USING THE MONTE CARLO METHOD FOR MAINTENANCE OPTIMIZATION

Martin LAMPA, Andrea SAMOLEJOVÁ, Dominika HRUBÁ

VSB - Technical University of Ostrava, Ostrava, Czech Republic, EU,
martin.lampa@vsb.cz, andrea.samolejova@vsb.cz, dominika.kostelova.st@vsb.cz

Abstract

With the development of computers and software products, the importance of the use of quantitative methods for managerial decisions has been growing even when it comes to industrial companies. Decision making represents one of the most important managerial activities, which managers have to adopt on an everyday basis when conducting their work. The importance of the term managerial decisions is strongly linked to the fact that the quality and results of the decision processes have a great impact on the efficiency, operation and prosperity of industrial companies. Information plays a key role in decision-making processes. They are usually perceived as gathering processes and a transformation of input data to output information. A fundamental role in the process of gathering and collecting data and in their transformation into information is played by managers, whose knowledge, experience and intuition are necessary for making correct decisions. Time pressures and the limitation of individual sources hamper a proper search for all data, based on which managers can obtain high-quality information for their decisions. Poor-quality information and subsequent poor-quality decisions can form one of the reasons for a business failure. The Monte Carlo method represents one of the easily applicable computer solution simulation algorithms. The Monte Carlo algorithm is used for finding relations among individual quantities, which form a solution of a given explored problem and which provide characteristics of random processes that can be reproduced on computers. The objective of this article is to demonstrate an example of the use of the Monte Carlo algorithm for optimizing the number of workshop maintenance employees.

Keywords: Management science, optimisation, simulation, Monte Carlo algorithm

1. INTRODUCTION

Computer technology has developed enormously during the last two decades. Its development has included the area of managerial decisions [1]. Mathematical methods, utilizing computers, have been used ever more often for a majority of issues related to managerial decisions. One of the easily applicable computer-solving methods is the Monte Carlo algorithm. It is a static stochastic method that uses random (pseudorandom) numbers for given calculations [2]. We will show one of its possible uses on an example of optimizing the number of maintenance employees for a workshop with 12 machines of the same type.

2. ASSIGNMENT

The task is to determine an optimal number of maintenance employees for a workshop with 12 machines of the same type. It has been statistically determined that, on average, 2 machines experience 1 defect per shift, 6 machines have 2 defects per shift and 4 of these machines have 3 defects per shift. The duration of the individual defects as a random quantity is governed by the standard probability distribution with an average of 30 minutes and a standard deviation of 10 minutes. One hour of downtime for a single machine corresponds to a workshop loss of 600 CZK. The average hourly wage amounts to 100 CZK/hour. The optimal number of maintenance employees should ensure a minimal cost related to the given defect repairs (the cost includes wages of the maintenance employees and losses caused by the outages).

3. SOLUTION CONSIDERATION

It is a simple task, the objective of which is to determine the optimal size of the servicing set (number of maintenance employees). The following two quantities are decisive for the solution:

- Intensity of the requirement inputs into the servicing set (machine breakdown rate during a shift) characterized by:
  - Number of defects during shift "*P*",
  - Defect duration "*x*",
  - Moment of the defect occurrence "*M*".
- Service intensity (number of maintenance employees who repair the defects during a shift) "U".

Extreme situation:

- Insufficient number of the maintenance employees:
  - Low wages of the maintenance employees "N_U",
  - High downtime losses "N_P".
- Excessive number of the maintenance employees:
  - High wages of the maintenance employees "N_U"
  - Low downtime losses "N_P"

The goal is to determine such a number of the maintenance employees "*U*" that will result in a situation when the cost related to defect repairs during shift "*N*" ($N = N_U + N_P$) is as low as possible (N_{min}).

4. SOLUTION ALGORITHM

The decisive quantities for solving the given task are random quantities. They acquire various values, depending on random effects of several factors. A retrospective statistical analysis came to a conclusion that the continuous variable of defect duration "*x*" can be considered a random quantity, which is subject to the so-called standard probability distribution law (the "fluctuation" of this quantity is affected by several factors, which are not too distinct and mutually independent - from the quality of the work of the maintenance employees and availability of the material and equipment needed for the given maintenance activities, to the level of the given workshop control system). The distribution function of the (standard) probability distribution assigns to every real number a probability that a random quantity "*x*" acquires a value that is smaller than this number (**Figure 1**).

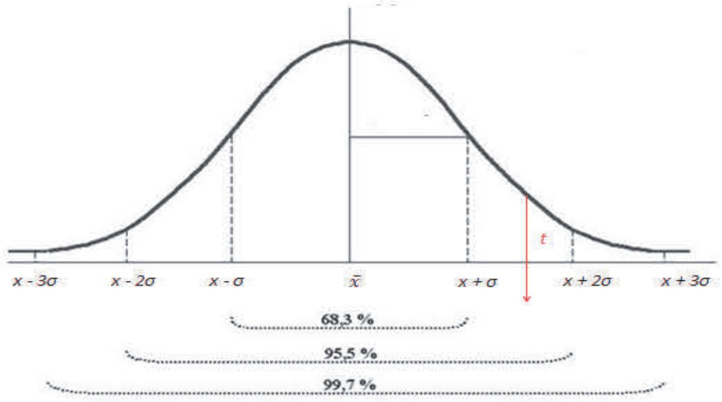

Figure 1 Normal distribution of the function $x = \bar{x} + t*\sigma$

x - (random) value of the defect duration quantity (min),

$\bar{x}$ - median value (average of the given values) of a standard distribution (min),

σ - standard deviation of the standard distribution (min),

t - standard variable

$\bar{x}$ = 30 minutes

σ = 10 minutes

The presented stochastic task can be solved by the means of an artificial experiment based on its logical-mathematical model (see the task solution consideration) [3]. This method represents an artificial simulation of probability situations and their assessments - coincidence simulation in compliance with the law, based on which (we assume) coincidences work. This methodology is called a simulation. Its basis and the result of its application is a statistical estimation of a probability of a given variant of the progress of real processes, i.e. including the given optimal variant [4].

The so-called Monte Carlo algorithm plays an important role among the simulation procedures [5]. Statistical probability estimations are executed by the means of artificial selections, utilizing certain random mechanisms - usually so-called random (pseudorandom) numbers [6].

Random numbers - a sequence (set) of statistically independent numbers (no number from the given sequence depends on any preceding or following numbers).

Task solution procedure using the Monte Carlo logarithm

Simulation of (prediction of the possible) defect duration "*x*" for 12 workshop machines for each of:

- 2 machines - 1 defect
- 6 machines - 2 defects
- 4 machines - 3 defects

} statistically determined average per shift

By entering the generator of random numbers - in our case, the availability table - we gradually generate five-digit numbers (for available five-digit values of the distribution function) that simulate the value of the distribution function and the corresponding value of the so-called determinant variable "*t*" for formula $x = \bar{x} + t*\sigma$, where $\bar{x}$ = 30 minutes, σ = 10 minutes.

Table 1 Simulation of the number of defects per shift

Number of defects per shift	Machine no.	Simulation of (prediction of the possible) defect duration "*x*"			Simulation of (prediction of the possible) the interval of the machine defect duration during a shift		Defect from the previous to the following shift
		Simulated value of the distribution function	*t*	Simulated defect duration $x = \bar{x} + t*\sigma*$	Simulation of the defect occurrence moment "*M*"	Simulation of the duration interval (*M* + *x*)	
1	1	0.86649	1.11	41	345	386	
	2	0.16864	-0.96	20	342	362	
2	3	0.85645	1.06	41	105	146	
		0.42190	-0.20	28	36	64	
	4	0.80733	0.86	39	473	480	0 - 32
		0.01427	-2.19	8	424	432	
	5	0.94168	1.57	46	86	132	
		0.43059	-0.17	28	435	463	
	6	0.93731	1.53	45	142	187	
		0.20554	-0.82	22	234	256	
	7	0.73917	0.64	36	28	64	
		0.62711	0.32	33	162	195	
	8	0.72154	0.59	36	364	400	
		0.69191	0.50	35	145	180	
4	9	0.48653	-0.04	26	5	31	
		0.03872	-1.77	12	138	150	
		0.75660	0.70	37	169	206	
	10	0.73898	0.64	26	476	480	0 – 32
		0.42042	-0.20	28	345	373	
		0.11921	-1.18	18	213	231	
	11	0.17588	-0.93	21	236	257	
		0.51643	0.04	30	61	91	
		0.24635	-0.69	23	371	394	
	12	0.57576	0.19	32	241	273	
		0.64616	0.40	34	383	417	
		0.60538	0.27	33	457	480	0 - 10
Σ machine time losses (downtimes) per shift (min)			788				

1) Simulation of the moment of defect occurrence "*M*" (prediction of the possible). In our case, by entering the availability table of random numbers once again, we gradually generate three-digit numbers that simulate the moments defects occur for a shift that lasts 0-480 minutes (**Table 1**).

2) Simulation of the defect duration intervals for individual machines during a shift based on the previous two steps (simulations). Their well-arranged records, table, diagram of the machine breakdown rate per shift (**Table 2**).

*x = 30+t*10 (min) (1)

Determining the (prediction of the possible) overall breakdown rate - downtime losses - of all workshop machines based on the simulation of the intervals of individual machine defect durations (from step 3) for a selected number of the maintenance employees.

Minimal number of the maintenance employees

$$U^{min} = \frac{\sum time\ losses\ due\ to\ the\ downtimes\ per\ shift\ (min)}{maintenance\ employee\ time\ fund\ (shift\ duration)(min)} \quad (2)$$

$U^{min} = \frac{788}{480} = 1.64$, based on which at least 2 maintenance employees are needed per shift

Maximal number of the maintenance employees $U^{max}$is determined by the maximum number of machines that are simultaneously experiencing a defect

U^{max}in the shift interval of 319 - 324 minutes, 6 machines are experiencing a defect simultaneously

U^{max} is a maximum of 6 maintenance employees

Table 2 Downtime losses for different numbers of maintenance employees

Shift interval from – to (min)	Number of machines experiencing a defect	Downtime losses (min) for a given number of maintenance employees					Shift interval	Number of machines experiencing a defect from – to (min)	Downtime losses (min) for a given number of maintenance employees				
		2	3	4	5	6			2	3	4	5	6
0-23	2	0	0	0	0	0	274-283	4	18	9	0	0	0
23-25	2	0	0	0	0	0	285	3	2	0	0	0	0
25-32	3	7	0	0	0	0	290	4	10	5	0	0	0
32-42	2	0	0	0	0	0	301	3	11	0	0	0	0
42-48	3	6	0	0	0	0	303	4	4	2	0	0	0
61	2	0	0	0	0	0	306	4	6	3	0	0	0
70	1	0	0	0	0	0	308	4	4	2	0	0	0
72	0	0	0	0	0	0	313	3	5	0	0	0	0
74	1	0	0	0	0	0	319	5	18	12	6	0	0
85	2	0	0	0	0	0	319-324	6	20	15	10	5	0
85-98	3	13	0	0	0	0	341	5	51	34	17	0	0
99	4	2	1	0	0	0	344	4	6	3	0	0	0
109	3	10	0	0	0	0	345	3	1	0	0	0	0
112	2	0	0	0	0	0	350	2	0	0	0	0	0
121	1	0	0	0	0	0	355	1	0	0	0	0	0
123	2	0	0	0	0	0	386	0	0	0	0	0	0
151	1	0	0	0	0	0	387	1	0	0	0	0	0
170	0	0	0	0	0	0	427	2	0	0	0	0	0
191	1	0	0	0	0	0	435	1	0	0	0	0	0
207	0	0	0	0	0	0	441	0	0	0	0	0	0
230	1	0	0	0	0	0	471	1	0	0	0	0	0
242	0	0	0	0	0	0	475	0	0	0	0	0	0
248	1	0	0	0	0	0	480	1	0	0	0	0	0
266	2	0	0	0	0	0							
267	3	1	0	0	0	0							
274	4	14	7	0	0	0	Σ		209	93	33	5	0

5. ASSESSMENT OF THE TASK SIMULATION SOLUTION

Determination of the optimal number of the maintenance employees "U^{opt}"

U = cost of the wages of the maintenance employees N_U (100 CZ/hour) + downtime losses N_P (600 CZK/hour)

$U = N_U + N_P$ (CZK)

2 maintenance employees:

N_U = 100 x 2 x 8 = 1,600 CZK

N_P = 10 x 209 = 2,090 CZK

U = 1,600 + 2,090 = **3,690 CZK**

3 maintenance employees:

N_U = 100 x 3 x 8 = 2,400 CZK

N_P = 10 x 93 = 930 CZK

U = 2,400 + 930 = **3,330 CZK**

4 maintenance employees:

N_U = 100 x 4 x 8 = 3,200 CZK

N_P = 10 x 33 = 330 CZK

U = 3,200 + 330 = **3,530 CZK**

5 maintenance employees:

N_U = 100 x 5 x 8 = 4,000 CZK

N_P = 10 x 5 = 50 CZK

U = 4,000 + 50 = **4,050 CZK**

6 maintenance employees:

N_U = 100 x 6 x 8 = 4,800 CZK

N_P = 10 x 0 = 0 CZK

U = 4,800 + 0 = **4,800 CZK**

6. CONCLUSION

For the specified assumptions related to the workshop breakdown rate during a shift, the optimal number of the maintenance employees from the perspective of minimizing the overall cost related to repairing machine defects is 3. The introduction of the Monte Carlo algorithm is particularly worthwhile for repeated, routine solutions of standard problems, which includes the optimization of the number of the maintenance employees, and for cases when the prepared algorithm can be incorporated into the automated company management system.

ACKNOWLEDGEMENTS

The work was supported by the specific university research of the Ministry of Education, Youth and Sports of the Czech Republic in VSB - Technical University of Ostrava No. SP2019/42.

REFERENCES

[1] BESTA, P.; SAMOLEJOVÁ, A.; LENORT, R.; ZAPLETAL, F. Innovative Application of Mathematical Methods in Evaluation of Ore Raw Materials for Production of Iron. *METALURGIJA*, 53 (2014) 1, pp. 93-96.

[2] TURBAN, E; MEREDITH, J. R. *Fundamentals of management science*. USA: R. R. Donnelye & Sons, 1991, 1010 p.

[3] KUTÁČ, J.; KUTÁČ, T.; BESTA, P.; ŠVECOVÁ, E. Choosing of appropriate operative evidence in company producing tubular products . In *METAL 2018*: 27th Anniversary International Conference on Metallurgy and Materials. Ostrava: TANGER, 2018, pp. 2024-2028.

[4] GROS, I.: *Kvantitativní metody v manažerském rozhodování*. Praha: GRADA Publishing: 2003. 432 p.

[5] GROS, I.; DYNTAR, J. Matematické modely pro manažerské rozhodování. Praha: VŠCHT v Praze: 2015. 303 p.

[6] SAKÁL, P.; JERZ, V. Operačná analýza v praxi manažéra. Trnava: SP SYNERGIA: 2003. 335 p.