

MONTE CARLO SIMULATION - CASE STUDY OF PUMP FLOW

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Abstract: *The article deals with the simulation, more specifically with the method Monte Carlo. Simulation, especially computer simulation has been in a rapid growth in recent years. Monte Carlo simulation with appropriate statistical software can predict performance through predefined parameters without expending production and testing costs. In this contribution is Monte Carlo simulation used for design of a small piston pump.*

Keywords: Simulation, monte carlo method, piston pump

1 INTRODUCTION

The term simulation is used more often but usually as a synonym of imitate or pretend. With the term of simulation, simulate, simulator we are coming across in many scientific disciplines. Moreover, it is used in various fields: computer systems, logistics and production systems, financial and econometric models, space travel, military operations, urban systems, etc. Simulation is a numerical technique for conducting experiments on the computer. Monte Carlo simulation is the computer experiment involving random sampling from probability distributions. During designing of production processes many challenges occur, for instance how to solve problems in the process, how to innovate or improve the process. One possibility is to simulate the production process. The simulation is experimenting with computer models based on the real production process in order to optimize the production processes, the entire processes or a system. It enables to experience the behavior of the system after implementation and to see the possible future scenarios and uncover problems. Simulation is not a tool which provides an optimal solution to the problem but it is a support tool that tests the impact of our decisions on the simulated model.

2 SIMULATION

The simulation model allows you to perform a number of experiments, analyze them, evaluate, optimize and afterwards apply the results to the real system. According to the definition a simulation is a research method, which comprised on the examination of a dynamic system. The dynamic system is replaced by a simulator, on which are afterwards performed experiments to obtain information about the original investigated system. It is a computer simulation, in which the simulator consists of a simulation program - model introduced to the computer. By using the simulation it is possible to solve several problems, such as: the most convenient management system, the best lay-

out of machines, the optimal size of the inventory, determine the number of machines and additional equipment, determining the optimal size of operating machines and equipment, determining the optimal dose size, determine the impact of failures and downtime the manufacturing process, and many other applications.

During the application simulations two basic rules are used:

- The benefits achieved by applying simulation should be greater than the costs required to implement simulation (quantitative and qualitative benefits).
- The simulation is justified if the direct benefits of simulation are more than the cost of the simulation.

The simulation should be used in the initial stages of the project process, because the most potential improvements of the system can be achieved in the initial stages. In the process of implementation and operation exists only a few degrees of freedom for a change. Proper and timely decisions are incomparably greater than the benefits of optimization in subsequent stages of the project.

Some of the reasons for using of the simulation are restructuring of the manufacturing process, reduce the risk of decision making, increase the efficiency, elimination of deficiency in the production process without interfering with the real processes, the need for predictions of future action, impossibility of implementing the production process, cost-saving, experiments can cause malfunctions in the equipment, experimentation on a real object is expensive (in terms of money, time).

Simulation is actually mathematical modeling; it means experiment on a real system is replaced by the solution of a mathematical model on a computer. The real system is a system which is the subject of our interest. The simulation model is a dynamic model (mathematical, logical, and so on.), which in a way shows current system; its structure and a set of rules under which the model in a way behave (generated data). The models can

be divided into mathematical and physical. Before the simulation model is built, is necessary to define the goal of the simulation (cost reduction, reduction of production, optimize deployment of production facilities), and to obtain input data. The term simulation experiment is a set of simulation runs - multiple repetitions of the basic cycle simulation for a specific time period and parameter simulation with partial evaluation of results. It is therefore a set of the operation's simulation in which a change of input quantities are performed.

3 METHODOLOGY MONTE CARLO

The theoretical basis of the method is based on the process modeling that generates data. Monte Carlo is an algorithm for simulation systems. Monte Carlo method means the numerical solution of probabilistic and deterministic tasks using many times repeated probabilistic experiments. It is a stochastic method using pseudorandom numbers. The actual simulation is a process of random selection of specific risk-factors of the predefined division. Simulation (number of simulation runs is recommended at least 1,000 times) selects a random number and applies it in the model definition. Randomness and objectivity is ensured by the random generator, thus pseudorandom numbers. The simulation output is a probability distribution

of the target variable (Tab.1), so the solution is probabilistic in nature and is dependent on what the distribution of the individual values generated. After the simulation, the aggregate statistics of evaluation indicators are created - arithmetic mean, standard deviation, mode, median, and coefficient of variation. The results can be represented graphically.

During simulation, values of random variables are substituted by generated large number of realizations of a given random variable, and then computed statistically. Monte Carlo method procedure:

- Defining the objective (purpose of simulation).
- Data preparation and selection of a tool,
- selection of key parameters of simulation – analysis of the problem.
- Determination of probability distribution of random variables, when developing an appropriate Monte Carlo model, very important step is to determine the correct constraints for each variable and the correct relationship among variables, design of particular parametric model.
- Simulation of the model.
- Output from the model and results of the analysis.

Discrete Distributions	Normal Distribution
✓ Continuous Probability Distributions	✓ Standard normal distribution
✓ Uniform distribution	✓ Exponential distribution
✓ Bernoulli distribution	✓ Log-normal distribution
✓ Binomial distribution	✓ Weibull distribution
✓ Poisson distribution	✓ Student distribution 2 distribution
✓ Hypergeometric distribution	✓ Fisher-Snedecorove distribution
✓ Uniform distribution	✓ Gamma distribution

Table1 Statistical probability distribution

3.1 Case study – piston pump construction

The pump is a hydraulic machine that delivers the energy needed to extrude or refill, transporting the liquid to a certain height. From an energy point of view, they are machines that sell the kinetic energy of a drive (engine) to a liquid. We know many kinds of pumps and many criteria of possible distribution. The piston pump draws a certain volume of liquid into the closed cylinder chamber at the next moment to push it out of the

piston. Their advantage is self-priming ability, insensitivity to pressure changes and the possibility of using liquids with higher viscosity. Piston pumps are mainly used for smaller volumetric flow rates but for high pressures. The disadvantage of the piston pumps is the much larger dimensions than the equally powerful centrifugal pumps as well as the greater procurement and maintenance costs. Piston pumps have a wide-ranging and numerous application in technical practice, used in the chemical industry as process pumps to transport a wide variety of substances at high pressures,

temperatures and large amounts of media generated. Specific applications of piston pumps for the transport of suspensions and abrasive mixtures are also used in the construction of pressure equipment for performing pressure tests. They are also used in process diaphragm pumps. Also of interest are the applications of piston pumps to drive hydraulic presses and transport liquid gases. Piston pumps are also used in high pressure water jet generation for high speed water jet cleaning and cutting applications. In view of these applications, the energy efficiency of piston pumps is an increasingly important requirement for such advanced machinery and equipment.



Figure 1 Piston pump

For the piston pump (Fig.1) design, we will use a simulation where through thousands of data produced by pumps, we will try to estimate the likely performance of the new model. For each simulation, we need to know the quantitative dependence (mathematical equation) that describes

the relationship of input parameters and their response to the expected output. If a suitable general model for the desired output is not known, regression analysis models or DOE Response Surface Methods are used.

Pump flow (Q) is an indication of the amount of liquid delivered by the pump per unit of time to the discharge pipe, can be described by the equation

$$Q = \pi \cdot r^2 \cdot l \cdot n \quad (1)$$

2r - piston diameter (r is radius),

l - stroke length,

n - number of strokes per minute.

Based on the performance of other pump models produced by the company, it is assumed that the piston diameter is a random variable with normal distribution with a mean value (average) of 12 mm and standard deviation of 0.05 mm. The stroke length is a random variable with a normal distribution with a mean value (average) of 30 mm and a standard deviation of 1.2 mm. N (30, 1.44). The number of strokes per minute is governed by normal distribution N (10, 0.009). Several thousand rows of simulated data are generated using the selected software support (Statistica, Minitab ..). The pump flow is calculated from these generated values. The results can be evaluated using numerical and graphical analysis.

The evaluation of the simulated data (10 0000) for the individual variables is shown of Fig. 2 (Average), Fig. 3 (Stroke Length) and Fig. 4 (Number of Stroke). There is a normal distribution histogram, selected position and variability characteristics (mean, maximum, minimum, variance, standard deviation), Skewness and Kurtosis, and 95% Confidence Interval for Mean.

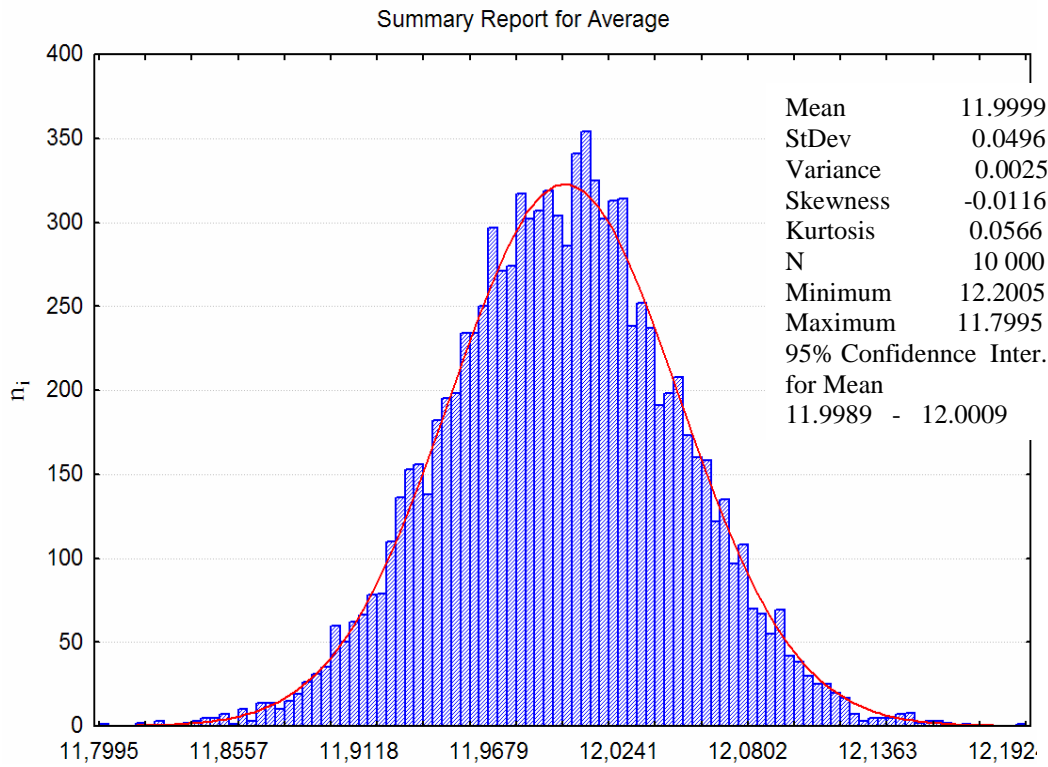


Figure 2 Summary Report for Average

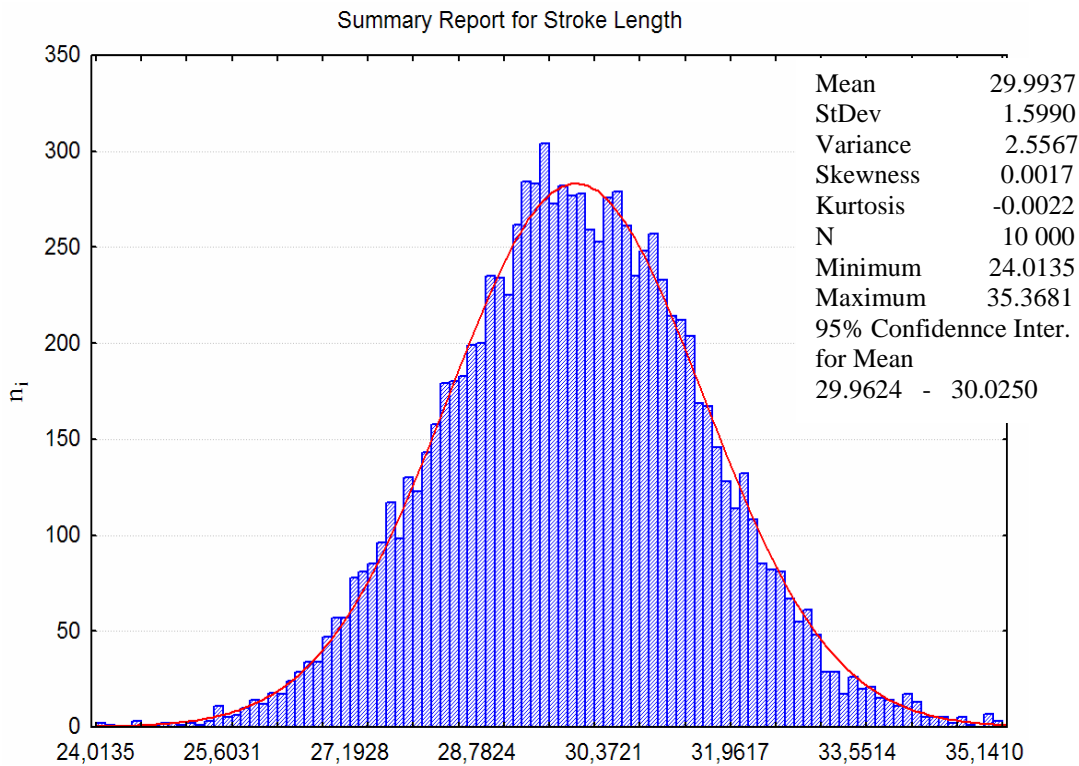


Figure 3 Summary Report for Stroke Length

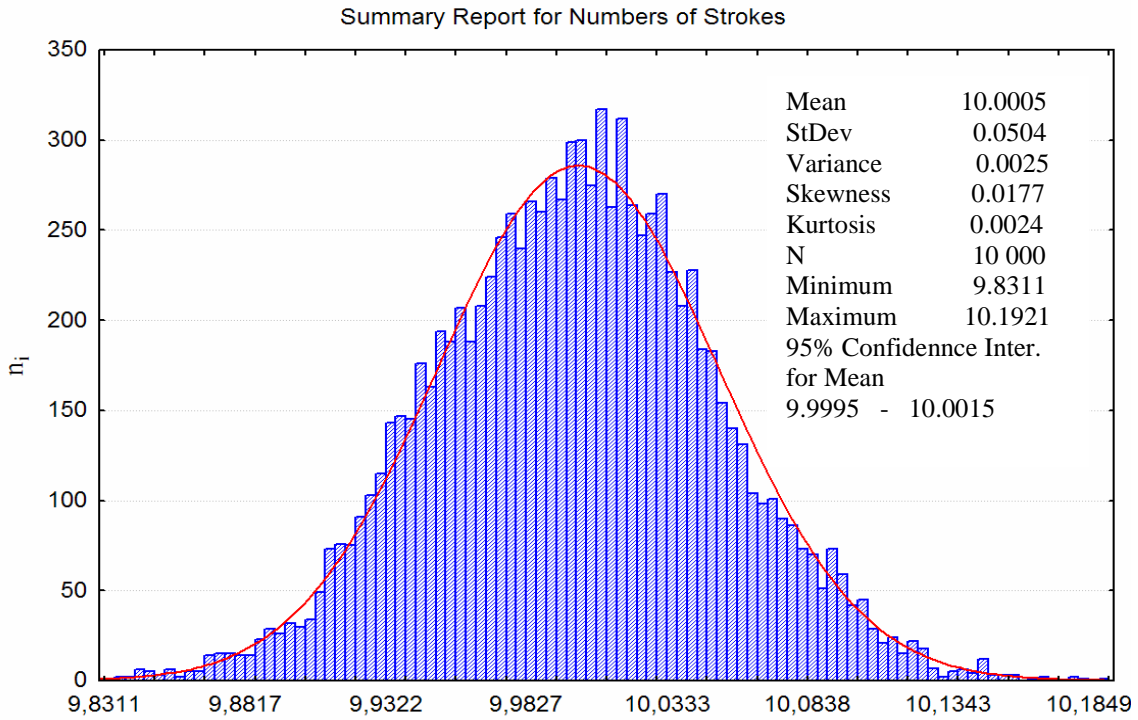


Figure 4 Summary Report for Number of Stroke

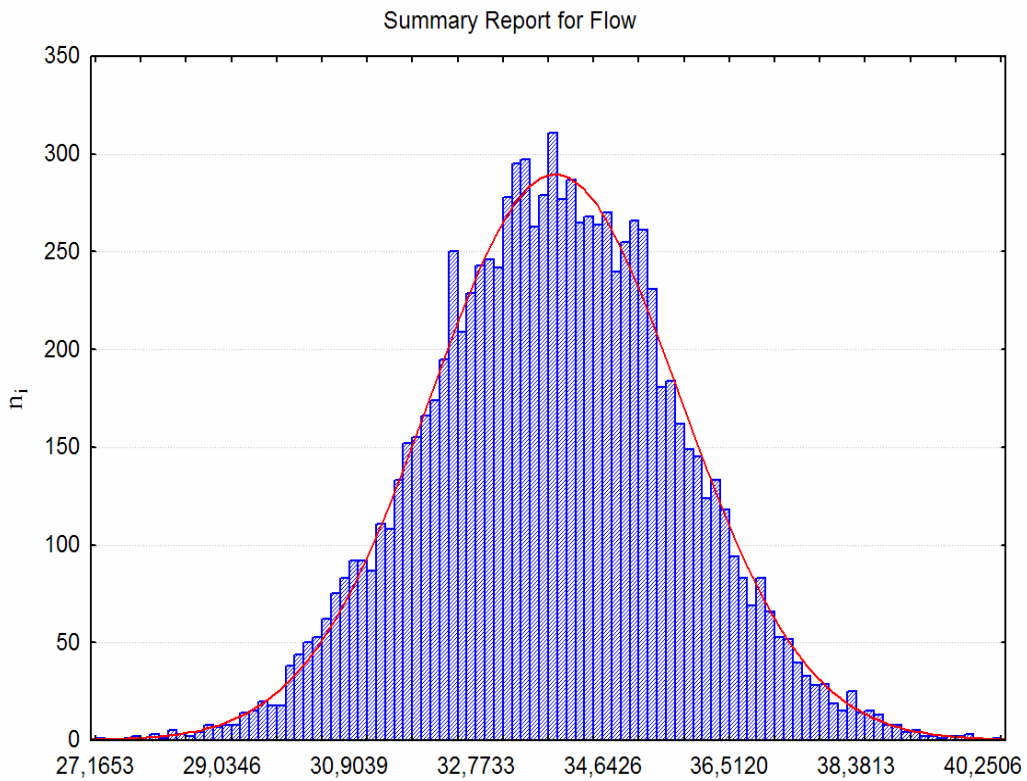


Figure 5 Summary Report for Flow rate

Based on randomly generated data, the mean pump flow rate of 33.9067 and 95% Confidence Interval for Mean is calculated (33.8707, 33.9428), but there is a high flow rate range when looking at the smallest and largest

values. This pump design seems to exhibit too much variability in the expected outcome of its primary function and needs to be further improved before it is produced. In order to improve the expected output, it is possible to optimize the model

inputs (average, stroke length, numbers of strokes) using the simulation tools.

Using Structural Equation Modelling, you can reconstruct some of these analyses, run Monte Carlo experiments, and find out for yourself how the test statistics tend to perform with particular combinations of model and sample size. Prior analysis of piston pump, using Monte Carlo methods, can inform our in advance about adequacy of parameters sample sizes, potential convergence problems, etc.

CONCLUSION

This article is an example of generating random inputs in the manufacture of a piston pump, demonstrating the possibility of being used in a simulation process. Simulation is important and has a stable place in the production process and also in business practice. It is not a tool to solve all problems, but can be used to optimize and improve.

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