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# PROCESS SIMULATION AND METHODS OF GENERATING RANDOM NUMBERS

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***Keywords:*** simulation model, mathematical modelling, random number generation
***Abstract:*** The article deals with the process of the simulation and the random number generation. Simulation, especially computer simulation has been in a rapid growth in recent years. The simulation is experimenting with computer models based on the real production process in order to optimize the production processes or the system. The simulation model allows to perform a number of experiments, analyze them, evaluate, optimize and afterwards apply the results to the real system. Production enterprises investing in technical training, to affect the time between research, development and production. In order to reduce this time interval is used in the design of the technological process by computers with suitable software. The mathematical description of the technological process whose outcome depends on factors entering into the process is defined as a mathematical model of the process. If the outcome of the process can not be expressed mathematically dependent on factors entering into the process it is a simulation.

## 1 Introduction

The current period is characterized by the development of technology where the most significant are computers and information technology. IT extends to all areas of our lives and also pushed through in engineering production and in particular the planning and design of production, modeling and simulation of production in production management, etc.

Production enterprises investing in technical training, to affect the time between research, development and production. In order to reduce this time interval is used in the design of the technological process by computers with suitable software. The mathematical description of the technological process whose outcome depends on factors entering into the process is defined as a mathematical model of the process. If the outcome of the process can not be expressed mathematically dependent on factors entering into the process it is a simulation [1].

Mathematical modeling is commonly defined as modeling, in which the shape of the mathematical model structure, as for instance variables, programs, functions, equations, logical conditions, operators and other mathematical objects. Mathematical system can not only have quantitative characteristics of site systems and processes, but also is characterizes by the qualitative aspect. Simulation is defined as the research method, which is characterized as during experiment on a dynamical system is replaced by its simulation model as it attempts are made to obtain information about the original investigation system [2]. Experimental testing process compare to the actual manufacturing equipment (model) is costly and time-consuming. Mathematical modeling and simulation of technological processes is using computer technology to optimize the production process without any real production equipment. To build such models for complex technological processes consisting of a large number of operations at a number of production machines is challenging and it is used the simulation approach. The modern concept of the production process is a Computer Integrated Manufacturing (CIM), the scheme is on Fig.1.

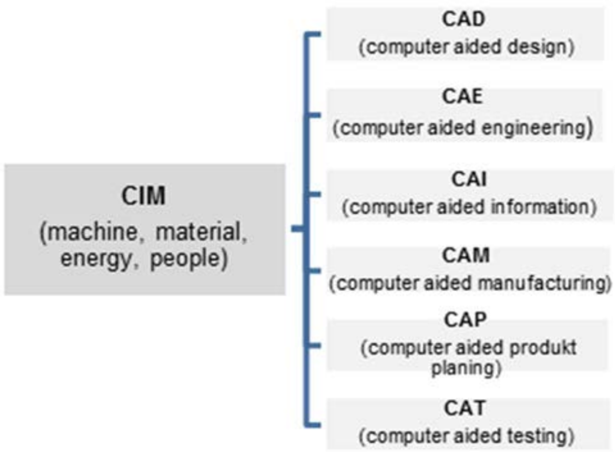


*Figure 1 Structure of production process – CIM*

## 2 Phaces of the simulation process

The simulation consists of the following steps - build the model, design of simulation experiments, perform simulation analysis [3], [4]. Modeling is probably the most important part of simulation, simulation modeling involves the following steps:

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- *Formulation of the problem* - defining specific problem, defining the overall objective of the solution and the impact of measures (quantitative criteria).
- *The collection and processing of data in the real system* - the collection of data about the systems specifications, gathering input variables, gathering information about the performance of the existing system, identification of randomness in the system.
- *Creation of the model* - the formulation of a development model, development schemes and network diagrams systems, setting simulation runs, transcription conceptual model into the simulation software in an acceptable form, review the scope of input parameter animation.
- *Validation of the model* - compare the performance of the model under known conditions with the performance of the real system, perform statistical tests, assessment simulation studies experienced analysts verify the correctness, completeness and consistency of the model.
- *Creation of documentation* - compiling documentation model for future use, a detailed record of objectives, assumptions, input variables of the simulation model, the number of attempts in the simulation.
- Selection of the appropriate experiment - the choice of performance measures, the number of input variables that are likely to affect it and the variability of each entry (number of possible configurations is the product of the number of input variables and levels of each input variable).
- *Determination of initial conditions for the simulation runs* - obtaining accurate information of each run, determine whether the system is stationary (performance measures do not change over time), or non-stationary (power changes over time), verify whether it is appropriate Whether or not the simulation run, the choice of its length, the choice of the appropriate starting conditions, the choice of size sample measured estimates, identification of correlations between output data.
- *Fitting Simulation* - perform simulations using simulation software packages.
- *Interpretation and presentation of results* - numerical calculation of estimates (eg median, confidence intervals) for the required performance measures for each configuration, determine the autocorrelation verification test hypotheses about system performance, design graphical presentation of the output data.
- *It offers a way forward* - recommendations for further action, which could include further experiments to increase accuracy and decrease preload estimates.

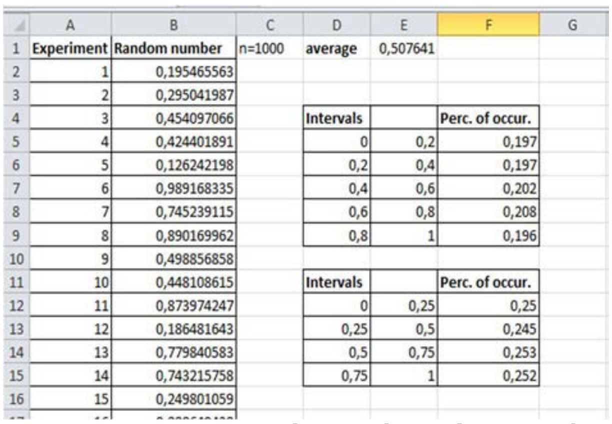
The simulation results are approximate but sufficiently accurate solution of the task, finding possible alternatives and appropriate conclusion [5]. The main point of mathematical modeling and computer simulation is that the original system replaces a computer model that can be implemented with the various computer experiments and their results retrospectively applied to the original system. On the computer you can change the system inputs and system parameters and model can be modified in different places. For these changes to the model reacts to change the output values. To create simulation models currently used specialized software. Methods of computer simulation can be addressed by using the MS Excel and its supplements: Risk Solver,risk, Risk Analyzer, MonteCarlo, Crystal Ball and others.

## 3 Methods of generating random numbers

In Microsoft Excel simulation models can be constructed in two basic ways:

- using built-in functions,
- using the "Random Number Generation" in Appendix Data Analysis

To generate random numbers you can use command RAND (), we get a random number with uniform distribution in the interval (0,1). To determine the percentage of occurrence of random numbers in the interval function is used COUNTIF (Fig. 2).



| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Experiment | Random number | n=1000 | average | 0,507641 | | |
| 2 | 1 | 0,195465563 | | | | | |
| 3 | 2 | 0,295041987 | | | | | |
| 4 | 3 | 0,454097066 | | Intervals | | Perc. of occur. | |
| 5 | 4 | 0,424401891 | | 0 | 0,2 | 0,197 | |
| 6 | 5 | 0,126242198 | | 0,2 | 0,4 | 0,197 | |
| 7 | 6 | 0,989168335 | | 0,4 | 0,6 | 0,202 | |
| 8 | 7 | 0,745239115 | | 0,6 | 0,8 | 0,208 | |
| 9 | 8 | 0,890169962 | | 0,8 | 1 | 0,196 | |
| 10 | 9 | 0,498856858 | | | | | |
| 11 | 10 | 0,448108615 | | Intervals | | Perc. of occur. | |
| 12 | 11 | 0,873974247 | | 0 | 0,25 | 0,25 | |
| 13 | 12 | 0,186481643 | | 0,25 | 0,5 | 0,245 | |
| 14 | 13 | 0,779840583 | | 0,5 | 0,75 | 0,253 | |
| 15 | 14 | 0,743215758 | | 0,75 | 1 | 0,252 | |
| 16 | 15 | 0,249801059 | | | | | |

*Figure 2 Generating random numbers, determine the percentage of occurrence*

The diameter 1000 of random numbers each time approximates to a value of 0.5 approximately 20% of the results in each of intervals, the distribution of numbers into five intervals, the numbers are distributed to the four intervals is 25% of the results. These results are consistent with the definition of the random number values are generated independently from each other, and of course each other, because the function of the "random" always calculates the numbers generated. The "Random" is also used to generate values for various probability distributions.

Example of generating random inputs for simulation model by using built-in functions is depicted on Fig.3 – Fig.6.

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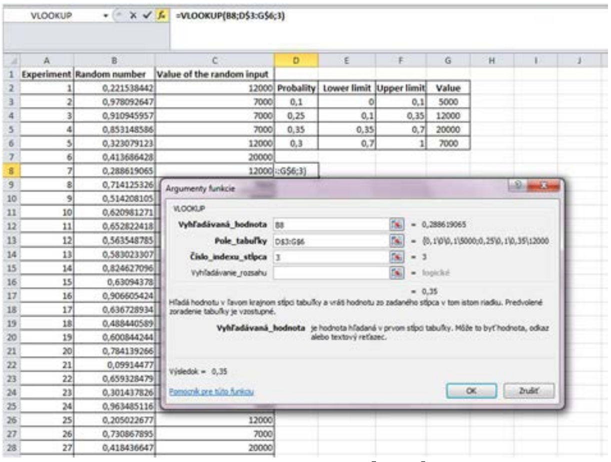

Figure 3 Discrete distribution

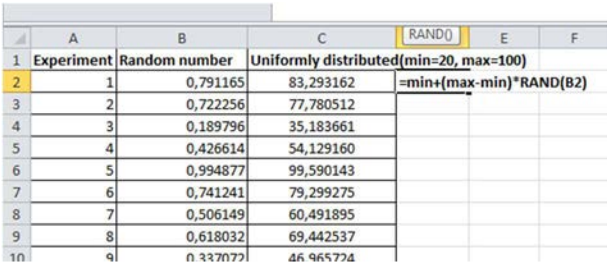

Figure 4 Uniformly distribution

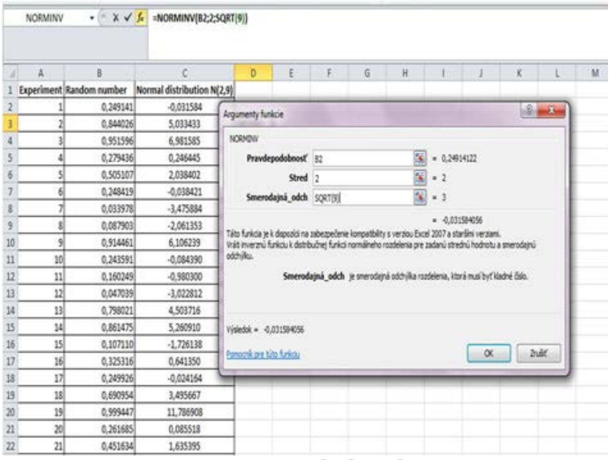

Figure 5 Normal distribution

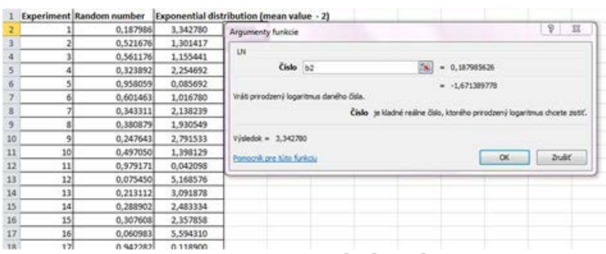

Figure 6 Exponential distribution

For generating random inputs of simulation inputs is possible to use a function "Random Number Generation" located in Data Analysis, example of generating 1000 random variables (normal distribution - N(2,9),uniform distribution - R(20,100)) is on Fig.7.

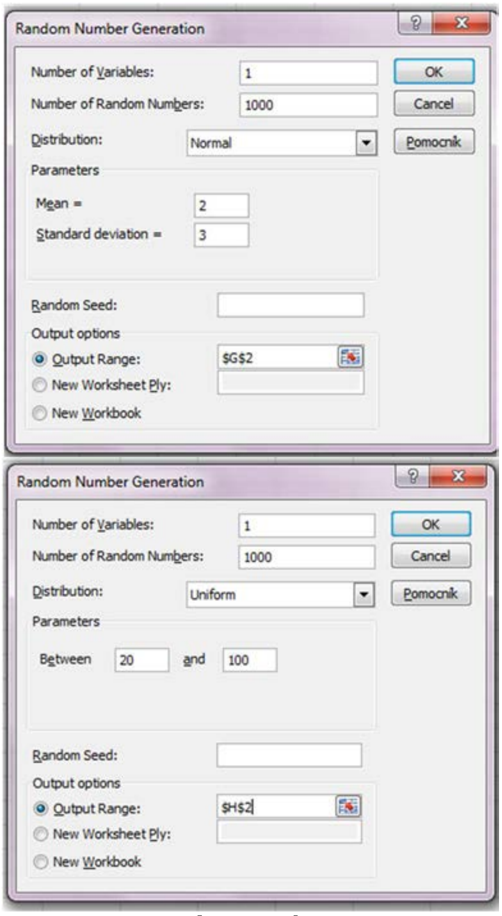


Figure 7 Random Number Generation

In the following part is used simulation software Risk, suitable mainly for simulations in the tabular processor Microsoft Excel. @RISK performs risk analysis using Monte Carlo simulation to show how many possible outcomes in a spreadsheet model exist and tells how the likelihood they might occur is. It mathematically and objectively tracks many different possible future scenarios and assess the probabilities and risks associated with each different one. This means that it gives an assessment which risks to take and which ones to avoid, allowing for the best decision making under uncertainty. Random inputs of model are generated by using add-on @Risk in the top menu in folder "Define Distribution", in option for discrete (Fig. 8) and continuous probability distribution Fig. 9. The second possibility is generating of random inputs is to write function directly into a cell – for normal distribution it is "RiskNormal (mean value, standard deviation)".

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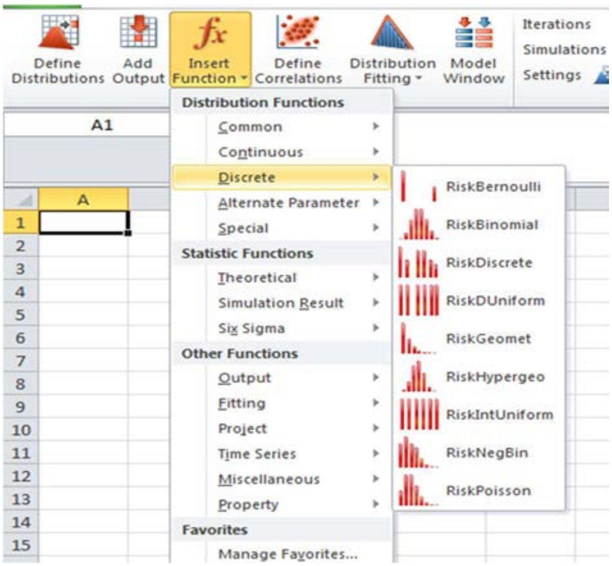

*Figure 8 Discrete probability distribution*

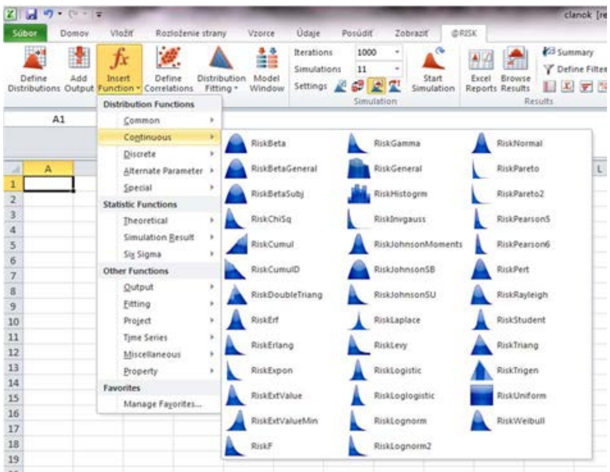
*Figure 9 Continuous probability distribution*

To create simulation models can also be used programming system messy, which produces models at different levels of difficulty. Models are created in Simulink (SIMulation and LINK), is a software product that allows the modeling, simulation and analysis system that inputs will change over time. Simulink starts from the basic MATLAB command "Simulink", or from the tool panel window with the basic libraries available blocks, divided into groups according to areas of application are to Fig.10. Simulation of dynamical systems consists of two steps:

- creation of using Simulink block diagram, making a connection between blocks and setting any necessary adjustment between inputs and outputs,
- setting time parameters simulation, running the simulation model created.

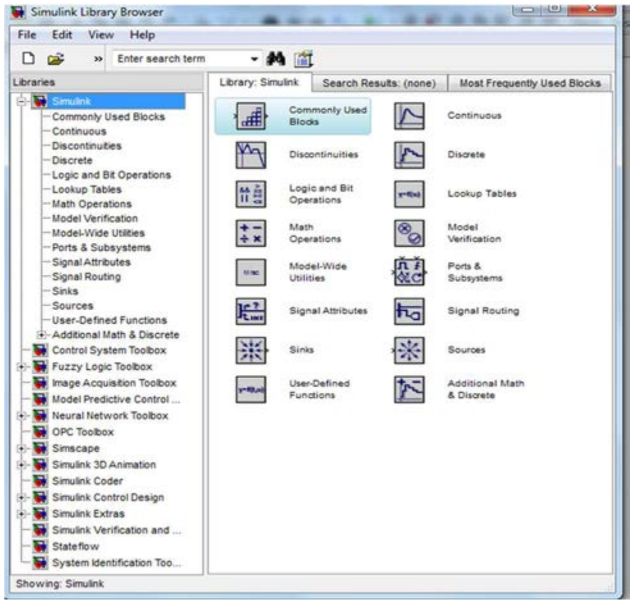

*Figure 10 Window with the basic libraries of Simulink*

## Conclusion

The article is an example of using the software simulation designed for simulation in Microsoft Excel spreadsheet and Matlab , demonstrated the possibility of its usage in order to show a universal method for problem solving. A simulation is an important and has a stable place in the production process and also in business practice. It is not a tool to solve all the problems, but could be used to quickly optimize and improve.

**Acknowledgement**
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# IMPLEMENTATION OF MONTE CARLO SIMULATION IN INVESTMENT DECISION MAKING

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***Keywords:*** simulation, investment, decision making, risk, efficiency
***Abstract:*** The aim of the paper is to point out to the risk analysis as an integral part of the evaluation of economic efficiency of investment projects. Traditional and probabilistic approaches of evaluation of projects efficiency are briefly characterized. The focus is taken on probabilistic tools, specifically on Monte Carlo simulation. Monte Carlo simulation utilization is demonstrated on a specific example from the economic practise. Businesses, in order to maintain their existence and ensure long-term effective development, must continuously invest into reconstruction and development of their technological base. Given that these investment projects significantly affect the future development of the company, it is important to assess their economic effectiveness in terms of profitability, liquidity and risk. Since the current business environment is developing dynamically and becomes uncertain, risk analysis shall receive in this process greater importance.

## 1 Introduction

Businesses, in order to maintain their existence and ensure long-term effective development, must continuously invest into reconstruction and development of their technological base. Given that these investment projects significantly affect the future development of the company, it is important to assess their economic effectiveness in terms of profitability, liquidity and risk. Since the current business environment is developing dynamically and becomes uncertain, risk analysis shall receive in this process greater importance.

## 2 Approaches to evaluation of investment projects

The traditional approach to evaluation of investment projects is based on financial criteria that the risk and uncertainty associated with the project either do not respected at all or only indirectly. Non-respecting of risk is associated with static criteria such as profitability and payback period of the project. Indirect integration of risk and uncertainty is associated with dynamic criteria such as net present value, index of present value, internal rate of return or discounted payback period. In this case, compliance of risk is implemented through a risk premium, which forms a part of the discount rate of the project.

The following facts can be considered as shortcomings of this approach [1], [5]:

- This is a single-scenario approach because cash flows of the investment project under consideration are based on a single, usually the most likely development of internal and external factors affecting cash receipts and cash expenditures of the project during its economic lifetime.
- Risk and uncertainty are taken into account only non-formalized as another aspect of the evaluation of investment projects.
- Optimism of managers who often underestimate the probability of an unfavourable development of individual risk factors affecting the results of the evaluated projects.

Shortcomings of the traditional approach to the evaluation of investment projects can be somewhat weaken by a sensitivity analysis. The substantial increase in quality of investment decision making in terms of respect of risk and uncertainty can be provided by probabilistic approaches, specifically scenarios and simulations. Monte Carlo simulation belongs to the most significant simulation models. It is used when there are more risk factors, usually of continuous nature. Its essence lies in generation of a large number of scenarios (hundreds to ten-thousands) and calculation of criteria for each scenario.

The main reason for using a Monte Carlo simulation is the quantification of the probability distribution for the overall project risk [4], [7]. On the basis of this distribution can be stated the expected value of project risks and how probably this value will be in the range of our interest [3], [8].

This method has also some drawbacks. These include high labour intensity and complexity especially when determining the probability distribution of risk factors and

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respect of their dependence. The greatest deficiency is considered the fact that the key risk factors that influence the most the results of the risk analysis are often based on an assessment of the present and past unpredictable. This can lead at the simulation to so called tunnelling effect and thus decrease the sensitivity of the search of new risk factors [2], [6].

## 3 Application of Monte Carlo simulation of concrete investment project

Risk analysis based on Monte Carlo simulation is applied on the project, which is aimed to expand the production of sanitary products. Its aim is to select such production equipment, which enables to achieve the required production volume and react flexibly to changes of market requirements in production assortment.

### *3.1 Economic evaluation of investment project*

Economic evaluation of investment project precedes the risk analysis which is based on the most likely scenario. It is processed using a financial model created in MS Excel. The financial model includes:

- *Input data* for determination of cash flows of the project and monitored financial criteria (such as investment costs, production volume, selling price, material consumption, energy consumption, repair and maintenance costs, personnel costs etc.).
- *Cash flows of the project* which take into account the construction period and the operation period of the production equipment. The construction period of the project is set at two months. The economic lifetime of the project is identified with the depreciation period of production equipment, i.e. estimated for a period of six years.
- *Financial criteria* for evaluation of the economic efficiency of the project are net present value (NPV), index of present value (IP) and discounted payback period (DPB), and criteria for risk analysis is net present value.

Calculated values of the above mentioned financial criteria are indicated in Table 1.

*Table 1 Financial criteria of the project*

| Indicator | Unit | Value |
|---|---|---|
| NPV | EUR | 2,282,800 |
| IP | coefficient | 1.69 |
| DPB | year | 3.48 |

From Table 1 it clearly results that the investment project is economically efficient. However, despite positive values of financial criteria, it is probable that the real development of input variables of the investment project can deviate from the considered most probable values. For this reason a risk analysis of the considered investment project processed.

### *3.2 Risk analysis of investment project*

Risk analysis using Monte Carlo simulation is carried out in the Crystal Ball system, which is an extension of MS Excel. The output variable is NPV whose base case is determined by the traditional approach (Table 1).

Risk factors of the project are determined using sensitivity analysis. They are followed in relation to the NPV at isolated changes of individual input variables by ± 10% from their most probable values. Twenty three risk factors have been considered. The results of the sensitivity analysis showed that the key risk factors include investment expenditures, sales price, material costs and production volume.

Uncertainty of individual risk factors is displayed using the normal distribution (risk factor is production volume), lognormal distribution (risk factor are investment costs) and Beta PERT distribution (risk factors are selling prices and material costs).

The probability distribution of selected risk factors of the investment project is illustrated in Figure 1.

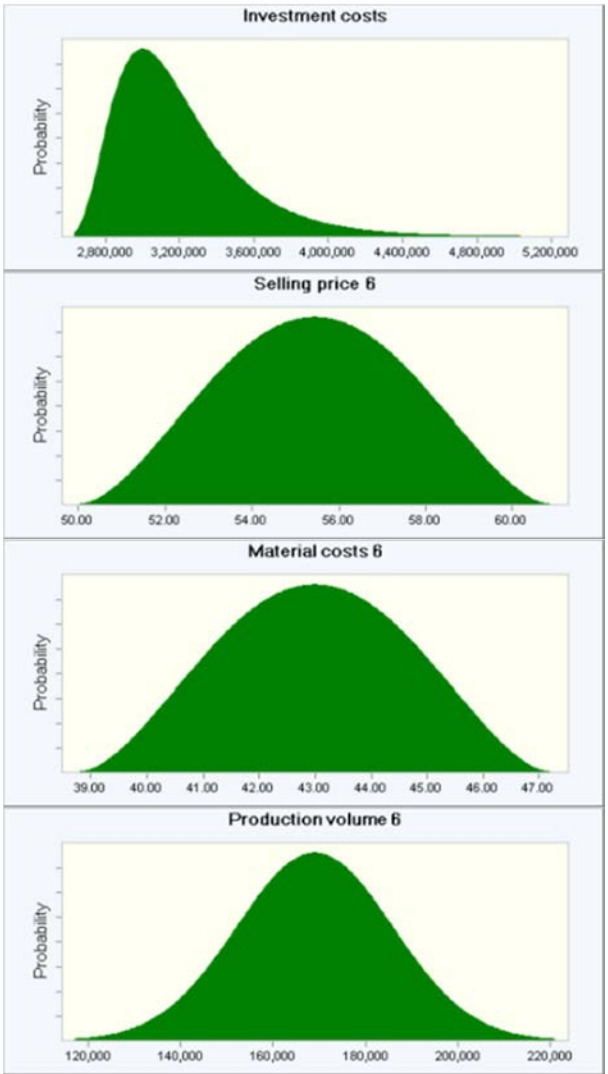


*Figure 1 Probability distributions of selected risk factors*

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The results of Monte Carlo simulations. The primary outputs of the Monte Carlo simulations are the probability distribution of NPV, statistical characteristics and percentiles (Figure 2).

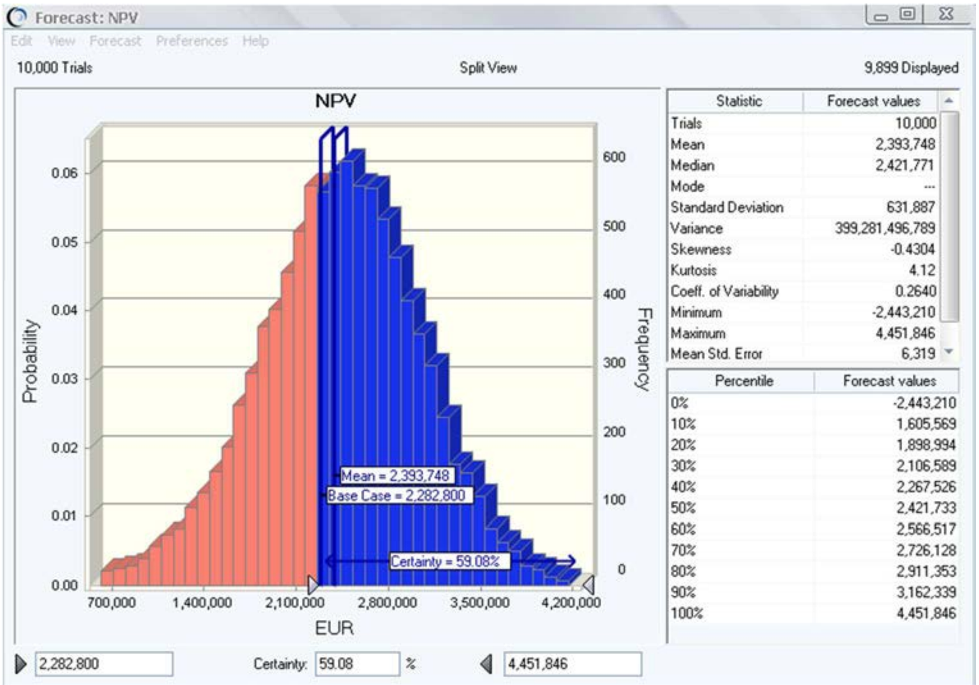

*Figure 2 Probability distribution of NPV*

Based on the values of statistical characteristics it is possible to mention the following conclusions. Mean value of NPV is by EUR 110,948 higher than the NPV calculated by traditional approach. With the probability of 95% the NPV of the project is expected in the range from EUR (- 2,443,210) to EUR 4,451,846. The probability that the NPV of the project shall exceed the most probable scenario is 59.08%, which means that lower values than EUR 2,282,800 shall be achieved with a probability of 100% - 59.08% = 40.92%. NPV probability distribution is approximately symmetrical; skew has a negative value, indicating that it is slightly inclined to the left, towards lower NPV. Given that the probability distribution of NPV is approximately symmetrical, variability characteristics of standard deviation, variance and coefficient of variation represent appropriate measure of risk of the project in relation to the NPV.

Another important output of the simulation is a sensitivity graph of NPV (Figure 3). It provides information about contributions of selected risk factors to the overall risk of the project in relation to the NPV, in both, graphical and numerical form.

It is evident from Figure 3 that the most important risk factor is the investment costs that contribute to the risk of the project by 36.5%. Another important factor is the selling price in year 4 of the project operation, whose contribution to the risk is 9.0%. The selling price is a risk factor monitored in time series.

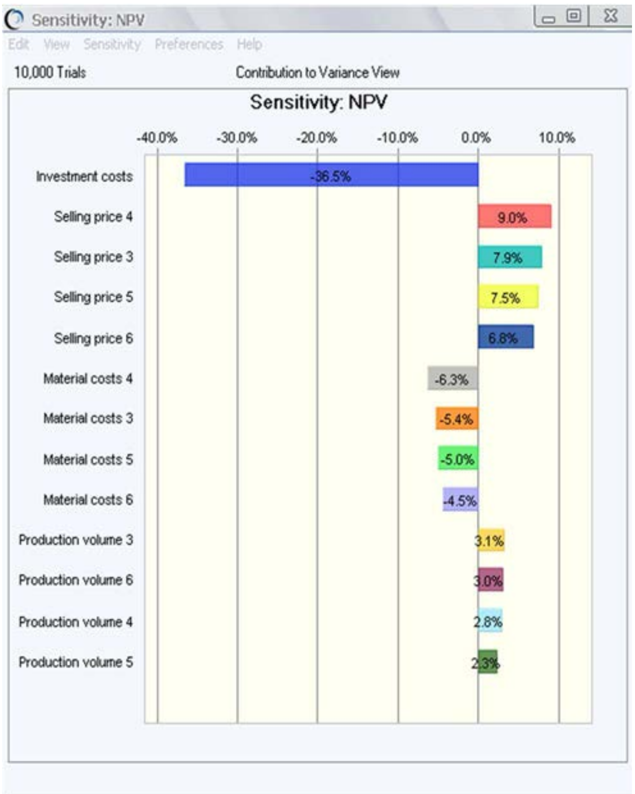

*Figure 3 Sensitivity of NPV chart*

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Thus, its cumulative contribution to the risk of the project for the period from the third until the sixth year of operation is 31.2%. The amount of contribution of risk factors material costs and production volume circulates by respective years in range from 2.3% to 6.3%. In both cases, these are also risk factors monitored in time series. Attention should be paid to material costs for which the cumulative contribute to the risk of the project amounts to 21.2%. In order to reduce the risk of this project it is appropriate to focus attention on the first three risk factors.

## Conclusions

The paper presents a probabilistic approach to evaluation of the investment project, which complements the indicators of traditional approach by thorough risk analysis. From an economic point of view, the assessed project is effective. The risk of the project is further analysed using Monte Carlo simulations. Based on simulation results it can be concluded that the project bears a low risk. However, application of Monte Carlo simulation is not a one-time event. The simulation should be repeated always when changes in the development of the analysed risk factors of the project have been detected, or when new risk factors have been identified.

**Acknowledgement**
This article was created by implementation of the grant project KEGA 004TUKE-4/2013 "*Intensification of modelling in teaching II. and III. degree in the field of study 5.2.52 Industrial Engineering*".

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# PROJECTING OF WORKING ACTIVITY BY USE OF TECHNOMATIC JACK

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***Keywords:*** working activity, physical load, simulation
***Abstract:*** Projecting of workplace and working activity by use of simulation enables flexible adjustment to new conditions and simultaneously implementation of ergonomic principles in the phase of proposal. In the article is given the analysis of working activity by use of tools of program Technomatix Jack and also the creation of the model of workplace as well as simulation of analysed working activity in the given program. By proposal of simple measures, repeated simulation and calculations it points at the possibility of solution of the analysed problem. An advantage of using Computer Aided **-** CA systems is that all changes in real system may be first simulated with a goal to predict their influence on behaviour and running of the system.

## 1 Introduction

For solution of problems in working system human – machine – environment are used computer systems which enable simulation of human factor in 3D environment. Big software systems are focused on full vital cycle of the product, superstructures of systems solve partial tasks from the area of ergonomics, independent software applications for complex solution of ergonomics are focused on certain areas, e.g. interior of the car and by help of small software applications are solved specific problems e.g. loading of the backbone of human during lifting burdens, etc.

## 2 Use of software application Technomatix Jack at projecting of working activity

For study of behaviour of human being during work with possibility of simulation and optimisation of working environment and also simulation and evaluation of influence of working activity and workplace on the human being is used the software application Technomatix Jack. This application is determined for study of human behaviour during work. Simultaneously it simulates mutual bonds in the system human – machine – environment with regard to ergonomics, effectivity of work and physical load of the worker [6], [7]. The result is a workplace which considers the abilities and possibilities of worker and enables more effective, more productive and safer production [2].

An advantage of using Computer Aided - CA systems is that all changes in real system may be first simulated with a goal to predict their influence on behaviour and running of the system. The simulation model is a dynamic system where occur events and states as in the investigated system and in the same order however in the majority of cases in various time moments [5].

### *2.1 Tools of task analysis in program Technomatix Jack*

The system of tools of Task Analysis in software Jack includes tools for ergonomic analysis by help of which it is possible to propose tasks in production with optimal safety and productivity [3]. Individual tools and their characteristics are given in table 1 processed according to [10].

*Table 1 Tools of task analysis*

| Tools | Charakteristics |
|---|---|
| *Low Back Analysis* | Evaluation of forces influencing the hip area of the backbone of virtual figure in the given position and with the given load. |
| *Niosh Lifting Analysis* | Determination of weight of the burden with which it is possible to manipulate safely in long term. |
| *Manual Handling Limits* | Determination of maximal acceptable weight for manual working acts. |
| *Working Posture Analysis* | OWAS – simple and fast check of comfort during work and determination of measures. |
| *Static Strength Prediction* | Determination of % of workers who manage to perform a certain task on the basis of determined position, effort and anthropometric parameters. |
| *Predetermined Time Analysis* | Estimation of time necessary for performance of work on the basis of movements, by help of system of measurement (MTM-1). |
| *Fatigue/Recovery Time Analysis* | Enables proposal of manual working activities with minimal risk of fatigue of the worker. |

| | |
|---|---|
| *Metabolic Energy Expenditure* | Estimation of demands for energetic output during certain work by help of characteristics of worker and description of tasks. |
| *Rapid Upper Limb Assessment* | Evaluation of risk of injury of upper limbs on the basis of position, involvement of muscles etc. |

# 3 Analysis of working activity

Projecting of working activity by use of Technomatix Jack was realised for firm which deals with production of aluminium castings for car industry by method of pressure casting. The investigated working activity is surface finish of aluminium castings of various shape and size. Factors which during this working activity influence the worker are as follows [4]:

- *noise* – the worker uses hearing protectors during all working shift,
- *lighting* – during unloading and inspection of the castings the artificial lighting is screened,
- *height of manipulation plane* – if it is not optimal the backbone and the body of workers are stressed,
- *physical load* – repetitive working activity can lead to overloading of exposed part of the body and also to decline of work productivity. Long term one sided pursuit of such activity leads to development of occupational diseases.

## *3.1 Analysis of physical load*

Castings with which the worker manipulates have a weight from 0.2 kg to 4 kg. They are the main factor at assessment of the extent of physical load on the worker. The worker carries out a demanding movement which causes loading of knees, backbone and hands. At regularly repeated activity during all working shift the probability of injury or development of disease is high. For decrease of local load it is necessary to make a complete analysis of working activity and working position. Its part is also the application of selected methods of evaluation of physical load.

The results of evaluation of working activity by tools are shown in figure 1. The model of workplace is created straight in Jack program. Into the virtual workplace is located a precise digital model of the human being [8], [9]. The result of Lower Back Analysis tool, which assesses the influence of load on hip area of the backbone is a small load on the area around vertebra L4 and L5.

From evaluation of position by help of Working Posture Analysis tool it results that the repetition of working movements can cause a serious damage of musculoskeletal system and it is inevitable to take corrective measures.

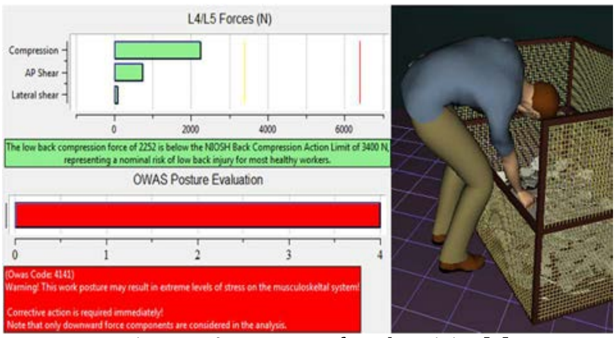


*Figure 1 Assessment of work activity [1]*

Since the results of evaluation of position by help of these two tools are greatly different a further tool was used for analysis of working activity – RULA. Detailed results of evaluation of position of upper limbs together with final score and proposals for solution are shown in figure 2.

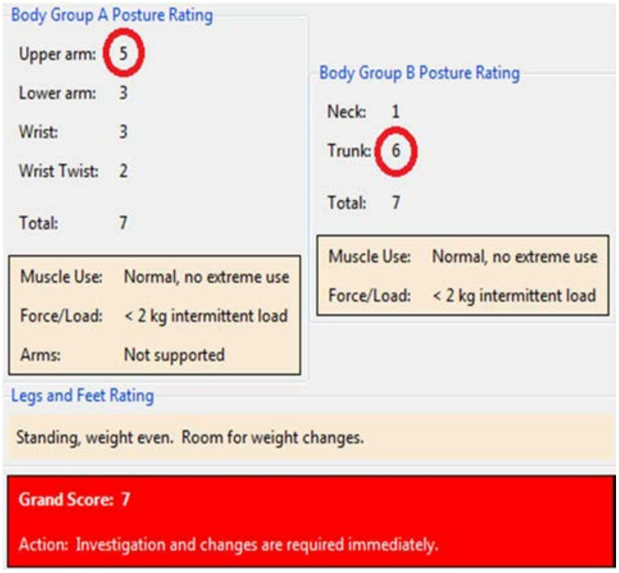


*Figure 2 Assessment of position by RULA tool [1]*

According to tool RULA is achieved score 7 what means that it is not allowed to perform this working activity during all working hours and it is necessary to take corrective measures for removal of detected risks. An advantage of application of RULA method is shortening of running time of evaluation of working position and flexible adjustment to conditions.

From comparison of results of three tools which were used for evaluation of physical working activity it results that the analysed working activity represents for the worker a risk of health damage.

Based on the results of an analysis carried out by help of Task Analysis tools in Technomatix Jack program a simple measure was proposed the introduction of which would cause decrease of excessive influence of physical load in the workplace of sanding and so the investigated

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working activity would also be made easier for the human being.

### *3.2 Way of decreas eof excessive loads*

A model of workplace was created in Technomatix Jack program .

The given model of workplace is composed of:

- model of guide rail,
- model of crate,
- model of sanding machine,
- model of container.

Individual components and items of workplace model are shown in figure 3.

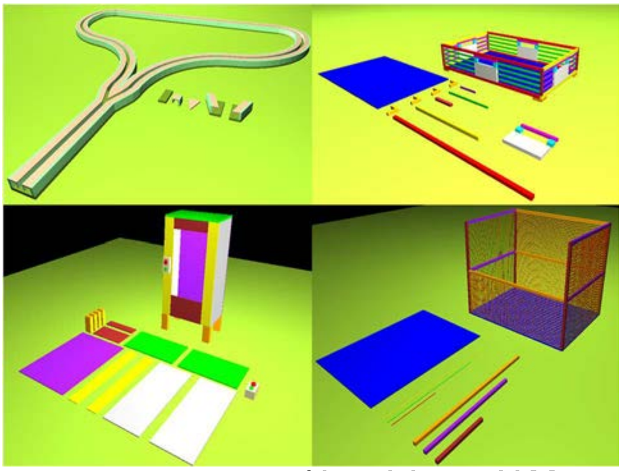

*Figure 3 Components of the workplace model [1]*

For simulation of working activity there was used the digital model of human being. The model of workplace of sanding cleaning of aluminium castings is shown in figure 4.

*Figure 4 The model of analyzed workplace [1]*

After creation of the model of workplace and implementation of model of the worker it is possible on the basis of the time of duration of individual working tasks to create a simulation of analysed working activity.

In model of the analysed workplace were solved the proposed measures with the goal of decreasing the physical load the influence of which was provably risky.

For removal or decrease of physical load are used measures of technical and organisational character. Technical measures have priority therefore for making the analysed working activity easier a forklift was proposed. Its use would remove the inappropriate working position in forward bend as well as decrease the load influencing the hands and body of the worker at manipulation with material. The model of forklift which serves the lifting of container with castings or pallet with cranes was created in the Technomatix Jack program. The truck is able to lift the container into the height which suits the worker best. Model of forklift is shown in figure 5.

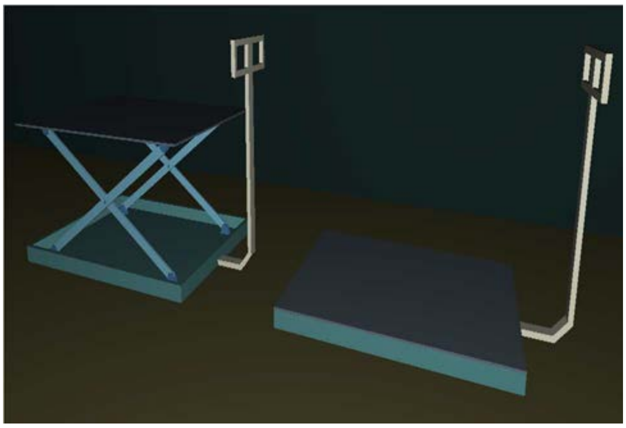

*Figure 5 Model of forklift [1]*

It is possible to adjust the forklift to workers with various body heights. The truck is mobile the worker will put it on the place which suits him. The surface of the truck is the same as the surface of the container. For verification of the correctness of proposal were used the same methods as before its introduction. Removing castings from the container and storing them on the hanging tree is by use of forklifts significantly facilitated. From the results of evaluation of tools RULA, Lower Back Analysis and Working Posture Analysis it results that a reduction in physical activity occurs in all assessed areas. The evaluation of physical load before and after implementation of the measure (proposal of forklift) is shown in figure 6.

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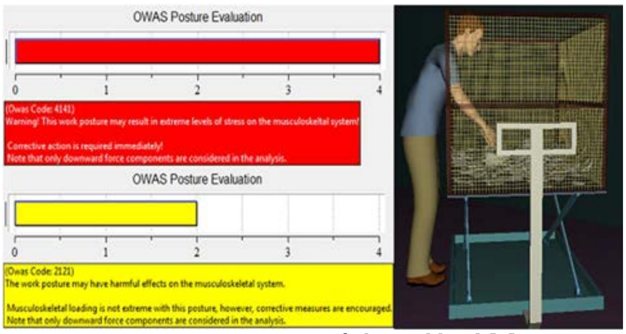

*Figure 6 Assessment of physical load [1]*

Tool Working Posture Analysis shows decline of score of loading during the analysed working position by 2 degrees what represents a change from critical unacceptable position to position with mild load.

Decrease of stress occurs also in the area of hip, the load decreased almost by half. This is confirmed also by results of evaluation by help of tool Lower Back Analysis. (Fig. 7) [1].

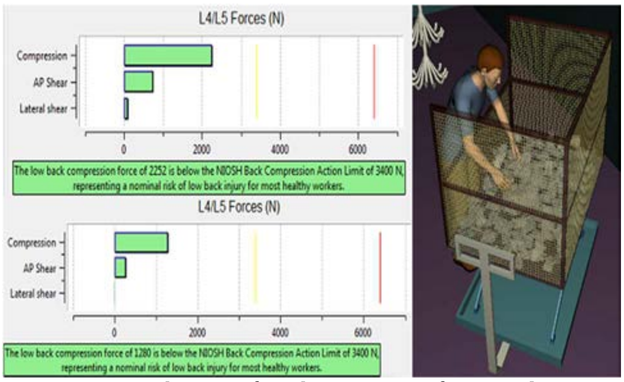

*Figure 7 Evaluation of working activity after introduction of measure*

Evaluation of load by RULA method points at improvement almost in all indexes. It was necessary to decrease the load mainly in the area of upper arm and body where the load at original position was critical. The results of evaluation of load before and after proposal of forklift are shown in table 2 prepared according to [1].

*Table 2 Evaluation of original and proposed position*

| Position | Evaluation | | | | |
|---|---|---|---|---|---|
| | Upper arm | forearm | wrist | body | Total score |
| Original | 5 | 3 | 3 | 6 | 7 |
| After introduction of proposal | **3** | 3 | **1** | **3** | **3** |

In green colour is marked the score which points at improvement of evaluation after introduction of proposed measure. The score has an unchanged value only at forearm. The total score at evaluation of physical load by help of RULA method decreased by 4 degrees what means improvement of working position from unacceptable to acceptable with mild physical load.

A benefit of introduction of measure of technical character into the analysed working activity and working position is simplifying of working activity, decrease of physical load, decrease of risk of threatened health but simultaneously also increase of productivity of work and effectivity of production.

## Conclusions

At performance of physical working activity there is a frequent occurrence of diseases of musculoskeletal apparatus which can result in occupational diseases. By revealing the risks which result from inappropriate working environment and inappropriately projected working activity it is possible to prevent the threatening of health of workers. It is possible to reveal these risks by help of created digital models and simulation of working activity.

By application of ergonomic tools of Technomatix Jack program and realisation of corrective measures it is possible to remove excessive physical load and to project the working activity so that it may not threaten the health of the human being and may enable him to provide optimal working performance.

**Acknowledgements**
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# THE REVERSE VALIDATION OF TRAJECTORIES FOR ROBOT

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***Keywords:*** reverse validation, inertial navigation system, robot, operation

***Abstract**:* The paper comments the new possibilities of utilizing the inertial navigation system in a manufacturing technique. It deals with new principles of robots and inertial navigation systems based robotized production systems operating reliability. The inertial navigation is self-supporting navigation technique utilizing for measuring accelerometers and gyroscopes. By them it is possible to watch a position and orientation of an object relative to a known starting point. Currently, for the 3D inertial navigation execution the inertial navigation system (INS) is used and you can encounter it on the board of army or civil airplanes where it is the primary source of navigation information. INS includes one navigation computer at minimum and a platform or module comprising accelerometers and gyroscopes. The reason to use INS for navigation is its autonomy and impossibility of purposeful interrupting its operation from the outside.

## 1 Introduction

The inertial navigation is self-supporting navigation technique utilizing for measuring accelerometers and gyroscopes. By them it is possible to watch a position and orientation of an object relative to a known starting point. A basic element of each inertial navigate system (INS) is inertial measure unit, that consists usually of three gyroscopes for angle speed measurement and three accelerometers for linear speeding-up measurement [1], [2] . By processing of the signals from this equipment it is possible to watch the position and orientation.

Inertial navigation is known by its application especially in aircraft industry, tactical and strategic missiles, space ships, submarines and ships navigation. The small, light and price accessible navigation systems with a chance to be applied also in other areas are produced on the present thanks to the MEMS (Micro-Electro-Mechanical Systems) technologies expansion.

A continual economic force of cost minimization and technological processes streamlining require innovations and improving. The new methods require detailed analysis of the issue and searching for new solutions. Among effects that require practical attention there belong also manufacturing technique inertial navigation systems applications, which can be applied for machines stability control, vibration progress observation in mechanical technologies, robots and robotized production systems operative, production system clashing cases preventing et cetera.

Continuous assessment of the controlled and navigated robot using the sensors for motion detection, i.e. gyroscopes and accelerometers can be ensured by inertial navigation. Via the navigation computer and data obtained from the motion detectors the position, orientation as well as the direction can be constantly determined without using external information sources. The current position of the object is assessed on the basis of knowing the initial position and subsequent continual measurement of acceleration and direction of the motion in the reference system. The inertial navigation principle is based on Newton´s laws expressing the motion change at using the external forces as well as the acceleration which is proportional to the orientation and size of the external force [3], [4].

## 2 Inertial navigation system analysis and description

Currently, for the 3D inertial navigation execution the inertial navigation system (INS) is used and you can encounter it on the board of army or civil airplanes where it is the primary source of navigation information. INS includes one navigation computer at minimum and a platform or module comprising accelerometers and gyroscopes. The reason to use INS for navigation is its autonomy and impossibility of purposeful interrupting its operation from the outside. The sensors of acceleration (accelerometers) as well as the sensors of angular velocity (gyroscopes) are firmly attached to the platform connected the navigated means.

The basic element INS is represented by IMU, Inertial Measurement Unit. Sensors whose outcome is influenced only by object motion on which the IMU is located are considered as primary sensors of IMU. These primary sensors in the inertial navigation are used for n are represented by angular velocity/speed sensors whose output signals after integration are used for the determination of orientation in space and the accelerometers whose output signals after precise compensating the gravitation acceleration and Coriolis force can be integrated into the velocity and position. Platform-free systems have the sensors located into the 3D coordinate system so that each axis of the navigated object corresponds to the accelerometer´s sensitivity axis as well as to the angular velocity sensor. Such an inertial measurement unit has six degrees of freedom, i.e. it allows the measurement of transaction and rotation movements in three-orthogonal axes. The inertial sensors accuracy is of key significance in the autonomous navigation [5].

For industrial robots the orientation, or precise determination of the programmed point in space is the necessary condition for their moving without collision or accident which is essential not only of a robotic device but of the running process as well. Currently, when for increasing the reliability of robotized workplaces operation in the production technology comes into consideration the main orientation is on integrating the inertial navigation systems into the control process and operation control of robotic as well as other peripheral means of production systems [6], [7] .

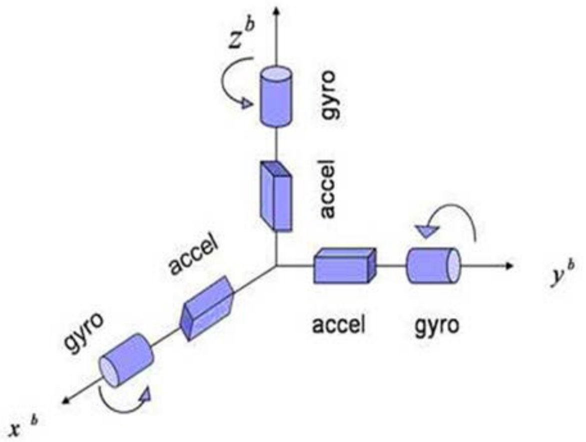


*Figure 1 Basic principle of INS activity*

A new and not researched control method of robots´ trajectory as well as of other means and components in production so far is represented by utilizing inertial navigation systems on the basis of hybrid MEMS (micro-electro-mechanic-systems) sensors which appeared not long ago. The research in INS is running in several branches of industry related to aviation, rockets, ships, however, nobody has researched these systems implemented in the field of control neither control of industrial robots in real time.

Inertial navigation system consists of a measurement unit comprising gyroscopes rotating around three axes X, Y, Z, then three accelerometers operating in these axes X, Y, Z (see Figure 1) and a navigation computer assessing data obtained from measurement devices/instruments.

The basis is represented by the system of autonomous robot´s trajectory control aimed at the prevention of collisions. In the new concept, the control of the current position is dealt with by the autonomous system of accelerometers and gyroscopes in three axes [8]. Another progressive method, not frequently used so far, is the utilization of INS in the system of robot´s trajectory control. If the robot´s position is not calibrated on a regular basis, the deviation will continuously increase and big differences between the real robot´s position and programmed position can grow which is unacceptable for practice.

The navigation autonomy, i.e. independence on external sources of navigation information was the main reason for INS implementation. In contrast to all other navigation systems the inertial navigation is completely self-sufficient and independent on external environment, i.e. the system can resist external influences such as magnetic faults, electronic disturbances and signal deformation.

If we implement INS as an independent control into the robot´s control system, the programmed position will be constantly compared to its real position in the working environment. Thus, the robot´s position will be continuously checked and calibrated via the navigation computer [9], [10], [11]. The deviation does not grow and there are no differences between the real and programmed positions of the robot.

## 3 Position of the Robot

In determining the position of a robot as well as its management is the ability to use the device, which works in the inertial coordinate system and can determine the position of the arm of the robot in its workspace. In this case, the robot arm is equipped with a detection device (an inertial navigation system), which detects the speed, acceleration and rotation of the arm of the robot in the coordinate system. Using this system, it is possible to determine the position of a robot in space very well where the other methods for the detection of the position cannot be used. The position can be obtained subsequently adjusted according to the requirements and the robot arm is then able to watch any route to reach the desired position.

Location data obtained from the inertial measuring device are sent to the management computer, which compares it with the required values and those are subsequently adjusted, so the required position can be reached by the robot arm. The data from the management computer are sent to the robot using a robot control system. The process of sending and checking data is called reverse validation [12].

Inertial measurement unit measures the kinematic values - angular velocity and linear acceleration. The earth can be considered an inertial system if we neglect spin, then taking into account a kinematic theory is true: if we know the initial position of the object as well as its initial speed at the object at the time while we measure R, together with the acceleration using accelerometer placed on the shoulder of the robot, so we can determine the speed of the object at the time.

Due to the use of mathematical operations integration occurs over time position error. The size of this error depends on the type of inertial measuring system or on the quality of the accelerometer in the system. One of the options to remove the positioning error is resetting the zero point of inertial measurement system at regular intervals.

In determining the position of a robot using a gyroscope, inertial measurement unit using the angular velocity ω measured around the axes x, y, z in Cartesian coordinate system. From the measured angular velocity using mathematical adjustments we calculate the angular rotation φ. This represents a motor rotation respectively rotation of each arm of the robot. So thanks to the output data of the gyro we can determine the position of the robot arm in space [13], [14]. The output of the gyro can be analogue or digital. Processing outputs is using the management computer to calculate the necessary change in order to move the robot arm to desired position in space. This type of controlling position is called a reverse validation.

When measuring the rotation of gyroscope an error occurred when integrated, which increases over time. This is also possible as in accelerometer removed by resetting the zero inertial measurement system. A fundamental difference between the accelerometer and gyroscope is that error of integration in accelerometer is greater than in gyroscope due to a double integration [15].

## 4 Application of inertial navigation system

Figure 2 shows robot 1 controlled by the central computer 2. In the place of robot 1 which is prior defined the autonomous system INS 3 is located and is connected to the navigation computer 4 which is connected via the series peripheral interface SPI 5 to the central computer 2. This way it is possible to continuously control the trajectory as well as the position of the observed point in the working environment of the robot 1.

If the initial position of robot 1 is defined, the initial position of INS 3 attached to the robot 1 is defined as well. The motion and current position of robot 1 controlled by the central computer 2 in the working environment is continuously checked and compared to the data of the autonomous INS system 3 about the position by the navigation computer 4 via the series peripheral interface 5.

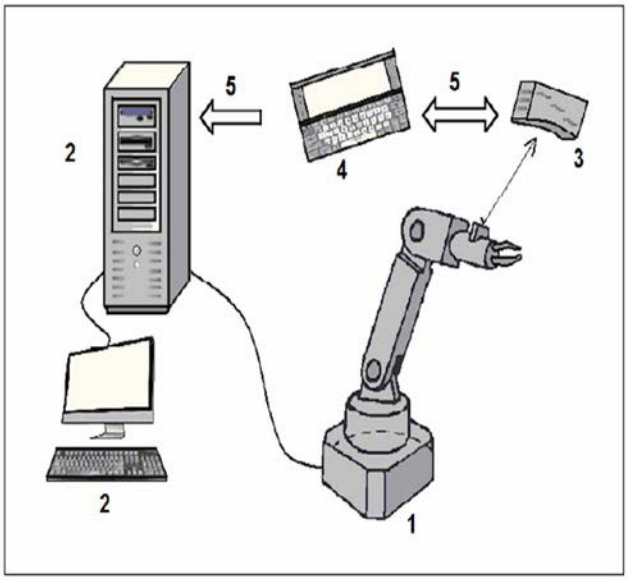


*Figure 2 Implementation of the robot´s autonomous trajectory control*
*1 – robot, 2 – central computer, 3 – inertial navigation system, 4 – navigation computer, 5 – series interface*

The navigation computer 4 validates the immediate position of robot 1 and by means of the series SPI peripheral interface 5 it communicates with the central computer 2 making thus the position of robot 1 more precise. This way the robot´s position is constantly assessed and specified by autonomous INS. We speak about Reverse Validation [16], [17] .

Once the autonomous INS system is applied in the system, no position sensors are necessary. During the repetitive motions robot 1 records the position deflections to the programmed position exponentially growing with the operation time. To minimize the measurement deflections, it is necessary to carry out the continuous calibration of the robot´s position by the system of autonomous control of the robot´s trajectory. When we deploy the autonomous INS system into the control system of robot 1, the calibration is not needed since the autonomous INS system constantly communicates with the navigation computer 4 via the series SPI peripheral interface 5. The central computer 2 assesses the data from the navigation computer 4 and compares them to the data form the control program. Then by the evaluation of the differences in data, it immediately declines the deflection to minimum in real time.

## 5 Conclusion

For industrial robots the orientation, or precise determination of the programmed point in space is the necessary condition for their moving without collision or accident which is essential not only of a robotic device but of the running process as well. Currently, when for increasing the reliability of robotized workplaces operation in the production technology comes into consideration the main orientation is on integrating the inertial navigation systems into the control process and operation control of robotic as well as other peripheral means of production systems [18].

A new and not researched control method of robots´ trajectory as well as of other means and components in production so far is represented by utilizing inertial navigation systems on the basis of hybrid MEMS sensors which appeared not long ago. The research in INS is running in several branches of industry related to aviation, rockets, ships, however, nobody has researched these systems implemented in the field of control neither control of industrial robots in real time.

The system of autonomous control of the robot´s trajectory can be used for the determination of the precise robot´s position in its working environment.

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# OPTIMIZATION OF NON-PRODUCTION PROCESSES

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***Keywords:*** non-production processes, management decisions, process
***Abstract:*** The success of major part of companies depends on offered product, its price and promotion and also on many other factors, e.g.: product innovation, quality of service, reliability, fast and flexible reaction on customers' needs, substitution of sequential processes by parallel, etc. For these reasons, companies should deals with business processes. They should also define and implement business processes accurately because performance of company directly depends on the performance of business processes. The article deals with improving the program of non-manufacturing business processes and defines individual steps that need to be analysed in detail.

## 1 Introduction

Process approach to corporate management is not only a competitive advantage but also one of the requirements of the ISO certification. Competitive environment leads companies to deal with their processes and find the ways to improve them. Power of customers caused that importance of marketing specialists who study the market and look for new forms of competition increased. Price is not the only determining factor. Due to the influence of competitive environment there arisen the problem of insufficient adaptability of companies with traditional organizational structure. The process organization with an effectively functioning quality management can react quickly to changes and also can maintain or improve its market position. One of the key factors of success is to accept change as part of the daily life of company. If company wants to be wants to be successful, it must look for new improvements and new product innovation. Company must assume an attitude both to products and processes. Appropriately selected monitoring and measuring processes will reveal weaknesses in organization which are also an opportunity for improving processes [2], [4].

## 2 Methods of improvement non-production process

If we want to improve the processes in non-production areas it is necessary to obtain management support. Managers have to decide if it is necessary to start process of improving. Then company can move to the next step which is particularly important for the philosophy of lean administration. Some company employees should be interested in process. All interested persons should be prepared and trained. Then some non-production areas should be analysed. At this stage the best methods that allow visualizing initial level will be applied. Then it is necessary to identification waste and vulnerabilities in non-manufacturing processes. Also we have to focus on the types of waste that occur in administration. After correct analyse in non-manufacturing process and after correct identification of waste it is needed to eliminate the waste and it is necessary to implement methods of improvement. The last step, called the audit of program improvements, evaluate the rate of success in removing waste in non-production area. The principle of individual steps is shown in figure 1 [1].

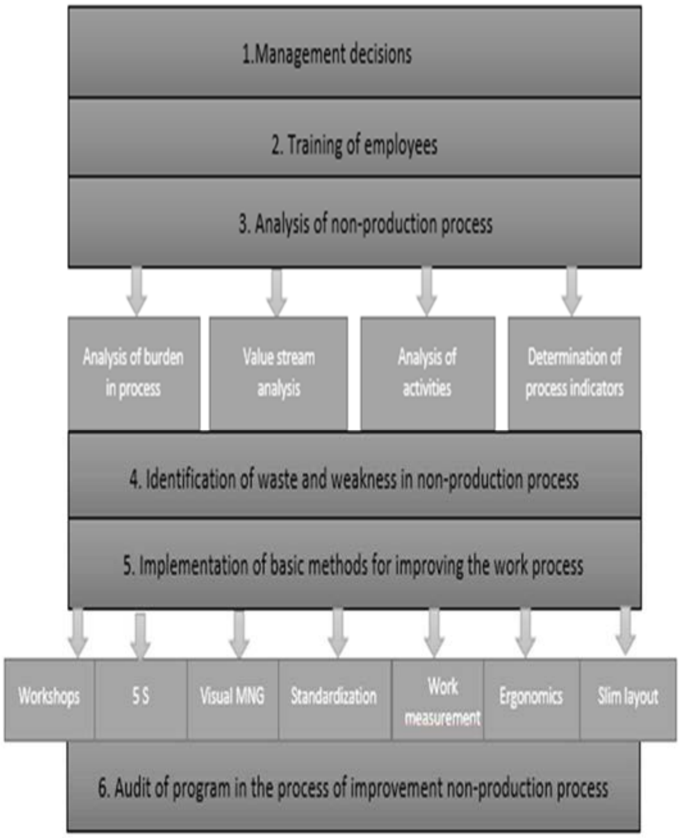


*Figure 1 The principle of improvement non-production process*

### *2.1 Management decisions*

Company management is responsible for the first step. It must decide if it is necessary to begin systematic process of improvement and if arrived the time of transfer to non-productive processes. This decision is not easy for managers because they get out of passive role to an active role. If this program will be realized, managers must become leaders of this program. Support for company management in decision-making can be, for example [3]:

- plan for the development of non-production areas within the frame of development of multinationals operating system,
- pressure from production,
- negative case studies of non-production processes,
- identified information from benchmarking,
- seminars, workshop about opportunities for improvement in the non-production processes.

### *2.2 Training of employees*

It is necessary to point out one difference compared to programs implemented within the production area. Profile of administrative workers differs in the level of educational attainment, higher ability of autonomous education, better practical skills related to complex processes, better possibility to influence the running process, etc.

In consequence of these differences, it is necessary to use a slightly different approach in the training of workers in administrative processes and choose the following principles [3]:

- inspiring form of training,
- materials and resources for self-study,
- training of analytical methods,
- own diagnosis of processes,
- training of teamwork
- definition of project and project management.

### *2.3 Analysis of non-production process*

In analysing of non-production process, it is necessary to use the best available techniques, which describes the initial state of process. First of all we are interested in description of burden the process, which usually has more dynamic features than process in the manufacturing sector. Furthermore, it is necessary to record material, information and value flow in the non-production process. We also have to put our mind to static description of the process by means of specific indicators, which are in some cases very similar indicators of production activity. Finally, we focus on the structure of the individual activities that are carried out in the process and their number is expressively larger [3], [5].

### *2.4 Identification of waste and weaknesses in non- production process*

During the identification of weakness in non-production process we can use knowledge of traditional forms of waste, but it is also important to focus on waste that is specific for non-production processes.
The basic forms of waste in administrative activities are following [4], [6]:

#### 2.4.1 Surplus production

It includes activities that do not increase company profit. It means they do not add value to the customer for which is customer willing to pay. Even the Japanese themselves consider this kind of waste as the worst. Examples are following:

- duplicate data storage (electronic and paper)
- problems given duplicate,
- extensive email distribution list.

#### 2.4.2 Unnecessary processes, procedures

It includes activities that we do in addition. Our customers do not need them. It is important to take a think whether activities that we do are useful and optimized and if they add some value. Here we can include the following activities:

- more information than the need to job performance,
- few documents to job performance,
- complex workflows.

#### 2.4.3 Information flow

Larea points out that waste is any movement of material and information that are not used for delivery of products or services directly to the customer.
Examples can include the following:

- complex information flows,
- capacity of information on the same shared disk,
- non-standardized information flows,
- inappropriateness of using the data format, for example: transport documents.

#### 2.4.4 Overstock

This kind of waste we encounter if we use, e.g.: building, office supplies, materials and products for offering the services by inappropriate and inefficient way. It means the way that does not add value. Excess Inventory is all resources in the process that we use even earlier than required. We have to realize that any stock requires space and during the process of accumulation we use the space, which can be used in other ways. These include:

- redundant provision,
- a lot of stored data and the excessive accumulation,
- lot of emails waiting to be processed,
- unused recycling.

#### 2.4.5 Unnecessary movements

It represents kind of waste that is either within the enterprise deployment and information system, or it is a distribution within the office or department. Examples:

- team does not work under one roof,
- inefficient layout of space in the administration,
- inefficiently organized meetings,
- mismanagement of space.

#### 2.4.6 Errors and corrections

If there are some mistakes in administrative activities we must perform that activity repeatedly. For that reason the activity is considered to be unnecessary. Whole process requires additional investment, time and work, so it does not contribute to the creation of added value. In practice, we meet with missing information, which are impulse for formation the next error.

- misunderstanding of assignments,
- incorrect specification of tasks,
- errors in documentation, incorrect background papers and not updated document
- layout of job, regardless of the potential customer.

#### 2.4.7 Wait state

Waiting arises when people wait for delivery of documents, waiting for meeting, for worker, for signature, etc.. This kind of activity is considered as a waste, because waiting can´t add value to the product or service. The most frequent types of waste in this area are:

- incorrect prioritization,
- waiting for the competent decision
- representation which extend the deadline,
- waiting for information, decision or materials.

#### 2.4.8 Inactiveness of knowledge

Exists in area where knowledge and skills of workers are not used. Development of corporate employees is the most important element to strengthen the competitiveness of company. Most of companies decelerate this development and do not invest in their workers. The most common methods in inactiveness of knowledge are:

- unused creativity of employees in the company,
- lack of training courses and workshops for improving processes,
- lack of support when submitting proposals for improvement.

#### 2.4.9 Unergonomic ways of working

It is important to make sure that the workplace and work tools are compatible with good ergonomics and its demands, so that everything will ensure good and safe health and promote the best medical services. Unergonomic ways of working are followed: working conditions - poor climate and noise at the workplace, maladjustment job aids and tools. This analysis belongs to complicated disciplines because different kinds of these losses coexist for a long time and thus become an accepted problem.

### *2.5 Implementation of basic methods for improving the work process*

Before we begin to implement any of methods, we need to analyse its advisability and adequacy. In general, there is a certain portfolio of basic methods for service, expense and administrative processes, which are also the basis for implementation more complex and complicated methods. These methods include [2], [7]:

- development of teamwork,
- utilization of methods of management by objectives and visions BSC,
- utilization of workshops to beating up,
- introduction of 5S in non-production areas,
- utilization of various forms of visual management,
- development of standardization in workplace,
- analysis of time-consuming work activities,
- application of working ergonomics,
- deal with slight layout.

### *2.6 Audit of program in the process of improvement non-production processes*

Evaluation of initial improvement program has several forms. Except the quantification aspect of improved the non-production process through the medium of selected process indicators, there are also mini audits of individual steps and methods of improvement [2].

## Conclusion

Reasons of process performance measurement do not have to be same for each organization. Through that, some reasons have common features and one of them is implementation of quality standards. Results that were found by measurement of processes performance:

- analyse problem that happened and deals with abstention of information. On the base of obtained information it is possible to eliminate concrete problem and manage individual processes effectively without unnecessary losses,
- help identify key business processes and their inadequacies. (It is more efficient to ignore the process that is not significant for company, but it is important to deals with key processes that have a significant impact on earnings, turnover, etc. and eliminate processes which are irrelevant and unprofitable. ),
- provide a real background papers of problem (Business management intuitively anticipate that something is not all right but only results of measurement allow the to compare the actual situation with the plan.),
- are available for identifying relationships between inputs and outputs as well as for

analysis of total results and their assignment fractional.

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