed model it is necessary to determine more priorities.

Acknowledgements

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