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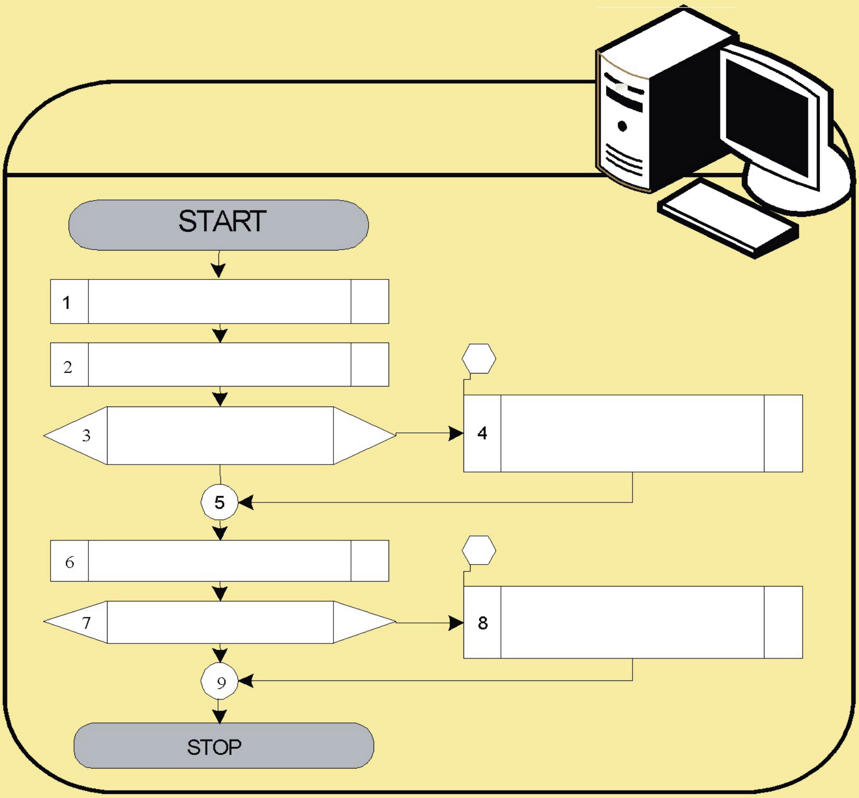

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deep drawing, Al alloys, sheet metal, numerical simulation

Jan SLOTA[*], *Ivan GAJDOS*[*], *Tomasz JACHOWICZ*[**],
Marek SISER[*], *Volodymyr KRASINSKYI*[***]

FEM SIMULATION OF DEEP DRAWING PROCESS OF ALUMINIUM ALLOYS

Abstract

This paper presents results of research with FEM simulation of sheet metal forming process. The two types of aluminium alloys from 5XXX and 6XXX series, which are used in automotive industry, were compared. The computer simulation and numerical analysis of deep drawing cup test were used to predict the ability of the forming of these alloys. The plasticity model Hill'90 was used for stamping simulations. The results of numerical simulation were validated by real experiment using sheet metal testing machine Erichsen 145-60. Both results were compared with regard to prediction accuracy in changes of thickness and ear profile.

1. INTRODUCTION

The increasing demands to reduce the fuel consumption of passenger cars, reduce consumption of energy and emissions released into atmosphere is a challenge for current automotive industry. Because of that the application of aluminium sheets became one of the main aspect in automotive.

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Its characteristic features, high strength, stiffness and density, excellent formability, great corrosion resistance and potential of recycling make it an ideal replacement for heavy materials, like steel and copper, in cars as a response to the requirements of weight reduction of auto body parts [1, 2].

Reduction of weight is mainly important because it is expected, that average vehicles weight will increase and automotive industry will continue to produce new models with high performances, luxury interior focused on high comfort and safety of passengers. As a rule, saved 10% of vehicle mass approximately equals a 5,5% reduction of fuel consumption.

Reduction of mass have a significant effect on fuel efficiency, for example if we are able to reduce weight of engine while maintaining the same parameters. This fact force the care manufacturers to consider using more of alternative materials (e.g. aluminium, composites or plastics) for auto body parts [1, 3].

Despite the excellent properties of aluminium, during the stamping several issues may occur. One of them is that elastic module of aluminium is about two-thirds lower that of steel and aluminium is therefore more susceptible to springback. This phenomenon is usually reduced by increasing of blank holding force, the amount of stretching and the sheet thickness. It is not always possible to increase the material thickness and increasing the blank holder force can cause disruption of material. Nevertheless it is possible to reduce the wrinkling by using the appropriate blank holding force. Also it is necessary to use appropriate lubrication for aluminium forming. The smoother texture of alumi-nium request dry, waxlike lubrication [4, 5].

This work is related to using of finite element method (FEM) for predicting of forming process of simple axis-symmetric cup. Influence of numerical model on quality of simulation results related to experimental results was compared. The thickness distribution, strain distribution, ear profile and punch forces were identified using experimental data and numerical simulation. In simulation mainly yield criteria, hardening curve and friction were considered, because these parameters have significant effect on precision of the numerical simulation results. In this work, two different aluminium alloy materials AW 6082 T6 and AW 5754 H11 were applied. It is shown, that the theoretical predictions are substantiated with experimental data from laboratory tests on a two grades of aluminium alloy sheets.

2. EXPERIMENTAL PROCEDURE

In this experiment we used two different materials from aluminium alloys, which are widely used in automotive industry mostly to obtain auto body components. Two different materials, frequently used in the car manufacturing industry were considered in this study: age hardened AW 6082 T6, which is mostly used to manufacture of outer auto body panels since it is precipitation hardened and free of Lueders bands and AW 5754 H11, which cannot be heat-treated is used for inner panel applications due to the formation of Lueders bands during forming. Thicknesses of materials were 1 mm for AW 6082 T6 and 0.8 mm for AW 5754 H11. Both materials were medium strength Al alloys with good corrosion resistance and their chemical compositions are shown in Table 1 and Table 2, respectively.

Tab. 1. Chemical composition of AW 6082 T6

Chemical composition	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Other
[%]	1.00	0.50	1.20	1.30	0.10	0.20	0.10	0.25	0.15

Tab. 2. Chemical composition of AW 5754 H11

Chemical composition	Mg	Mn+Cr	Mn	Si	Fe	Cr	Zn	Ti	Cu	Other
[%]	3.60	0.60	0.50	0.40	0.40	0.30	0.20	0.15	0.10	0.15

The mechanical properties of used materials were measured from tensile test. This test was carried out on universal testing machine TiraTEST 2300. The specimens used in tensile test were cut in the 0°, 45° and 90° directions related to rolling direction. Basic mechanical properties and levels of planar anisotropy are ilustrated in Table 3 and Table 4.

Tab. 3. Results from mechanical testing of AW 6082 T6

Dir.	$R_{p0,2}$ [MPa]	R_m [MPa]	A_{80} [%]	r [-]	r_m [-]	Δr [-]	n [-]	n_m [-]	Δn [-]
0°	314	342	13.7	0.528	0.588	-0.139	0.087	0.086	0.0003
45°	307	337	14.2	0.657			0.086		
90°	313	341	12.0	0.509			0.086		

Tab. 4. Results from mechanical testing of AW 5754 H11

<table>
<tr><th>Dir.</th><th>$R_{p0,2}$ [MPa]</th><th>R_m [MPa]</th><th>A_{80} [%]</th><th>r [-]</th><th>r_m [-]</th><th>Δr [-]</th><th>n [-]</th><th>n_m [-]</th><th>Δn [-]</th></tr>
<tr><td>0°</td><td>146</td><td>231</td><td>14.7</td><td>0.655</td><td rowspan="3">0.797</td><td rowspan="3">-0.214</td><td>0.282</td><td rowspan="3">0.283</td><td rowspan="3">-0.0002</td></tr>
<tr><td>45°</td><td>136</td><td>220</td><td>19.6</td><td>0.904</td><td>0.283</td></tr>
<tr><td>90°</td><td>137</td><td>221</td><td>18.8</td><td>0.723</td><td>0.283</td></tr>
</table>

Deep drawing cup tests were performed on universal sheet metal testing machine Erichsen 145-60 with a tool set B2. With this test, it is possible to establish, if the material supplied corresponds to the prescribed technological properties. The equipment is shown on Figure 1. This tool set consists of cutting and drawing tools with hydraulic ejector located in the punch. The blanks were cut using the cutting tool originally equipped on machine. Diameter of the blank was 90 mm.

Fig. 1. a) universal testing machine Erichsen 145-60,
b) tool set for deep drawing cup test [source: own study]

Figure 2 shows the geometry of the tool used in deep drawing cup test. It was the symmetric tool for drawing of cylindrical cups with the die inner diameter of 52.5 mm and punch outer diameter of 50 mm. Die radius was 5 mm and punch radius was 3 mm. The drawing ratio of process was $\beta = D/d = 1.8$ mm. Applied blankholder force was constant during the whole process and set on value 8 kN. In order to minimizing of the friction coefficient and preventing of cup tearing, special lubrication by PTFE foil was applied. During the test, both of the punch and the blankholder forces were measured.

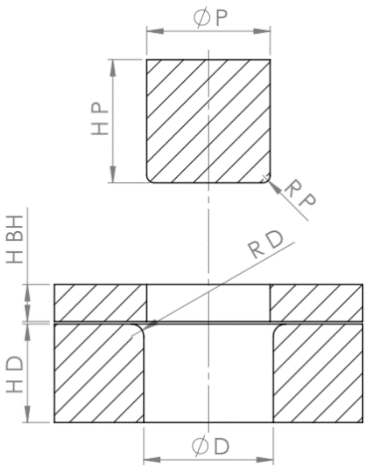

Fig. 2. Geometry of the drawing tool used in deep drawing cup test [source: own study]

It was proposed to investigate the relevance of the FEA approach to predicting the deep drawing process of an aluminium alloys, focusing on the yield criterion as numerical parameter which considerably affect the results [6].

Numerical simulation of process consists of two steps. The first step was holding the sheet metal between the die and the blankholder. The second step was drawing of cylindrical cup by the punch. FEM model of the deep drawing test with typical phases of the process is shown in Figure 3. As for the simulation of the test, the FE explicit code was used to solve the problem. Parameters of numerical simulation process are given in the Table 5.

Tab. 5. Parameters defined in explicit code of FEA

Parameter	Value	Parameter	Value
Mesh type	Triangular	Element type	Shell
Mesh size	5 mm	Friction coefficient	0,05
Level of refinement	2	Yield function	Hill90
Mesh size after refinement	1,25 mm	Hardening curve	Krupkowski
Number of integration points	5	Tool mesh	0,5 mm

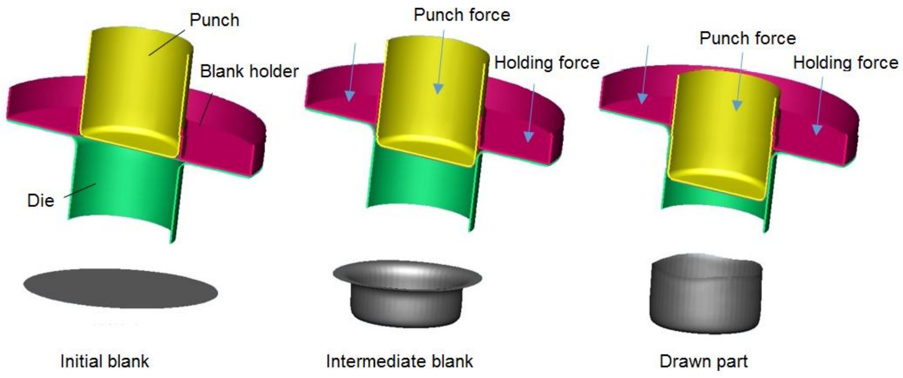

Fig. 3. Main steps of deep drawing cup test [source: own study]

The yield function define the condition for the elastic behaviour limit under multi-axial states of stress, after which the material continues deforming plastically until failure, showing a hardening behaviour. The plasticity models Hill'48 and Hill'90 are usually used for stamping simulations. The Hill'48 yield locus is based on the R-values obtained from tensile tests in three directions: 0°, 45° and 90° to the rolling direction. The Hill48 criterion cannot describe the behaviour of sheet metals with an r-value less than the unity and the yield stress under balanced biaxial tension significantly higher than the uniaxial yield stress in the plane of the sheet. This behaviour was observed for aluminium alloy sheets having an r-value under 1.0. To capture this behaviour, non-quadratic yield formulations were developed for anisotropic materials. Hill proposed a non-quadratic form called Hill'90, which requires the identification of five material parameters, four from uniaxial tensile tests and one from balanced biaxial tests [7].

Material of blank defined in numerical simulation was in the case of yield function approximated using Hill 90 yield criterion for plane stress problems with planar anisotropy, which is defined by following law:

$$\left(\frac{\sigma_1}{\sigma_0}\right)^2 + \left(\frac{\sigma_2}{\sigma_{90}}\right)^2 + \left[(p+q-c) - \frac{p\sigma_1 + p\sigma_2}{\sigma_b}\right]\left(\frac{\sigma_1\sigma_2}{\sigma_0\sigma_{90}}\right) = 1 \tag{1}$$

where: σ_0 – uniaxial tensile yield stress in the rolling direction,
σ_{90} – uniaxial tensile yield stress in the direction normal to the rolling direction,
σ_b – yield stress under uniform biaxial tension, and *c, p, q* are parameters defined as:

$$c = \frac{\sigma_0}{\sigma_{90}} + \frac{\sigma_{90}}{\sigma_0} - \frac{\sigma_0 \sigma_{90}}{\sigma_b^2} \tag{2}$$

$$\left(\frac{1}{\sigma_0} + \frac{1}{\sigma_{90}} - \frac{1}{\sigma_b}\right) p = \frac{2R_0(\sigma_b - \sigma_{90})}{(1+R_0)\sigma_0^2} - \frac{2R_{90}\sigma_b}{(1+R_{90})\sigma_{90}^2} + \frac{c}{\sigma_0} \tag{3}$$

$$\left(\frac{1}{\sigma_0} + \frac{1}{\sigma_{90}} - \frac{1}{\sigma_b}\right) q = \frac{2R_{90}(\sigma_b - \sigma_0)}{(1+R_{90})\sigma_{90}^2} - \frac{2R_0\sigma_b}{(1+R_0)\sigma_0^2} + \frac{c}{\sigma_{90}} \tag{4}$$

where: R_0 – the R-value for uniaxial tension in the rolling direction,
R_{90} – the R-value for uniaxial tension in the in-plane direction perpendicular to the rolling direction.

According to [7], the use of Hill90 criterion is more appropriate than Hill48 for aluminium alloy and high strength steels. Advanced models like BBC2005, Corus-Vegter or Corus-Vegter Lite need a lot more test data which is not always available.

3. RESULTS AND DISCUSSION

Based on the measured mechanical properties in particular directions, we can say that the tested materials will behave very differently during forming. For achieve the best forming properties it is necessary for material to have low yield strength and also high ultimate tensile strength values, high value of elongation and ratio $R_{p0,2}/R_m$ as low as possible. The differences between max and min values in particular directions (0°, 45° and 90°) were up to 10 MPa for both materials. Coefficients of normal anisotropy r were less than the unity, what means that the strain occurs mainly as deformation in the sheet thickness.

Fig. 4. Drawn cups from materials AW 6082 T6 (left) and AW 5754 H11 (right) [source: own study]

The fully drawn cups of each material are shown in Figure 4. In the deep drawing cup test has been explored a number of parameters, as force on punch, cup height and wall thickness of drawn part. It was assumed that material AW 6082 T6 will need to deform higher force than material AW 5754 H11. The forces on punch are illustrated in Figure 5.

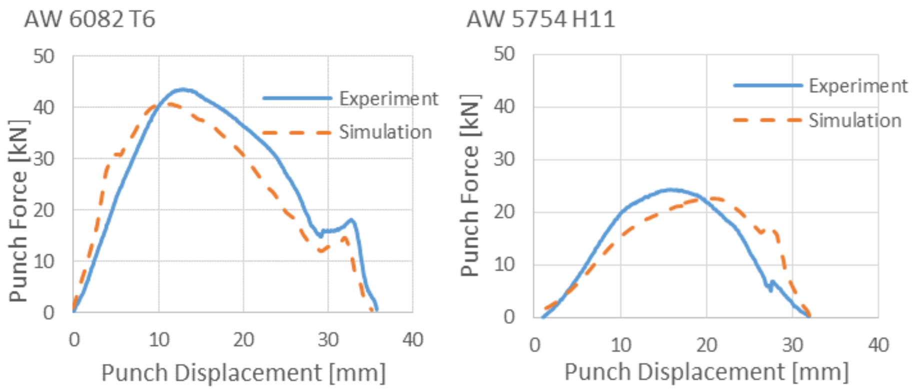

Fig. 5. Comparison of punch forces during the test [own study]

The maximum punch force for material AW 6082 T6 of 43.2 kN was obtained at the punch displacement value of 12–13 mm. In this time should be completely formed radii of a tool. The punch force decreased to value of the punch displacement at 28 mm. The force recovered due to the loss of contact between the blankholder and the die. The punch force again increase at value 32 mm because of ironing effect between the punch and the die. This was due to the increase of the blank thickness which occurred during the first forming step, when the material was strongly compressed circumferentially in the region of flange. Material AW 5754 H11 behave similarly just the maximum of the punch force was 24.3 kN and it was obtained at the punch displacement value of 15–16 mm. The force decreased to value 26 mm and then recovered to the punch displacement 28 mm.

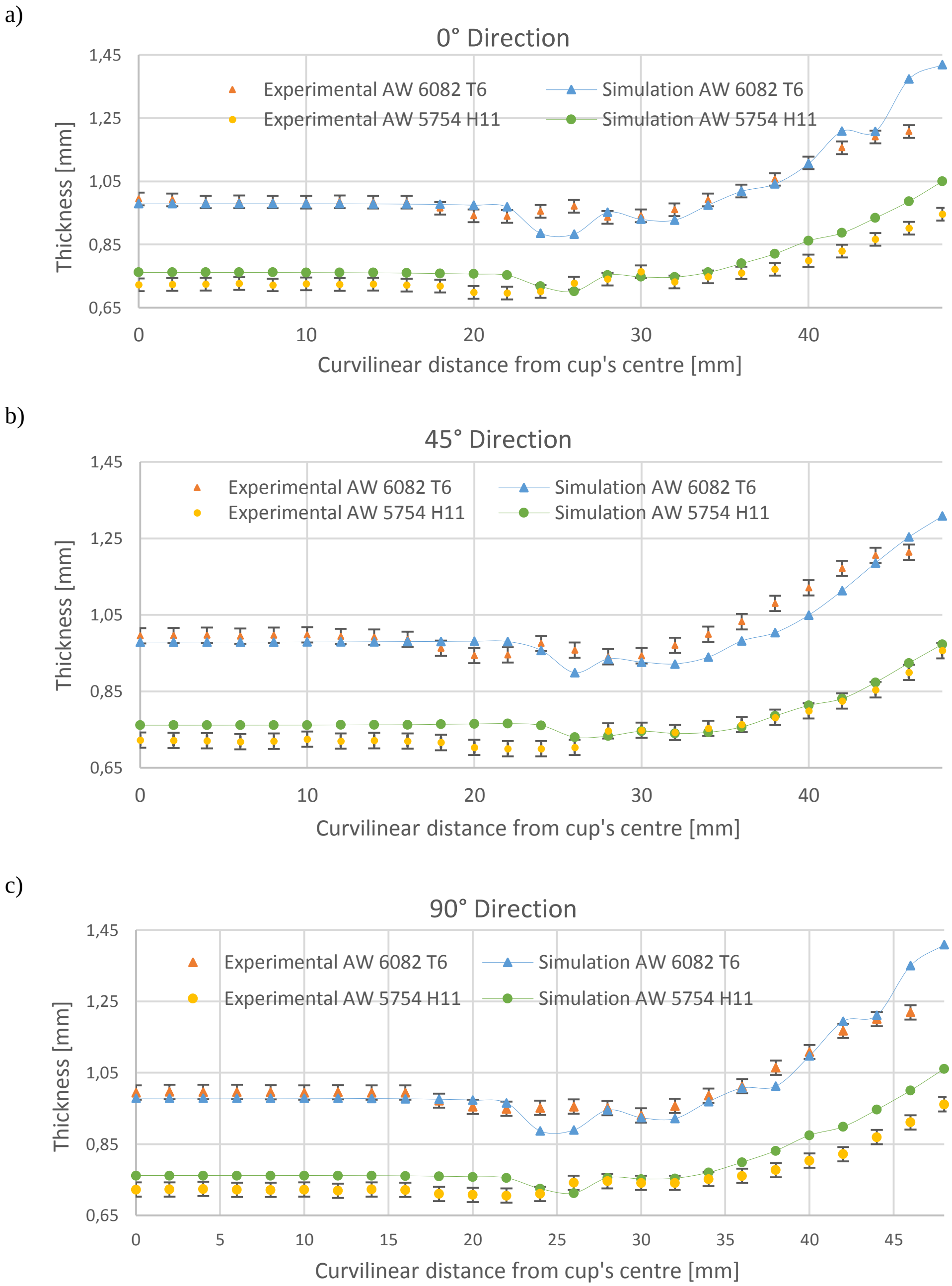

Fig. 6. Thickness distribution of the drawn cup measured at a) 0°, b) 45° and c) 90° with respect to the rolling direction [source: own study]

The thickness distribution of cup was measured too. Experimental samples were measured by micrometer in three directions and distance of measured points was 2 mm. On bottom of cups was thickness equal with value of initial blank. Closer to the radii of cup thickness starting to decrease. After the radii was completely formed thickness started to increase due to ironing effect (T6 – 141.9%, H11 – 139.9%).

The distribution of sheet thickness was compared with numerical simulation. The results are shown in Figure 6. We can see that the results from numerical simulation are very similar to values measured on real cups. The biggest differences are in the end of wall section, where thickness is influenced by ironing effect. Thickness in this areas increase rapidly, which is clearly shown in Figure 7. Results from numerical simulation are in good agreement with experimental results.

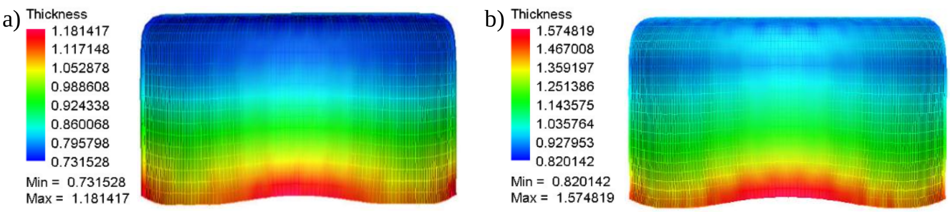

Fig. 7. Thickness distribution in drawn cups: a) AW 5754 H11, b) AW 6082 T6 [source: own study]

The cups was fully drawn without crack occurred. The area right after bend radius in the wall was the most critical due to minimal thickness of the drawn piece. Strain on the walls was high due to the ironing effect but there is no risk of fractures. Only risk on the walls was secondary wrinkling, but using appropriate blankholder force this effect was excised.

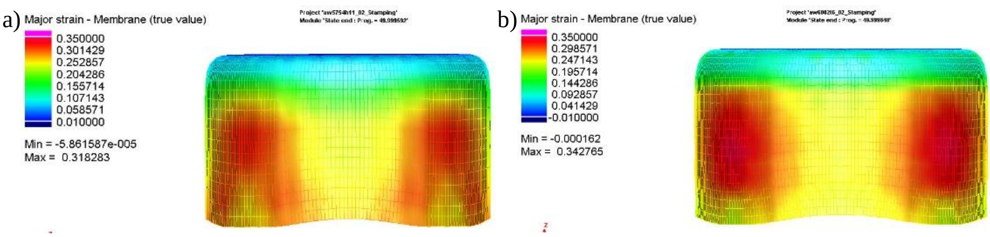

Fig. 8. Major strain distribution: a) AW 5754 H11, b) AW 6082 T6 [source: own study]

The next measured parameter was the ear profile of the cups, so the heights of cups were measured. The measurement was executed around circumference of drawn pieces with pitch of measured points after 45°. Creation of the ears is an undesirable effect of deep drawing processes and therefore materials with lower ear coefficient are more suitable for deep drawing process. The cup height is for material T6 approximately 30.11 mm whereas the punch displacement is 48 mm. For material H11 is the cup height higher with 30.26 mm and punch displacement is also 48 mm. This difference allows the cup to be fully drawn by the null value of the punch force at the end of process. The four peaks were at angles of 45°, 135°, 225° and 315° with respect to the rolling direction reached minimum height at 0° and equivalent position. No secondary peaks were observed as we can see in Figure 9.

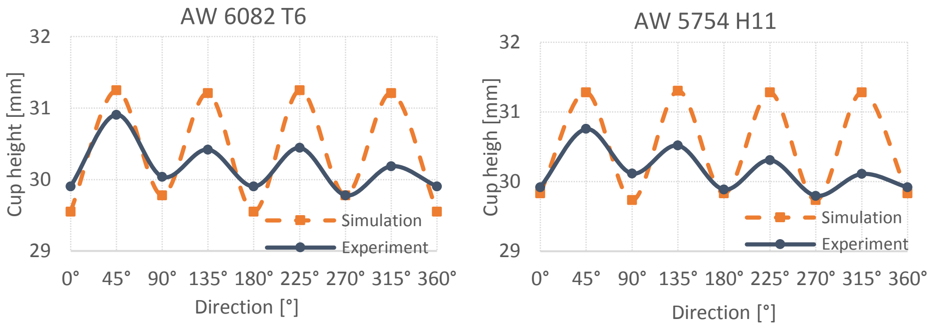

Fig. 9. Ear profile of the cups [source: own study]

The finite element analysis was used to compare results from real experiments performed on two different aluminium material with computed values from explicit solver. These results were compared in order to determine the adequacy of numerical simulation and they were the punch force, thickness distribution of cups in particular directions and ear profile of the cups.

In the case of punch force the maximum force measured during the experiment for AW 6082 T6 was 41.909 kN, while maximum force in numerical simulation was 43.193 kN (Figure 5). The overall course of forces form simulation was very similar to experiments. According to the simulation punch force increases rapidly in the beginning of the process and when the force was highest difference between simulation and experiment was around 3 kN, where simulation shown lower valued of force than was measured. The maximum force was measured at the same distance around 12–13 mm. After that the force start to decrease in the same rate in simulation and experiment and was lower around 2.5 kN in simulation.

The thickness distribution of a cups was confirmed by numerical distribution of the thickness and the ear profile is presented in Figure 9. Only the small deviations occurs in thickness distribution of the cup. The ear coefficient was computed from the equation:

$$h = \frac{h_{max} - h_{min}}{h_{min}} * 100\ [\%] \tag{5}$$

where: h_{max} – maximum ear,
h_{min} – minimum ear.

The ear coefficient of the experimental samples was 3.79% and numerical result 5.73% was little high than experiment. According to this information we can concluded, that material model set in simulation FE code is respond to behaviour of material in real conditions.

In case of the material AW 5754 H11, the punch force was 24.270 kN while maximum force in numerical simulation was 22.602 kN (Figure 5). For this material force do not fully reflect real experiment. Initially force rise in same rate as the experiment and therefore maximum force was reached later, at 15–22 mm. After reaching peak, the force gradually decreases. Position which show where the material was going out from under the blankholder appeared in the same place as during the experiment, but according to simulation the force should be much higher. The thickness distribution of a cups from AW 5754 H11 was slightly underestimate numerical distribution of the thickness and the ear profile is presented in Figure 10. The ear coefficient of experimental drawn piece was 3.22% and for the cup from numerical simulation 5.28%. This result is similar for both materials.

3. CONCLUSIONS

Influence of numerical model on simulation results was measured on simple axis-symmetric cups. Along with the numerical simulation, experiment under the same technological conditions, which served for comparison equality of results from numerical simulation and experiment was carried out. On the basis of carried out research it was shown, that model of yield criteria according to Hill48 is less proper for special alloys like Al alloys than other advanced models. Material of blank defined in numerical simulation was in the case of yield function approximated using Hill90 yield criterion. The results from numerical simulation are very similar to values measured on real cups.

The biggest differences in thickness distribution are on the end of wall section, where thickness is influenced by ironing effect. The punch force for material AW 6066 T6 was almost two-times higher compared to AW 5754 H11. The ear coefficient of experimental drawn pieces was similar for both materials and the difference between numerical simulation and real experiment about 1–2% was found.

Results from numerical simulation are in good agreement with experimental results. To reach better conformity of numerical results with experiments means keeping same technological conditions as in the real experiment and select advanced material models (especially yield criteria, friction and other), which need higher costs due to many necessary experiments, preparation of tests and data evaluation.

Acknowledgement

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Abaqus, xFEM, numerical analysis, crack propagation

Patryk RÓŻYŁO[*]

NUMERICAL ANALYSIS OF CRACK PROPAGATION IN A STEEL SPECIMEN UNDER BENDING

Abstract

The paper compares numerically modeled crack propagation in a steel specimen with a real process of fiber separation. The objective of the study was to perform numerical analysis of crack propagation in order to determine the shape of a crack and the distribution of stresses in the entire model. A CAD model of the test specimen was prepared based on geometric parameters determined for a real model. The numerical analysis was performed using the computer simulation program Abaqus 6.14. The experiment of specimen bending was conducted using bench tools. Crack propagation was simulated by the numerical method xFEM which enabled visualization of fiber separation in the test specimen. The numerical results of crack propagation were compared with the experimental findings about cracking in a real specimen.

1. INTRODUCTION

The process of permanent fiber separation is nowadays a common problem in operation of machines. The essence of improving operational conditions of machines lies in reducing manufacturing and structural defects of their subassemblies in order to avoid undesired problems in the future. Given their long-term operation, it is impossible to avoid occurrence of undesired processes that will have a negative effect on operation of these machines. The real degradation of their technical condition is often caused by temporary exceeding

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of both maximum fatigue strength and experimentally determined maximum strength of material. The most popular steel subassemblies are exposed to overload and failure on a nearly constant basis.

Crack propagation in machine components is a very complex problem. During their operation, structural members can be subjected to loads, which can lead to partial or total material decohesion. The current problems of crack mechanics were described in the study [4], which discusses the problem of microcrack development leading to element failure.

Cracking is defined as partial or total separation of material due to applied loads. The process of cracking is typically divided into three stages. The first stage of crack occurrence is the initiation of defects in material structure of a given member. Another stage consists in gradual development and combination of the initiated defects due to cracking, whereas the final stage involves the occurrence of the main crack that leads to failure of the structural member [7].

Crack propagation processes in steel machine components can be investigated by numerical analysis such as the finite element method (FEM).

The correctness of simulating real processes by numerical methods depends on defining their boundary conditions. It is also important to possess both the knowledge about essential properties of materials and the skill of defining interactions between implemented models. Also, what plays a significant role in crack analysis is the preparation of a finite element mesh (by xFEM).

Specialist simulation software enables predicting strains and stresses inside machine components by simulating real processes which occur when these components are being operated. The authors of the studies [5, 6] describe the application of finite element method to selected problems of engineering constructions mechanics.

The publications such as [2, 3, 8, 9, 10, 11] deal with advanced problems of crack propagation in materials resulting from the applied boundary conditions and loads acting on these materials.

Advanced systems for numerical computations such as ABAQUS allow us to generate a finite element mesh, thereby enabling us to simulate failure caused by permanent separation of material fibers.

The finite element method has a positive effect not only on improving properties of structural subassemblies, but also on reduction of stresses. In the long run, the reduction of material effort leads to longer and defect-free operations of the subassemblies. Correct analysis of structure design requires specific knowledge, skills, experience and time. Only in this way can defects of design be avoided in the future.

2. MATERIALS AND METHODS

The tests were performed on a C45 steel rectangular specimen with symmetric cut-outs in the centre. The numerical model of the real object was designed in compliance with the real specimen's geometric dimensions using Abaqus 6.14. The specimen was described by mechanical properties which are listed in a table given below.

Tab. 1. Characteristics of C45 steel [1]

Material: Steel C45	
Young's Modulus [MPa]	210000
Poisson's Ratio	0.3
Yield Strength [MPa]	360
Tensile Strength [MPa]	610
Elongation [%]	15.5

The numerically modeled element was assigned plastic-elastic properties. The tested model was characterized by relatively small overall dimensions. The main aim of the research was to determine the shape of fiber separation for the investigated cracking problem. The sample was designed with basic mechanical properties due to static analysis.

Since the numerical computations only involved the problems of statics, neither time nor specimen weight were examined.

The geometric dimensions of the object are given in mm, while the specimen itself has a nominal thickness of 1 mm. The real and numerical models are shown in the figures given below.

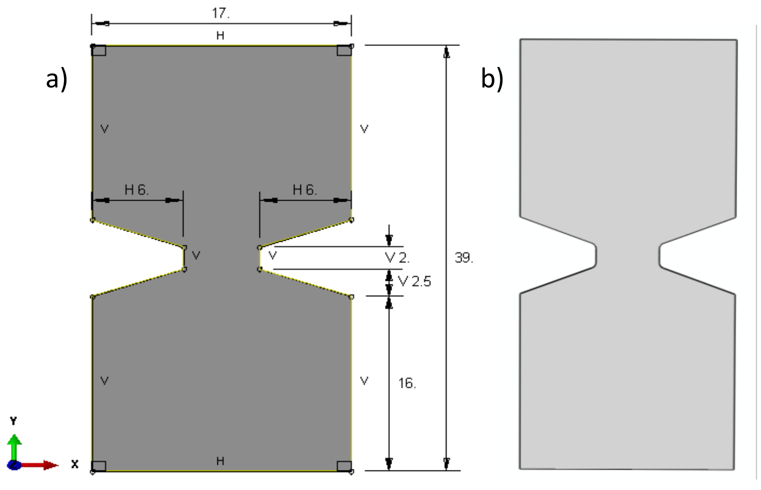

Fig. 1. Test specimen: a) geometric dimensions, b) numerical model with internal fillets at 0.5 mm narrowing [source: own study]

Fig. 2. Real specimen [source: own study]

The numerical model entirely reflected the measurements made on a real element. The numerical model was described by suitably defined boundary conditions which complied with the real process of crack propagation. Some part of the external upper and lower surfaces were totally fixed (all degrees of freedom were blocked) in the spots indicated in a figure below. The lower part of the specimen's flank was subjected to load in the form of 10 MPa pressure. The pressure was distributed uniformly over the entire surface and acted in the opposite direction to X of the global system of coordinates, which led to specimen bending. The boundary conditions describing the test specimen are shown in a figure below.

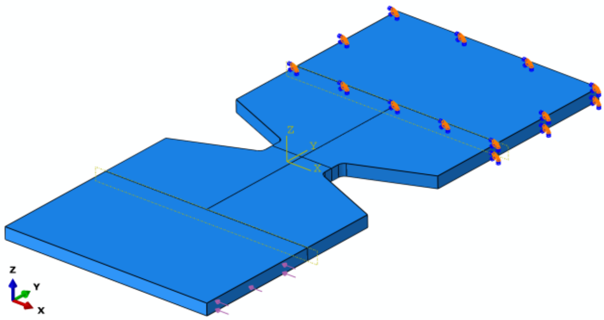

Fig. 3. Boundary conditions of the numerical model [source: own study]

The discretization of the numerical model was performed for the highest possible preparation of a finite element mesh. The numerical model of the specimen was partitioned in order to obtain the most accurate possible type of FEM mesh. The partitioning was continued until a hexagonal mesh was generated. This kind of mesh yields optimal results for solid models. The finite element mesh was made up of hexagonal elements using the Sweep mode (which is typically used for simple geometry elements). The elements were made more dense relative to the central axis of the entire object. The object was modeled using C3D8R elements with 10998 mesh elements and 15332 nodes. The C3D8R elements with three degrees of freedom and reduced integration produce highly accurate results because false forms of strain are eliminated due to the application of higher order polynomial equations [12]. The developed numerical model and the finite element mesh are shown in a figure below.

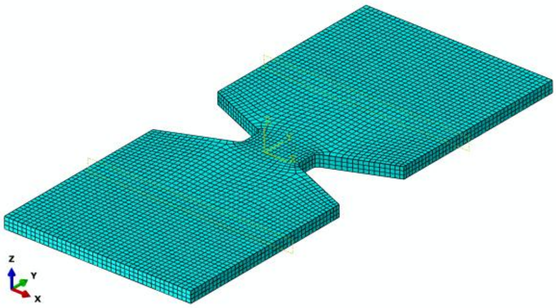

Fig. 4. Numerical model with a FEM mesh [source: own study]

The mesh density was increased not only globally but also locally in order to obtain the best results possible. To this end**,** three mesh elements were generated over the thickness of the entire model to obtain more precise analysis results. When using the finite element method, it is important that the meshing and mesh density be prepared in a correct way in order to prevent false results and stress concentration in unexpected regions. Crack propagation was initiated in Abaqus using the xFEM method (to initiate and propagate processes of material fiber separation) for the entire numerical model. The real model was mounted in a vice and subjected to bending with bench tools until material cracking.

3. RESULTS

The numerical results reflect the stages of cracking and enlargement of the crack's shape. The form of crack propagation was modeled numerically by the xFEM method. Based on critical stresses (when the material suffered permanent specimen failure), the program indicated the region and direction of crack initiation in the model. Implemented in numerical environment, the advanced xFEM method allows us to simulate crack initiation and its development once the parameters of the analyzed process have been precisely defined. The results of crack propagation in the test specimen as well as increases in stresses and local enlargement of the simulated crack are shown in figures below.

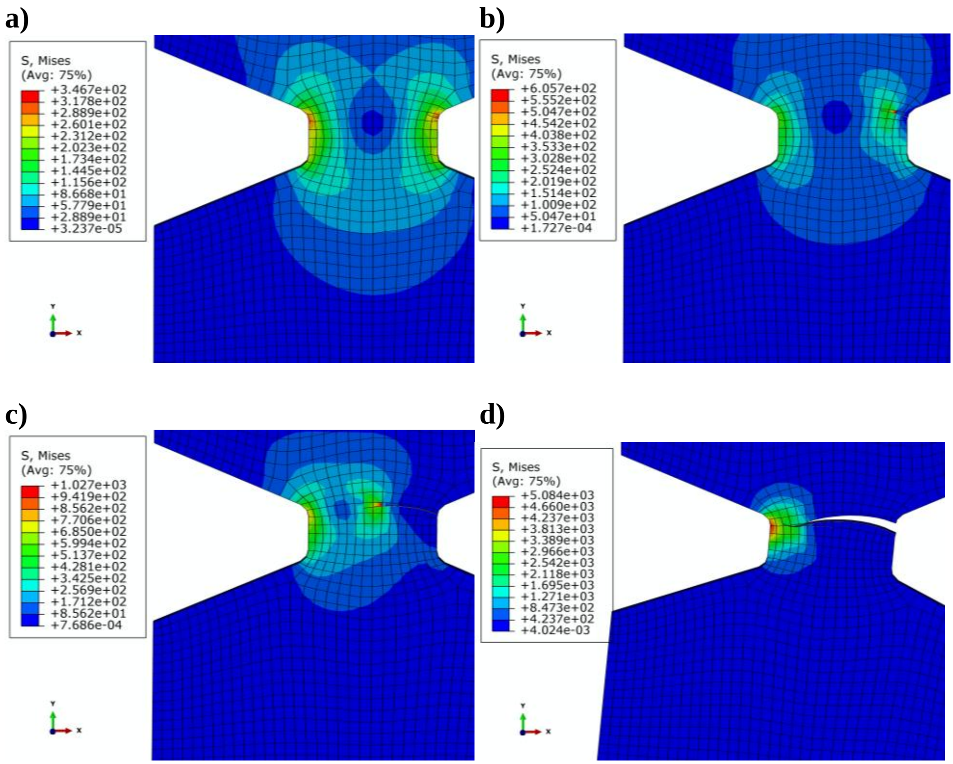

Fig. 5. Crack initiation and propagation [source: own study]

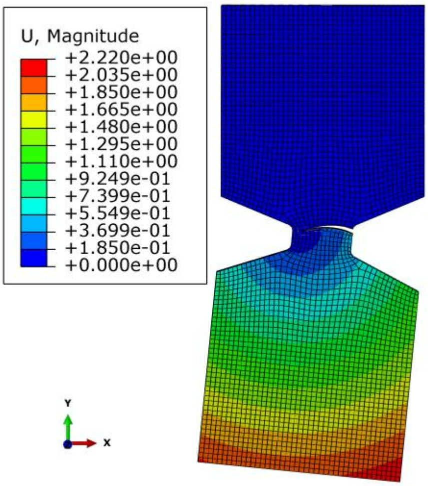

Fig. 6. Distribution of material displacement during cracking [source: own study]

Crack initiation occurs exactly in the narrow region of the specimen, right at the fillet radius. Using FEM analysis, it was possible to define a relationship between the crack initiation point and the increase in load.

The above characteristics and images of the tested point are shown in a figure given below.

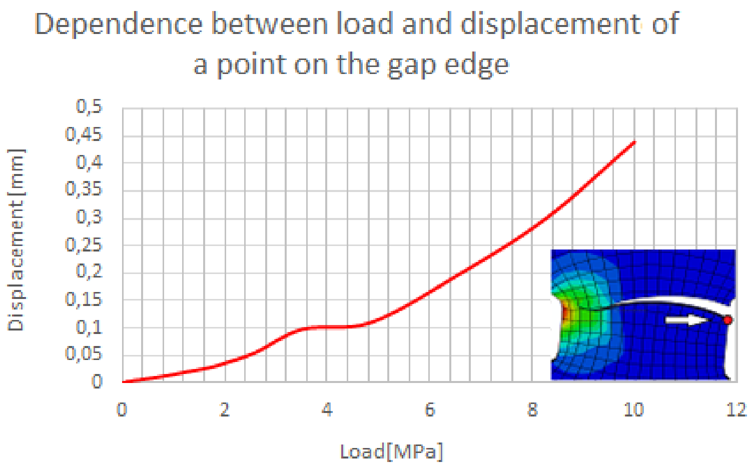

Fig. 7. Load characteristics versus crack initiation point displacement [source: own study]

The width of the narrowing is 5 mm. The total length of the produced crack is practically as wide as the narrowing.

Initially, when the applied load ranges from 0 MPa to 3.5 MPa, the displacement of the crack initiation point increases almost linearly compared to low displacements of about 0.1 mm due to specimen deformation. When the applied load ranges from 3.5MPa to 5 MPa, cracking occurs yet practically no displacement can be observed. From about 5 MPa onwards, the point displacement dramatically increases due to the proceeding separation of material fibers. At the highest load of 10 MPa, the displacement of the point within the initiated crack is almost 0.45 mm, which corresponds to the maximum displacement observed for the numerical model.

The shape of the crack resembles an arch described by a similar radius over the predominant length of the crack. The subsequent part of this paper will present images of the simulated distribution of displacements in the specimen due to the applied load.

a) **b)**

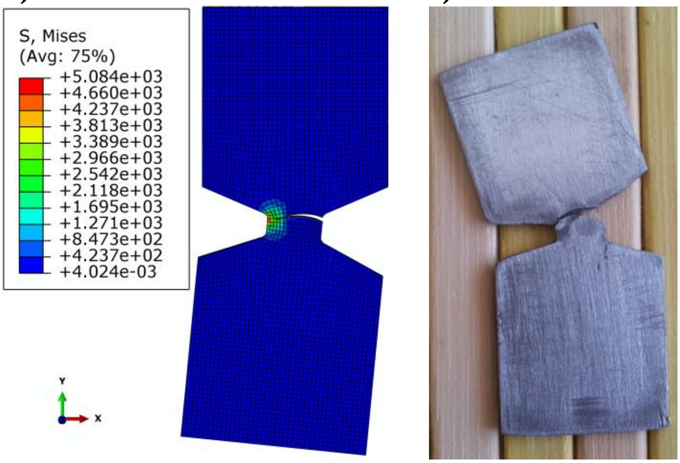

Fig. 8. Comparison of cracking in numerical (a) and real specimens (b) [source: own study]

The numerical results can be used to illustrate the shape of crack that resembles that in the real specimen. The shape of the enlarging opening initiated in the upper part of the specimen's narrow region just before the minimal fillet radius. Further crack propagation in the form of an enlarging opening occurred along the narrowing where stresses temporarily increased and their values significantly exceeded the assumed steel strength.

The cracking of the numerically prepared specimen initiates at the moment of excessive material effort at about 350 MPa, i.e. at the moment when the first nodes got separated in the narrow region of the specimen. The reaching of strength limit only initiated the cracking process; however, crack propagation occurred with gradual loading of the numerical model. The cracking continued until producing a full opening that could be simulated by the Abaqus program with constant support of the xFEM method.

At the final stage of crack propagation, the value of reduced stresses is exactly 5084 MPa (the program writes it as 5.084e+03, which should be read as $5.084*10^3$); therefore, it exceeds the element material's strength by several times.

The results enable performing further optimization analyses for similar specimens aimed at reducing both their weight and stresses. The simulations were performed based on predefined boundary conditions, which made it possible to obtain correct results in the form of distribution of stresses in the FEM model. The numerical analysis indicated regions of reduced stresses and displacements in the test specimen, and revealed crack enlargement. The test provided information about the degree of material effort in the test specimen and enabled visualization of the crack propagation process.

4. CONCLUSIONS

Finite element method enables us to analyze complex physical and mechanical advanced processes via complicated computations which solve real problems.

The numerical analysis revealed that – at long or excessive operation – loads exceeding maximum allowable strength exert a negative effect on the specimen, usually leading to its undesired, irreversible failure.

The FEM results demonstrate that specimens must be correctly and carefully prepared and subjected to strength testing in order to reduce their susceptibility to external loads.

Nowadays the problems of advanced engineering pertain to preventing material, structural and production defects. Numerical analyses enable us to predict the behavior of structural members and mechanisms of processes already at the stage of their design.

The modeling of complex processes which simulate real physical processes and mechanical behaviors helps prolong service life of produced mechanism and eliminate defects of design.

Summing up, the FEM results have led to the following conclusions about the investigated process:

- with correctly defined boundary conditions it is possible to obtain detailed information about mechanical and physical processes which occur during operation of machines,
- finite element method and advanced xFEM algorithms enable producing material cracking results that model real processes of crack occurrence already at the stage of design prior to the production of machine components,
- xFEM results of crack propagation help prevent technological and manufacturing problems in the future,
- the kind of load and the place where it is applied have a significant effect on the shape of the crack and crack initiation region,
- the characteristics of crack initiation and propagation regions enable us to determine the impact of external loads, progressing displacements and deformations.

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spatial evaluation, WGA, spatial tool, GIS, academic

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DEVELOPMENT OF GIS TECHNOLOGIES AND METHODS IN EDUCATION

Abstract

The paper goal is to analyze GIS opportunities as constructive pillar for student performance. The presented methodology aims to explain spatial evaluation techniques through geo-tools, which could turn into a comprehensive strategy for student education. The paper aims to emphasize the vigor influence visual impact release on error checking. The analyses aim to create an optimized methodology toward a sustainable development process. Spatial tools as executable units and geo-databases as storage units are the future of modern technologies whose embracement leads the analyst into a higher level of control. Due to vast implementation in multiple fields and life routines GIS technology comes as an attractive discipline toward students' curiosity, easily to be absorbed and subject to further development.

1. INTRODUCTION

The explosive growth of the geo-web and geographic information contributed by users through various application programming interfaces has made GIS powerful media for the general public to communicate [1]. It is thought that universities must fulfill student requirements. In general according to students' requests academicals entities structure their curricula. Still the intention remains to offer the students high probability of a fast enrolling in a working environment.

The offered educational programs are required to represent and furthermore support the current situation of the country. In times of technological change they frequently reflect the impact of the opportunities afforded by evolving technology

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and the changing labor demands of the economy in which they sit [2]. In Albania issues such as natural hazards, pollution concerns, business development, and logistics management, strictly related to spatial extension require sustainable know-ledge about GIS technologies.

There is lack of GIS specialists, caused by weak policy followed by academicals institutions. Contrasting growing numbers for geo-specialists request reveal the uncertainty of students approach toward this discipline. Hence we must invert the trend with the goal of creating a new GIS generation.

Maps have always been the referring point from which has found support any analyzes developed related to earth phenomena. Spatial technologies such as Geographical Information Systems, Remote Sensing and Global Positioning Systems have turned into the pillar of many issues and human concerns. The “G” part of GIS is a two-dimensional or three-dimensional map representing real world phenomena, the “I” stands for the database supporting descriptive information, ending with “S” covering the model created by the assemble of hardware, software, methods and people [3]. Using GIS as a decision-making tool is a smart way of gathering all the things you already know and placing them in a single spot so you can see the entire picture [4].

Hence derive the primary key of success for such a complex geographical system. The right to “mix” into a single environment unlimited and diverse variables able to create the most complete panoramic of the studied issue. GIS tends to manage the ability to adapt multiple layers from multiple sources, to succeed by arranging geo-databases and statistical data into spatial extensions, conceive facilities by executing analytical queries.

GIS is quite usual to be absorbed without drawback from all levels of followers due to its massive deployment into every kind of institutional entity whether public, private or NGOs. Due to constant application of spatial technology in working environments’ it comes quite natural to transmit and analyze GIS from a vast range of aspects.

With the development of communications and grid technology, mobile GIS and grid GIS technology have entered people's vision; mobile GIS combine co-mmunications technology to GIS to achieve Mobile Location Services.; Grid GIS based on grid technology, break all closure marginal and make GIS fully integrate into the Internet environment, is a completely distributed architecture [5].

2. GIS LEARNING METHODOLOGY

We assign two projects (fig. 1), the first concerns to spatial data management, the second relates to spatial data evaluation. For the first project the paper goal is to analyze a GIS based platform in order to create a self-learning environment by design (fig. 2). Deliberately we aim to improve apprentice’s conscience by developing their skills in the management of spatial tools.

A GIS is a tool for supporting a wide range of spatial analysis techniques, including processes to create new spatial objects classes, to analyze object location and attribute, also model using multiple classes of objects and the relationships between them [6].

Learners get assigned specific tasks which require minimal GIS knowledge to be performed independently without interfering to the rest of the group. The collected data meet into a unique geo-database where overlapping information has been handled by the application code.

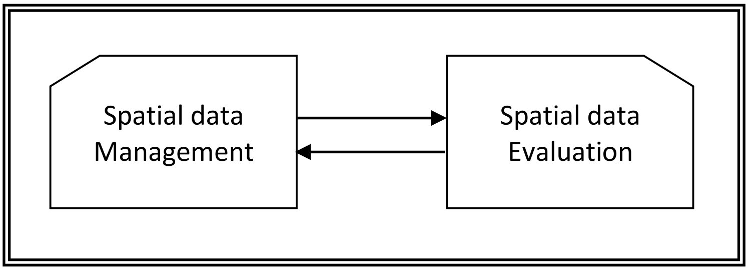

Fig. 1. Spatial interaction, learning methodology [source: own study]

The second project concerns to develop students spatial analytical skills to manage data evaluation. The experiments shown in the paper reveal three types of data inconsistency: spatial, temporal and attribute.

We simulate errors related to the country territory. The goal of the paper is to cultivate researcher's conviction that visual evaluation will always offer larger opportunities compared to numerical evaluation. Anyway geographical information systems are the ideal platform that involves both mapping presentation in-front also numerical presentation in-back. The offered possibility to integrate into a single platform statistical data associated with geographical entities should be considered an advantage for data analyzers. Researchers can benefit from both options.

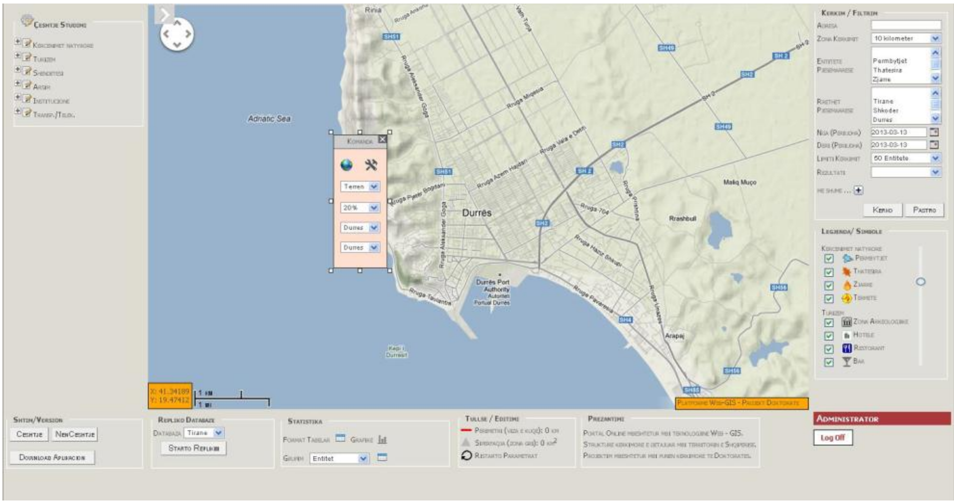

Fig. 2. Modularity backstage [source: own study]

3. SPATIAL DATA MANAGEMENT PROJECT

Students performance is monitored constantly, from their data input to the level of accuracy and update the selected information has been chosen. Still any error or misunderstanding can be recovered any time facilitating the operational procedure. The goal is to create a synchronous group with a satisfactory level of collaboration. Due to the online environment the platform relies on, it enables the extension of working hours beyond the institution limit, creating a pragmatic application fully adoptable in a vast variety of facilities and free from any time constrain.

GIS is a multi-concentrated discipline including a wide range of profiles that turns in the eyes of the students into an attractive and stimulatory trend to be followed and practiced. Experience show us that people specialized in GIS field benefit from larger opportunities to get involved into projects and institutional entities. Geo technologies allow students to study local to global phenomena and incorporates fieldwork [7].

They connect students to the real world, outbounding the institutional theoretical limit. By so we increase student awareness and promptitude toward the assigned task. Students are assigned into small groups, usually no more than the fields of the studied area. Figure 3 show the login process, where each student receives unique credential data, further can be personalized. The thematic chosen in this paper is Tourism. Five fields mean that five students are required to carry on the project.

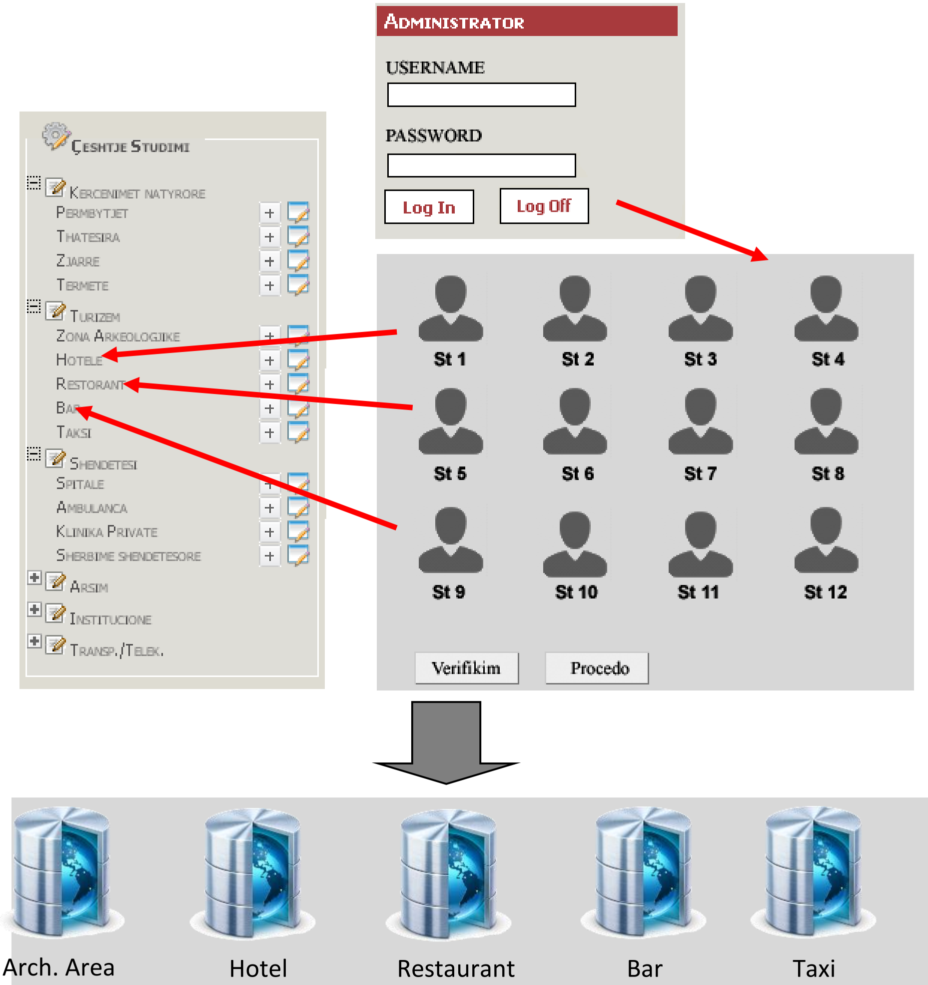

Fig. 3. Class management [source: own study]

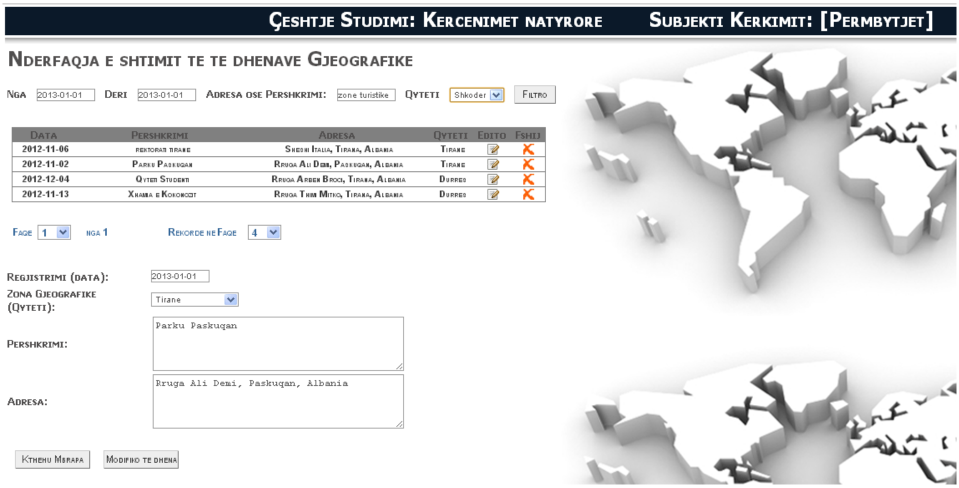

Fig. 4. Spatial data management module [source: own study]

The spatial area should not be much extended; this would require larger groups and multiple students for a single field due to the vast amount of geographical data to be processed. Taking into account the geographical area of the country, we assume that fragmenting the territory at district level is the most adaptable spatial extension. Hence it is required the student to have sustainable knowledge about the assigned area, by so the assignation process must be carefully conceived.

Further the student manages his own geo-database. Each storage unit is autonomous from other units with unique attributes. This creates an optimal environment for the student. Each row reflects the geographical coordinates and attributes of the object. The advantage of the application consist in that the student cooperate with each other as for geographical allocation concerns, still compile their personal environment where any executed query is applied without interference to each other work (fig. 4). As such it turns comprehensive to benefit from a clearly and distinct evaluation process of both collaborative and individual student performance.

The platform can be accessed online or downloaded to be subject of further investigation. The modularity structure of WGA creates the perfect condition to develop student performance and creativity. On the other side students are encouraged to enrich the platform with new modules according to the revealed issues during the projects development. GIS has the potential to enhance spatial thinking itself [8]. A new understanding, or a new narrative, or a new solution to a problem, could emerge from a map because we can so easily expand our frame of reference, which is the basis for spatial relations and spatial cognition [9]. The possibility to work both online and offline is a stimulus for a larger approach toward the platform.

4. SPATIAL DATA EVALUATION PROJECT

We could stare a table of numbers all day and never see what would be immediately obvious when looking at a good picture of those same numbers [10].Data quality can be assessed through data accuracy (or error), precision, uncertainty, compatibility, consistency, completeness, accessibility, and timeliness as recorded in the lineage data [11]. Large amounts of data expressed through statistical variations turn to be more difficult to interpret and analyze. It is expected that the level of complexity for error evaluation increase sharply with data acquisition.

The world is evolving at a rapid pace and in this environment, "information is considered power", and this is what GIS performs best, "manipulates information to provide better decision-making" [12]. Since the first steps GIS technology has contribute to bring problem perspective into a different level of management.

Map researchers developed continues efforts to present digital maps as a potential source of solution for multiple issues. Through digital mapping the researcher create a new approach exploiting the human spatial cognition abilities. Cognition of geographic information deals with human perception, memory, reasoning, problem-solving, and communication involving earth phenomena and their representation as geospatial information [13].

When it comes for error evaluation we notice two types of cognition, spatial and numerical. Numerical cognition involves anything that deals with numbers and figures. Here we mention any tabular data registered in complex storage units such as database management systems or spreadsheet applications. Numerical cognition requires specialized people to perform evaluation task and error detection.

It means that apart from personal knowledge about the environment which the current issue is being analyzed the researcher need to have substantial applicative skills in the field of software management. As for spatial cognition we claim anything concerned with the acquisition, organization, utilization, and revision of knowledge about spatial environments [14].

Anything related to spatial environment leads directly to mapping evaluation and as a result the need to exploit spatial tools into a geographical information system. Spatial cognition is the last step of a long process of data manipulation, strictly connected to cognitive agents to act and interact in space intelligently and to communicate about spatial environments in meaningful ways [14]. That’s why the advantage of spatial cognition is that it doesn’t necessary need GIS experts to perform the evaluation. In contrast with numerical cognition the researcher is basically required to own sustainable knowledge about the studied area.

5. EVALUATION METHODOLOGY

GIS gain much of their power from being able to collate and cross-reference many types of data by location; hence they can integrate many discrete datasets within a single system [15]. Hence multiple people can work on the same project, using multiple sources. By so the possibility for errors is highly probable. Meaning during mapping process the user must follow a continuous and rigorous checkup. According to Peng citation we can divide inconsistency into spatial, temporal, and attribute and inconsistency among any combination of space, time and attribute [16].

Spatial inconsistency refers to problems that emerge due to errors in the distribution of entities into a specified spatial extension. Temporal inconsistency is associated with the period which the geographical entities reveal or belong to. At last we claim attribute inconsistency related to mistakes developed on data elaboration mainly expressed through charts, diagrams, or geographical schema. Further we proceed to analyze each inconsistency model through the country territory paradigm.

Case one: Attribute inconsistency

Case one takes into account the most polluted shoreline zone in the country coastline. Coliform bacteria have been used to evaluate the general quality of water. Two other groups of bacteria that are present in feces are: fecal streptococci (FS) and Clostridium (FC) [17]. Our investigation considers the values obtained by the Public Health Institute which has set a limit rate of 100 for water pollution. The map reveals that the attribute data are structured improperly. As we see from the geo-database almost all checkpoints exceed the limit of 100, which means that necessarily the chart (fig. 5) must show high values for FS and FC indicators which in fact doesn’t seem to happen.

Case two: Spatial inconsistency

Case two refer to spatial inconsistency. We consider the population density of the country (fig. 6) at a comparative level. The analytical process comes to be much easier and approachable from the user's side not only to distinguish but also to define the areas that need correction or the type of errors that have been made [18]. The fact that the geographical data is expressed through digital mapping and not rough database rows increases the possibilities of perception that the map on the left is the correct one; meanwhile the one on the right contains corrupted data [18].The understanding of the analytical perception of the human choice for the current situation comes as a result of several factors:

– The user may have personal information (knowledge) about the country territory;
– The user may have a partial knowledge about the country; still he assumes that generally the highest population density lean near the capital and the surrounding areas, also toward coastal zones and that generally the density decrease moving from the center to the suburbs;
– Smaller the area extension, imply higher population density.

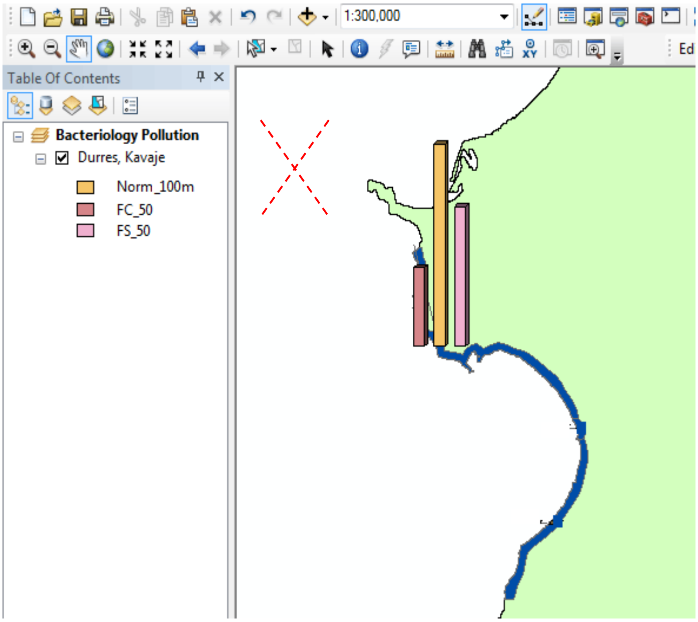

Fig. 5. Attribute (Logical) inconsistency, Albania Coastal Pollution [17]

FC-50,FS-50 values		
Ch. P.	**FC-50**	**FS-50**
1	1073	669
2	906	687
3	679	435
4	640	591
5	455	424
6	281	206
7	247	194
8	199	161
9	186	142
10	171	135
11	162	124
12	162	107
13	154	118
14	151	104
15	142	118
16	140	93
17	130	95
18	121	92
19	118	88
20	115	72
21	114	81
Av.	271	226
Norm	**100**	**100**

Tab. 1. Coastline check values [source: own study]

22	23	24	25	26	27	28	29	30	31
54	91	95	112	112	159	318	325	404	460
20	38	39	56	50	56	256	177	296	326

Consider to presume and define errors by performing data control through standard database. GIS claims the ability to associate tabular information with map presentation which turns to be a powerful tool compared to routine databases. That’s why through spatial tools we developed the skill to reveal possible errors and data inconsistency. The relationship between spatial technology and human perception is the key for error evaluation.

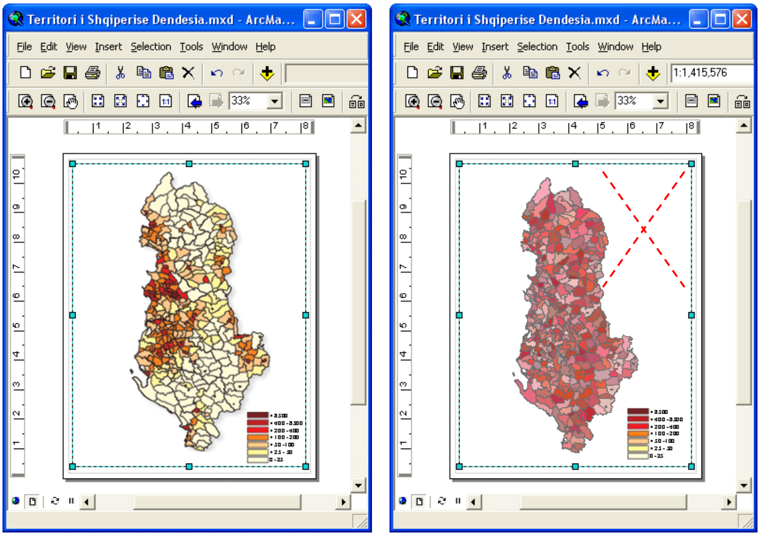

Fig. 6. Spatial inconsistency, Verified issue: Population density [source: own study]

Case three: Temporal inconsistency

We analyze the administrative division of the country (fig. 7) territory between two periods.

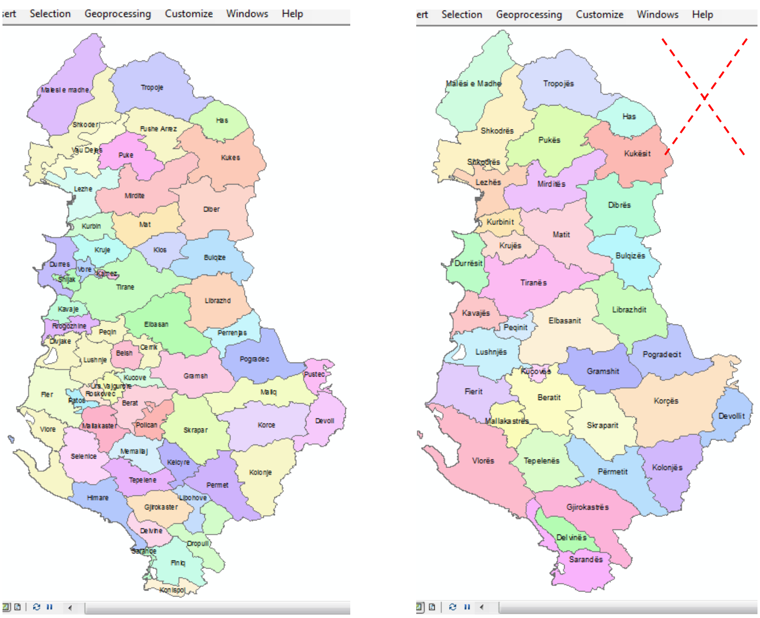

Fig. 7. Temporal inconsistency, Verified issue: Administrative division [source: own study]

Albania is divided into 12 administrative counties. These counties were further divided in 36 districts. Recently, the government introduced a new administrative division to implement in 2015. Districts so far considered as direct sub-units of counties with be suppressed in circumstances where municipalities are reduced to 61 in total, which mean that municipalities with become the new sub-units of counties and the term district with no longer exist. Hence it is possible that in its “infancy” the administrative map may turn into a source of confusion.

6. CONCLUSIONS

Geographical information systems (GIS) are computer systems developed for the collection, storage and processing of information referenced to some form of location coordinates, with this location information usually being a key element of any analysis [19].Today we perceive GIS technology as a powerful mainstream in various web-based maps such as Google Earth, position allocation devices such as Global Positioning System, remote sensing technologies such as satellite imagery, etc.

The field of GIS is rapidly encompassing previously disparate fields, incorporating tool and skill sets into a unification of technology and science [20]. In such an eager market GIS specialist can quickly find themselves into comfort-table positions, followed by a large number of duty assignment possibilities due to its chameleon singularity to be adapted and integrated into vast issues.

The paper present a web-based platform build for informative and communication purpose. Its modular structure allows the usage in the academicals sector. The application aims to improve students’ knowledge on spatial technology. We analyze two projects concerning spatial data management and spatial data evaluation.

The first project present the process of compiling data for tourism issues through a selective group of students, each with specific and distinct assignments with the scope of evaluating their individual and collaborative skills. The possibility to modify the application code enables students to overpass the line that represent simple users allowed to insert and modify geographical data, by throwing the application into a higher level of complexity. This way they become owners of the proper GIS knowledge. By so we stimulate students’ performance creating future GIS specialists.

The second project is structured into three subcategories: attribute, temporal and spatial inconsistency. Maps are becoming a determinant issue with a developed ability to transform numerical and statistical information into “visual” perspective, object to a much easier analysis and manipulation process [18]. The way people conceptualize space is an important consideration for the design of geographic information systems, because a better match with people’s thinking is expected to lead to easier-to-use information systems [21].

The way people identify entities within a spatial extension turns to be a powerful tool in error detecting process. Every time analyze is performed there will always be room for mistakes. First of all we have to be good enough to notice something is wrong. The matter is how we are going to handle the verified situation.

Categories of people believe that relying issue evaluation into a spatial environment could be much more prolific than proceeding with numerical analysis. Research in GIS is like geographical data-the more closely one looks, the more interesting issues appear [6]. As such we induce in increasing student curiosity and willingness to enlarge their efforts for a closer approach toward GIS based issues.

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side-slip angle, race car, VI-CarRealTime, track

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IMPACT OF FRONT AND REAR WHEEL TRACK ADJUSTMENT ON RACE CAR LAP TIME

Abstract

The dynamics of race cars is an extremely broad issue, as there are many factors which have an impact on a race car's behaviour on the road. This study examines the relationship between lap time of a race car and different adjustments of front and rear wheel tracks. The analysis is performed using VI-CarRealTime simulation tool provided by VI-grade, a global leader in racing simulation tools. To explain the difference between the front/rear wheel track ratios, the values of side slip angle in corners are used. The best adjustment is determined.

1. INTRODUCTION

VI-CarRealTime is a simulation program for testing car adjustments in a virtual environment. The use of the program substantially reduces the costs associated with real vehicle dynamic testing. Many racing companies use software of this kind. The VI-grade solution enables testing various changes in a virtual model in real time.

First, a virtual car model is loaded in a build mode. The car model is a collection of subsystems like suspensions, steering system or power-train. Many systems are predefined in order to shorten calculation time. Some parameters can be easily changed without rebuilding the whole subsystem. Moreover, it is

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possible to design your own subsystems. For example, a complete suspension could be created in VI-Suspension Gen.

After the car model has been loaded, the user selects simulation settings. There are many predefined simulations including checked lap time on a given road or acceleration on a given distance.

The last step involves performing results analysis in a postprocessor. The program generates animation and plots desired for physical values in a time function.

Vehicle dynamics analysis, both in real and virtual models, is based on numerous factors. The best race car must have a good power-train [1] and excellent handling [2]. In order to achieve mechanical advantage, power-train constructors should introduce high-efficiency engines and optimal transmission. Excellent handling can be achieved in two ways. The first one is mechanical grip derived from tire properties [2], car suspension adjustment and mass distribution. In race cars such as a Formula SAE vehicle a double wishbone suspension system is very often used [3]. This kind of suspension has 12 head points, which is important if perfect adjustment is be made [4]. Sometimes a double wishbone suspension with a push or pull rod is applied.

Another method for excellent handling is grip derived from downforce [5]. It could also be computer-modelled by CFD programmes. These programmes are used for testing airflow around the car exterior [6]. Nowadays, downforce is an important element of race car design.

The authors of this study analyse handling derived from different front and rear wheel track adjustments. A better front/rear track ratio implicates better lap time of a race car.

To better understand this topic, some definitions are introduced. The track t is the distance between the wheels on each axle. It is measured in the middle of the wheels. The wheelbase r is the distance between the car's axles.

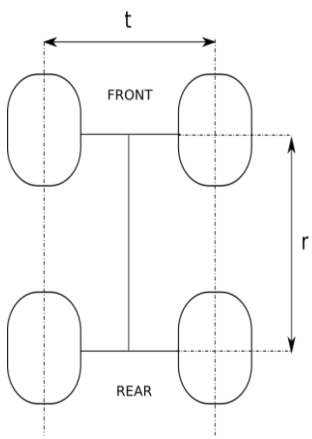

Fig. 1. Track and wheelbase measurement [source: own study]

The track and wheelbase measurements were made in accordance with the formula shown in Fig. 1. The chassis lateral acceleration is the quoined square of the car velocity and the corner radius [7]:

$$a_c = \frac{V^2}{r} \tag{1}$$

Another important terms are: side slip angle, camber angle and lateral force [7]. The side-slip angle α is the angle between the longitudinal force Fx and the velocity vector ν . The camber angle γ is the angle between the plane comprising the horizontal axis z and the tire plane. The lateral force Fy is the force tangent to the ground and orthogonal to both axis x and axis z [8].

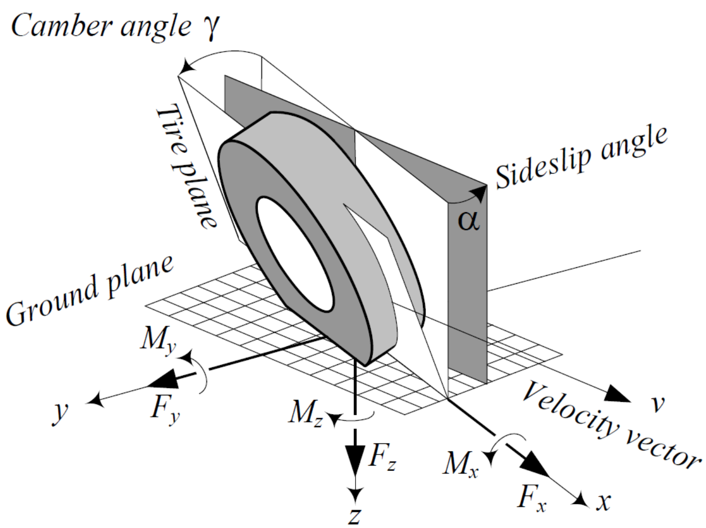

Fig. 2. SAE tire coordinate system [8]

The SAE tire coordinate system is shown in Fig. 2. The lateral force is generated when the car is going around a curve. The lateral force causes velocity vector deflection from axis x and the side-slip angle increases. The increasing lateral force causes an increase in the side-slip angle.

2. COMPUTER SIMULATION ASSUMPTIONS

The simulations based on a complete model of a representative Formula SAE vehicle are performed using VI-grade. This model was entered in the Virtual Formula 2015 Competition [9]. The authors modified some construction parameters and the driver's path. The aim of these modifications is to achieve the best possible lap time on a given road. The following parameters are modified:

- the wheelbase is set to 1525 mm,
- brake front bias is set to 66%,
- pressure in the brake system is set to 0.068 MPa,
- front wheels toe angle is set to 2 degrees and the camber angle is set to 1 degree,
- the rear wheels toe angle is set to 0 degree and the camber angle is set to -1 degree.

The engine and transmission are not modified. The engine is set behind the driver's back. The car has a rear wheel drive. The differential is of the LSD type [10-12]. The mass distribution (front/rear) is equal to 48.5/51.5. The front and rear suspension is Double Wishbone with Push Road [13, 14]. The car's exterior is not equipped with elements increasing downforce like front or rear wings.

The simulations have been performed in MaxPerformance event included in the VI-CarRealTime software. Performance factors were as follows [15]:

- Longitudinal Acceleration Performance Factor = 1.11,
- Longitudianal Brake Performance Factor = 1.04,
- Lateral Performance Factor = 1.015.

Such a combination of performance factors allows us to do a lap without drifting. Another assumption is that any wheel cannot leave the road completely on visualisation. In order to assure comparability of the results, the adjustments (excluding tracks) and the driver's path are maintained unchanged in each simulation. The difference between the front and the rear wheel tracks is about 8%.

3. SIMULATION RESULTS

Table 1 gives the statistics of each simulation. These statistics are generated by a Phyton console of the VI-CarRealTime software. The simulations proceeded smoothly and without any complications.

The differences between the cases are significant. The best lap time is achieved by a car with a wider rear wheel track. The lateral acceleration force is the highest for this car. The values of maximum speed are almost equal. Based on the simulation statistics, it can be claimed that the car with a wider rear track is the fastest of the described profiles.

Tab. 1. Simulation statistics [source: own study]

Simulation Statistics – car with wider rear track (front track – 1100 mm rear track – 1200 mm)		Simulation Statistics – car with wider front track (front track – 1200 mm rear track – 1100 mm)	
Lap Time	110.190 s	Lap Time	111.160 s
Lateral Acceleration MAX	1.1916 G	Lateral Acceleration MAX	1.1331 G
Lateral Acceleration MIN	-1.2680 G	Lateral Acceleration MIN	-1.1445 G
Speed MAX	163.126 km/h	Speed MAX	162.786 km/h
Simulation Statistics – car with both tracks 1100 mm		Simulation Statistics – car with both tracks 1200 mm	
Lap Time	111.040 s	Lap Time	110.360 s
Lateral Acceleration MAX	1.1233 G	Lateral Acceleration MAX	1.1268 G
Lateral Acceleration MIN	-1.2495 G	Lateral Acceleration MIN	-1.1648 G
Speed MAX	162.763 km/h	Speed MAX	163.133 km/h

A preview of collocation in the sample corner is shown in Figs. 3–6. This image comes from VI-Animator software for previewing simulation results.

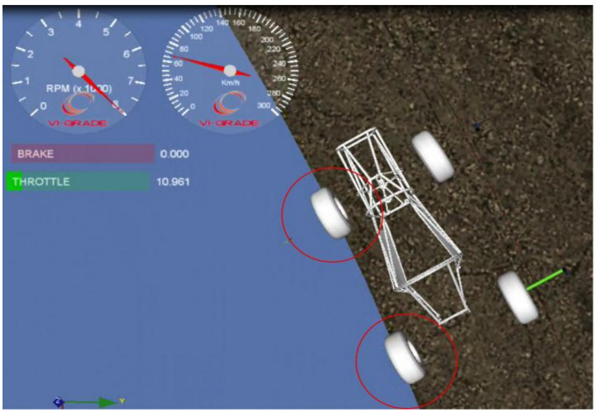

Fig. 3. Preview of collocation in the sample corner, car with wider rear wheel track [source: own study]

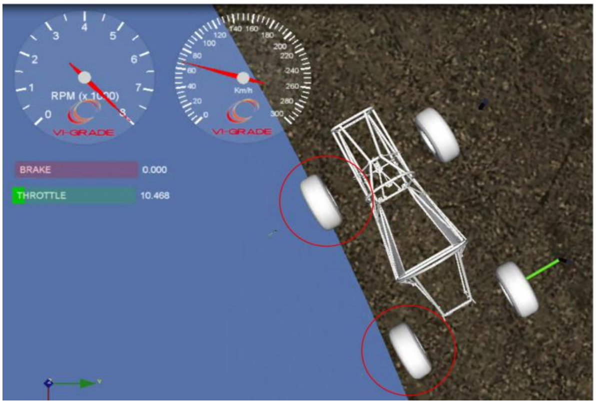

**Fig. 4. Preview of collocation in the sample corner,
car with wider front track [source: own study]**

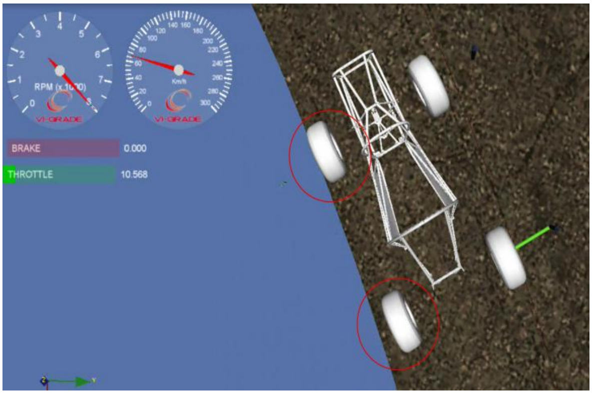

**Fig. 5. Preview of collocation in the sample corner,
car with both tracks equal to 1100 mm [source: own study]**

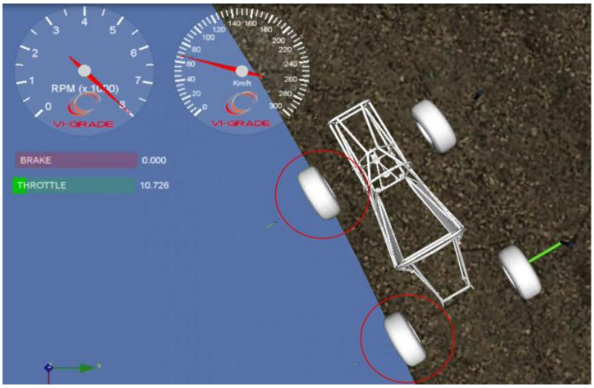

**Fig. 6. Preview of collocation in the sample corner,
with both tracks equal to 1200 mm [source: own study]**

The car in Fig. 3 could get the most of the road width. The car in Fig. 6 is really close to falling short of the condition saying that no wheel can leave the road completely. The cars in Fig. 4 and Fig. 5 cannot get the most of the road width. If the driver's path is changed, the car with both tracks set equal to 1100 mm could shorten the lap time.

The greatest differences between the side-slip angle and the chassis lateral acceleration in each case are presented in Figs. 7–10.

Points 1–10 indicate differences in the side-slip angle. In Fig. 7 the side slip angle is the highest. This can be best seen in points 3 and 7.

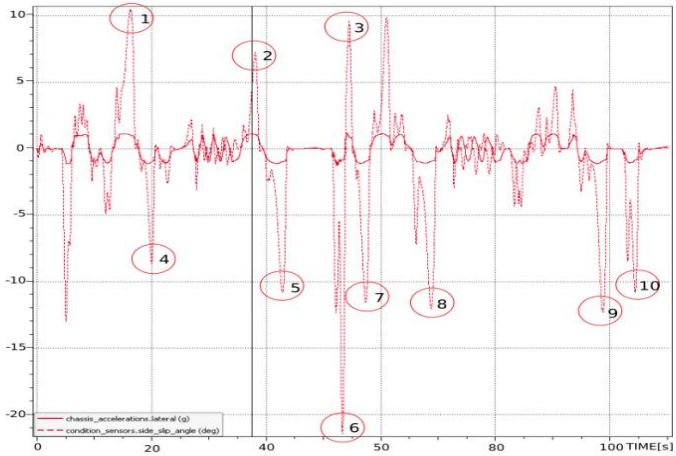

Fig. 7. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with wider rear track [source: own study]

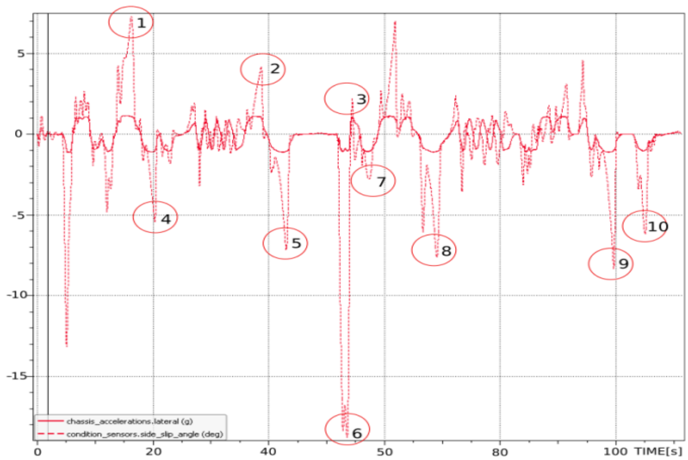

Fig. 8. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with wider front track [source: own study]

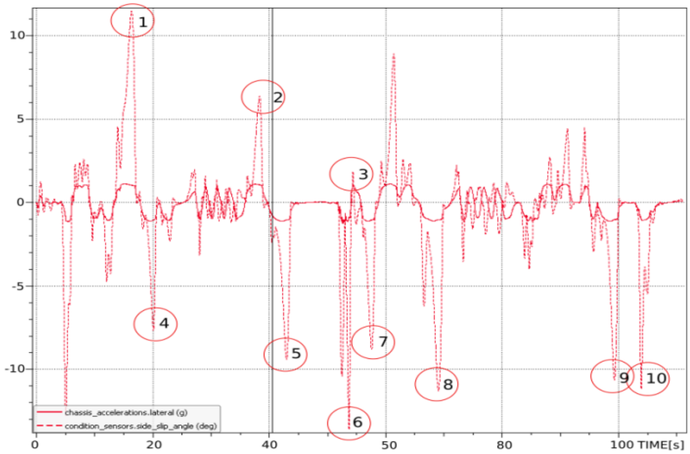

Fig. 9. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with both tracks set equal to 1100 mm [source: own study]

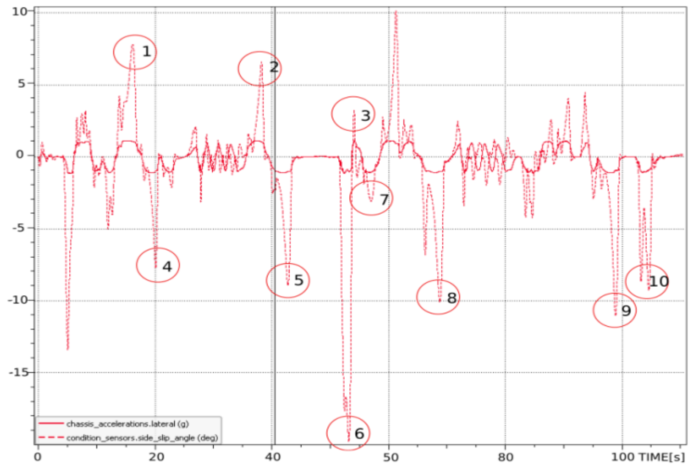

Fig. 10. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with both tracks set equal to 1200 mm [source: own study]

Since the car's motion is slip-free, the side-slip angle is proportional to the lateral force [4]. The sum of the lateral forces on the wheels is equal to lateral force of the chassis. The chassis lateral force is the product of the chassis lateral acceleration and the car mass. According to Equation (1), the chassis lateral acceleration depends on the car velocity and the corner radius. The road for each case is the same. The car velocity in the corners is the highest in Fig. 7.

3. CONCLUSIONS

The numerical results and their analysis enable us to verify basic assumptions of the model already at the stage of preliminary design. This will reduce both manufacturing time and costs of the production process. Given today's technological development, computer-based simulation tools have become an essential part of the manufacturing process.

The results demonstrate that the best performance is achieved by a car with a wider rear wheel track. The car with this adjustment can transfer a higher lateral force prior to losing traction. As a result, the car can take corners faster and achieve a better lap time. Nonetheless, it is also worth noting that this adjustment enables setting the engine in central position. Consequently, mass balance is better. It must be noted that the results hold for a situation when the car is not provided with aerodynamic equipment such as front and rear wings. If the front wing generating considerable downforce is applied, the results could be different.

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tool wear, edge state, milling

Jakub MATUSZAK[*]

TOOL WEAR MEASUREMENT AFTER MILLING OF ALUMINUM ALLOY USING COMBINED ROUGHNESS AND CONTOUR DEVICE

Abstract

During separation of work surface in machining process and transforming it into chips, tool remains in constant contact with the workpiece. During this contact, there are a series of phenomena leading to the tool wear. Tool wear monitoring, and determination of tool life which is a signal to replace the tool with a new one, is important to ensure the continuity of production process in any company where elements are produced by machining. The article presents the results of tool wear measurement after milling of AlSi10Mg aluminum alloy using combined roughness and contour device.

1. INTRODUCTION

During the cutting process in the area of contact between the tool and the workpiece, there are a number of phenomena including elastic and plastic deformation, internal and external friction, a temperature increase, the built-up edge. These phenomena contribute to the wear of the tool. In the era of modern, fully automated machining centres, the tool becomes the weakest link, which constitutes a barrier to automating of the process. At the time of tool wear or damage, the process must be stopped and the tool should be replaced with a new one. The problem is that the new tool does not always have the same dimensions as the previous one. Despite the use of laser or touch probes allowing

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for appropriate positioning of the tool relative to the object it is not always possible to achieve the same position. In many articles [1, 2, 3] the examples of on-line tool wear monitoring systems for controlling the process are widely described. The problem of fast tool wear is particularly evident during machining of hard materials or materials containing hard alloying elements. In such cases the machining parameters are often chosen so that one tool is able to produce one element (one surface - in the case of large components) [4]. Tool wear directly influences the surface roughness, the force in the cutting process, the type and shape of the chips, the properties of the surface layer and the increase of temperature in the cutting zone.

Precise measurement of tool wear indicators is essential to capture the moment tool cutting ability loss. Determination of tool dimensional stability affecting processing errors is important because of the risks of generating objects whose dimensions are not in the required tolerances.

There are a lot of tool wear mechanisms, which may include: mechanical, adhesive, diffusional, thermal and chemical wear. Form of tool wear, which often is examined and analyzed in scientific publications relates to mechanical wear, which in turn can be divided into mechanical abrasion and mechanical strength.

Information concerning the wear tests are contained in ISO 8688-1: 1989 – Tool life testing in milling, which includes information on the following indicators of tool wear on the flank and rake faces. The most frequently discussed indicator of tool wear is flank wear VB, which is defined as loss of tool material from the tool flanks, resulting in the progressive. According to ISO flank wear can be divided into: Uniform flank wear (VB1), Non-uniform wear (VB2) and Localized flank wear (VB3).

Methods of tool wear measuring can be divided into direct and indirect. Indirect methods include measurements of forces, acoustic emission, vibration, surface roughness and temperature. Force measurement as an example of indirect indicator of tool wear is shown at [5]. Whereas, direct methods are related to measurement of tool and geometric changes around the cutting edge. There are two most common varieties of direct methods. The contact method is the first version, which can be carried out directly on the machine, for example, by tool touch probe or laboratory methods with the use of contact device [6, 7]. Combined roughness and contour device is in this group of methods.

The second group consists of non-contact method carried out on the machine e.g. using a laser tool probe or a method based on image analysis using a CCD camera or using scanning electron microscopy, often used for precise measurement of diamond tool wear [8]. These methods allow to create 3D images and on their basis – analyze the tool wear indicators, the examples of which are shown in [9, 10].

The article presents results of tool wear measurement after milling of AlSi10Mg aluminum alloy using combined roughness and contour device.

2. MATERIAL AND EXPERIMENTAL CONDITIONS

The experiment was carried out with the use of cutter after milling of aluminum alloy AlSi10Mg. Hard silicon grains are composed of the alloy, whose share in the composition is 10%, and which may lead to the tool wear. Tests were performed on a Hommel-Etamic RC120 device. View of measuring stand is shown in Fig. 1.

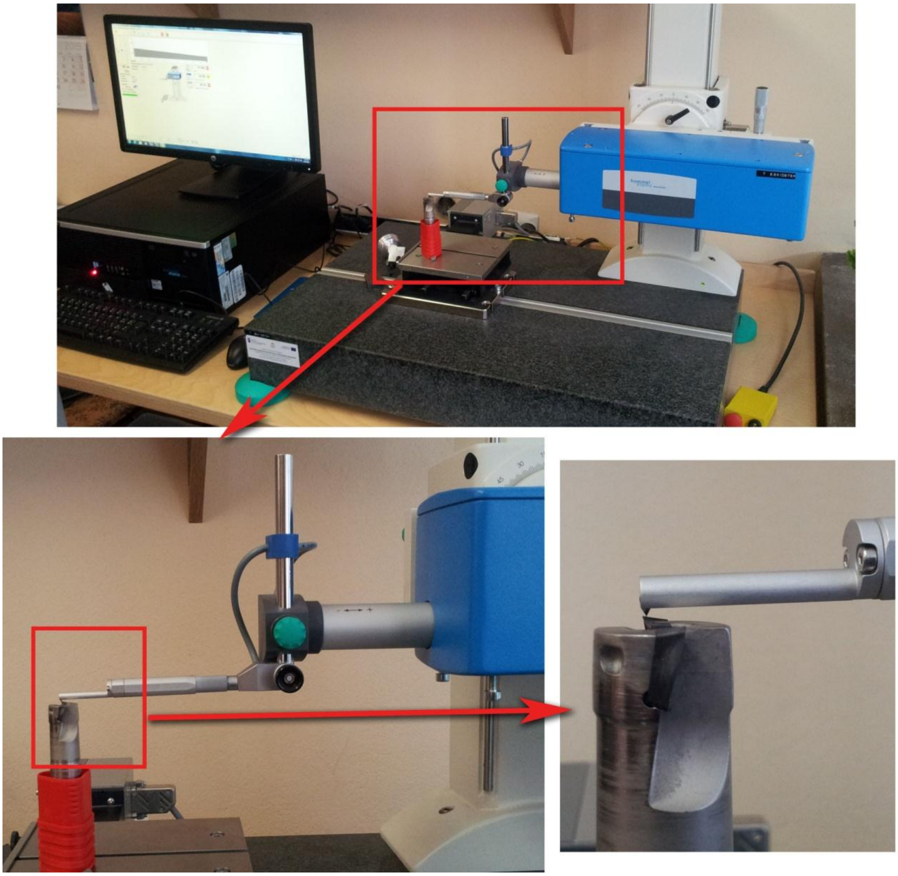

Fig. 1. View of measuring stand [source: own study]

In the studies ISCAR cutter with the diameter of 20 millimeters, with two inserts, dedicated to the machining of lightweight alloys was used. Flank face areas were scanned and contour edge of the cutting inserts was analyzed. Microscopic view of scanned regions are presented in Fig. 2.

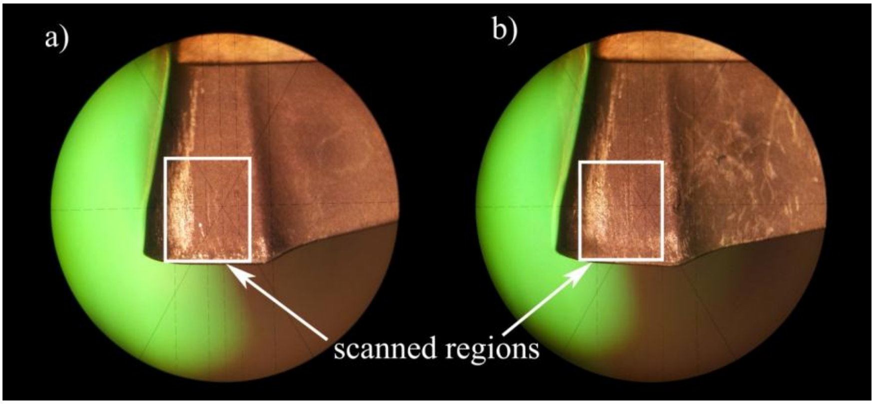

Fig. 2 Microscopic view of scanned regions: a) insert no. 1, b) insert no. 2 [source: own study]

3. RESULTS

Figure 3 shows the method of determining the radius of the cutting edge. Contact tip of measuring device moving in a perpendicular direction to the cutting edge determines the edge contour. The software allows entering the arc in the scanned contour and determination of the radius of the edge. Compensation of measuring tip radius is included. In Figures 4 and 5 views of scanned flank faces and the shape around edges are shown. Rectangular areas with dimensions of 1.4 x 2 mm were scanned.

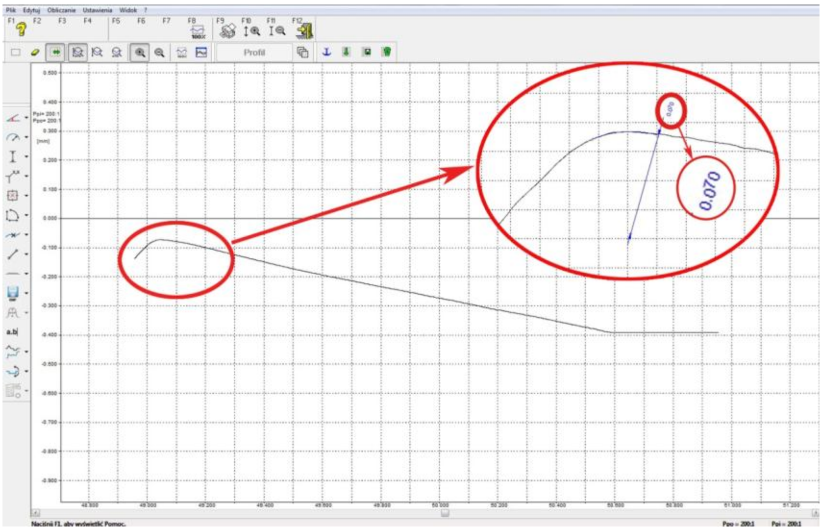

Fig. 3. Measurement of edge rounding [source: own study]

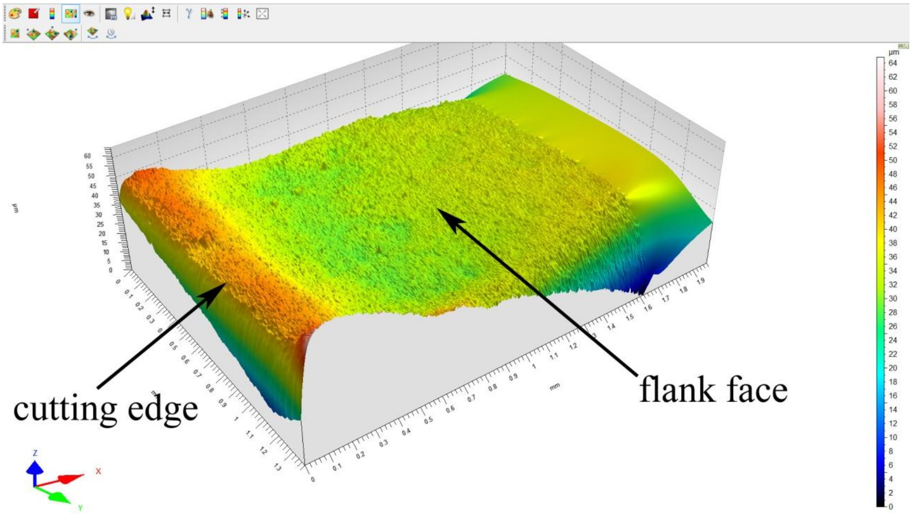

Fig. 4. Flank face topography of insert no. 1 [source: own study]

On the basis of the presented topography, there was no significant tool wear of working surfaces and the unfavorable state of the cutting edges.

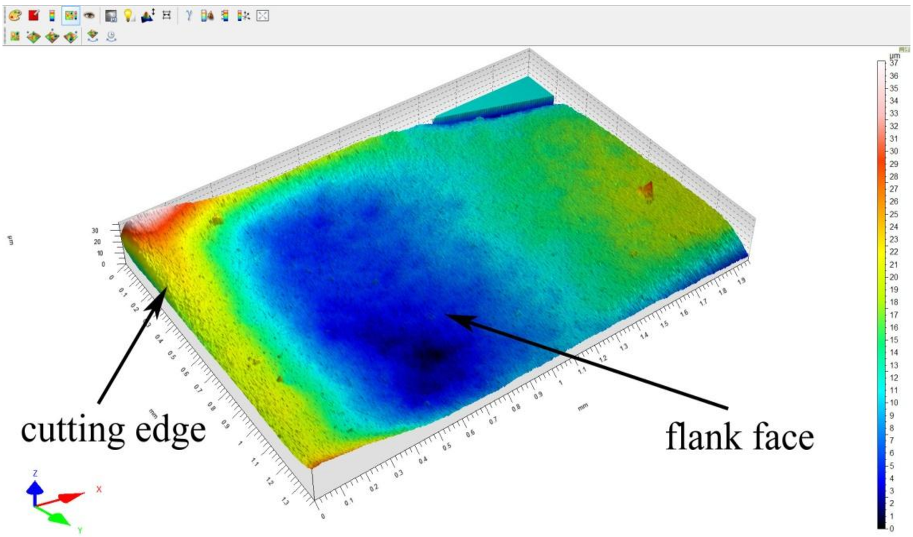

Fig. 5. Flank face topography of insert no. 2 [source: own study]

In addition, 3D map can be represented in 2D and perform measurements of length, angle and area. Measurement of the length shown in Fig. 6

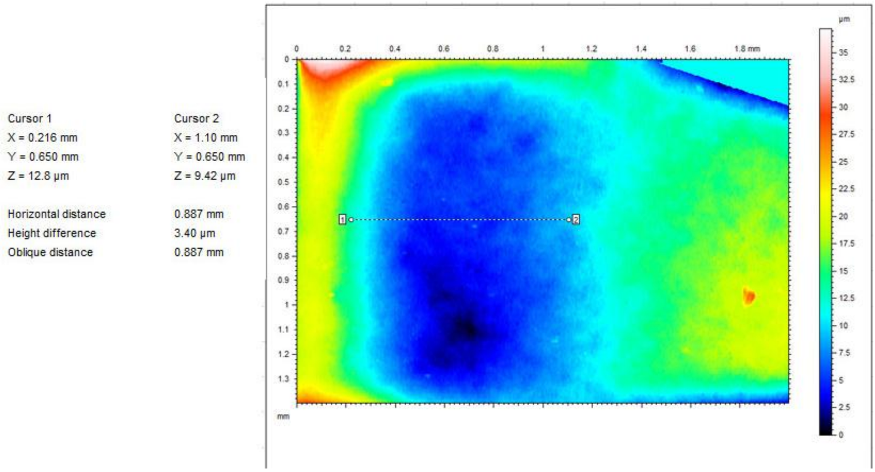

Fig. 6. Length measurement on the 2D map [source: own study]

4. CONCLUSIONS

The article presents the results of tool wear measurement after machining of AlSi10Mg aluminum alloy. The experiment was carried out using combined roughness and contour device. This method allows to measure the full analysis in terms of tool wear indicators. The ability to analyze the 3D map offers more information about the tested surfaces. In addition, on the flank face scanned map all tool wear indicators can be measured. On the basis of the conducted experiment, a significant tool wear was found after machining of AlSi10Mg aluminum alloy. One can expect a higher tool wear after machining of aluminum alloys with a high silicon content above 20%.

Acknowledgement

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COMPUTER-AIDED PRODUCTION TASK SCHEDULING

Abstract

The following paper is devoted to computer-aided production scheduling. The initial presentation of principles of deterministic scheduling was followed by the description of typical production environments and completed by the classification of production tasks scheduling methods. Furthermore, LiSA software was introduced and applied to build a schedule based on actual production data. In conclusion, the effectiveness of production task scheduling was evaluated with selected logarithms offered by LiSA software.

1. INTRODUCTION

Modern, highly competitive market exerts constant pressure on production companies to meet the growing demands of customers [12]. To keep pace with the market, it is vital to establish the job processing capability of a particular company, which can be aided by developing the task schedule. Devising such a schedule can, nevertheless, often prove somewhat problematic [6]. A varying degree of processes complexity and availability of resources are two of numerous potential constraints contributing to the complexity of job scheduling, thus making it quite a time-consuming task. With the purpose of facilitating the production process, planning computer software for production scheduling is employed. Unfortunately, commercially available production task scheduling software is burdened with numerous limitations [16]. It is owing to that fact that great effort is put into developing effective scheduling algorithms.

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New generation of software, represented by LiSA package, enables devising job scheduling solutions for different variants.

2. DETERMINISTIC TASK SCHEDULING

Conducting the computer-aided process of task scheduling requires proper representation of the analysed production system in the form required by LiSA software. Hence, developed models of production environments contain certain assumptions and simplifications [3]. Computer-aided scheduling demands that the analysed and sequenced processes be deterministic, *i.e.* allowing for no chance variation. This implies that all parameters are known and fixed [10].

2.1. Types of production systems

Sequencing and scheduling of production consists in distributing tasks (involving certain number of operations) between *processors*, *i.e.* machines realising a particular process [7]. There are three basic models of production systems approached in the theory of task scheduling [10, 14]:

– *flow shop,*
– *job shop,*
– *open shop.*

In a flow-shop system, which is represented by an assembly line, the order of tasks realised on all machines is identical. Specialist literature frequently describes the problem of *permutation flow shop*, where the permutation of the set of tasks defines the decision variable [9].

Job shop is one of the most widespread systems for task scheduling. In this system, the sequencing of tasks is determined by technological constraints: the machine route is fixed and the job order can be selected. Frequently, such environments are referred to as *general job-shop* [17].

Open-shop systems are rarely found in the theory of work scheduling. What is characteristic of these types of environments is that the order of jobs is arbitrary [5]. The lack of pre-defined sequence of job orders determines that finding the optimal solution is highly complicated, particularly in terms of processing time. The space of calculations and searching for solution expands on account of a substantial number of diverse schedule variants [14].

2.2. Job-shop

The job-shop model is the closest representation of a typical production environment found in the mechanical engineering industry, hence the subsequent part of the paper will focus on general job-shop scheduling problem.

Typical solutions to job-shop scheduling problems found in literature are based on a set of following simplifications [3]:

1. No two tasks of the same job can be scheduled in parallel.
2. Each machine is capable of carrying out one task at a time.
3. Each job has a limited number of operations of one per machine.
4. Each task is processed completely.
5. Task processing time can be entered manually.
6. Waiting time between two successive operations is allowed.
7. There are no two identical machines.
8. Machines can be idle. Machines perform one task at a time.
9. No machine failure. Machines are available throughout the whole manufacturing process.
10. All technological constraints are known and fixed. No variation is allowed.
11. No alternative process plans are allowed.

The following assumptions might or might not be reflected in reality, nevertheless, their introduction is essential to developing a scheduling model for the production process. It is only through simplification of an existing production system that computer-aided production task scheduling can be conducted and its optimisation evaluated.

3. TASK SCHEDULING METHODS

Development of a production schedule is frequently a complex computational challenge. The literature discusses cases where task scheduling becomes an NP-hard problem [15, 18, 4]. NP-hard problem of scheduling involves long execution time of algorithm. The complexity of solution increases with the growing number of performed tasks, as well as with the growing number of machines carrying out the production process. The only effective optimal algorithms developed so far could solve this problem for one- and two-machine problems (*e.g.* Johnson algorithm [11]). That is why, there is an ongoing search for diverse scheduling methods, based on effective scheduling algorithms [13].

In general, scheduling solutions can be classified under two categories [5]:

– exact – guaranteeing determination of an optimal solution,
– approximate – the determined solution is non-optimal, however, the solution is delivered in a substantially smaller running time and requires engagement of fewer resources.

In terms of task scheduling methods the following could be mentioned [10]:

– Full and Random Search,
– Discrete Programming,

– Branch & Bound Algorithm,
– Expert Systems,
– heuristic scheduling methods (Dispatch Systems, Priority Rules, Local Search),
– evolutionary algorithms (Genetic Algorithms, Evolutionary Programming, Classification Systems).

4. LiSA SOFTWARE

At present, production scheduling processes are widely supported by a number of computer programmes. One drawback of production scheduling modules is their limited capabilities and flexibility, which proves to be a significant disadvantage, owing to the fact that frequently different job sequencing variants must be analysed. This often involves the change of the character of processed tasks or the objective function; furthermore, total completion time at different priority rules is analysed.

It is, *inter alia*, for the aforementioned reasons that LiSA software is a practical solution for solving deterministic problems of task scheduling. The name is an acronym, which stands for *Library of Scheduling Algorithms*. The programme is equipped with an uncomplicated and intuitive interface, shown in Fig. 1.

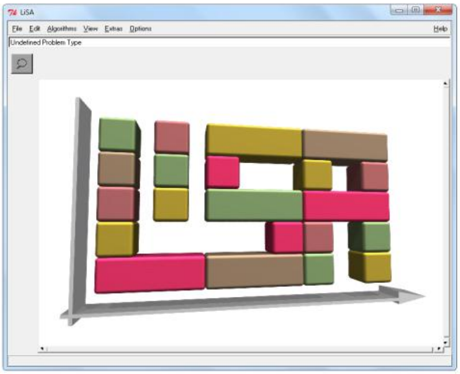

Fig. 1. LiSA – main interface [source: own study]

The user easily inputs data regarding the production process, which are subsequently inserted in suitable matrices; what is more, the application offers random generation of data. All data is gathered in XML files, hence the access to input data as well as results is facilitated. The work with LiSA programme can be stopped at any time, saved and continued when required.

To conduct a computer-aided process of job scheduling it is required that the number of jobs and machines is defined, along with other essential data, such as [1, 2]:

– processing times of particular jobs – in matrix of processing times *PIJ*:

$$PIJ = [p_{ij}], \tag{1}$$

where: p_{ij} – processing time of job i on machine j.

– machine orders – in matrix of machine orders *MO*:

$$MO = [o_{ij}], \tag{2}$$

where: o_{ij} – rank of jobs i on machine j.

– set of operations – in matrix of set of operation *SIJ*:

$$SIJ = [m_{ij}], \tag{3}$$

$$m_{ij} = \{0,1\},$$

where: m_{ij} – information regarding processing of operations i on machine j (0 – operation is not processed, 1 – operation is processed).

LiSA uses the classification for deterministic scheduling problems called the Graham, or $\alpha \mid \beta \mid \gamma$ three-field, notation (Fig. 2), where α describes machine environment, β – constraints, γ – the objective function. Such notation enables clear description of a given task-scheduling problem [8].

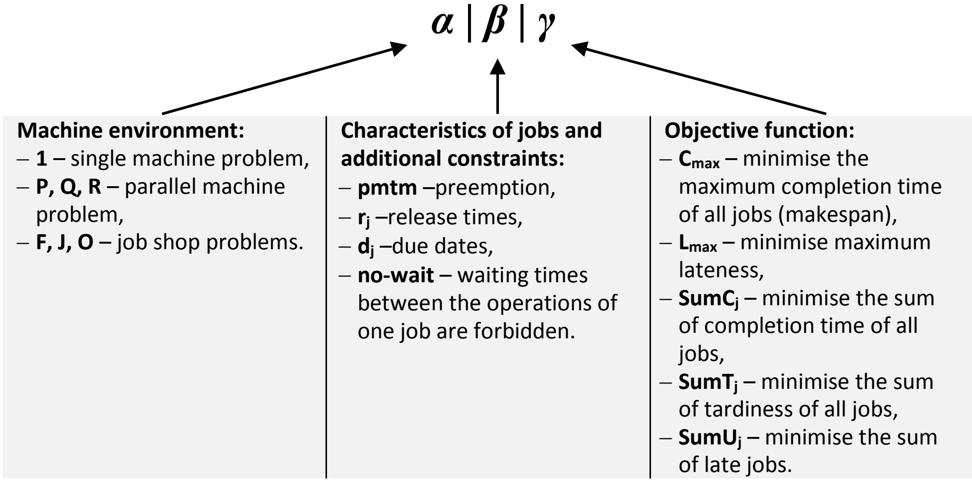

Fig. 2. The three-field Graham notation used by LiSA software [source: own study]

LiSA software solves deterministic task scheduling problems using its library of algorithms. The programme, furthermore, enables modification of existing solutions and implementation of new ones. Determining a job-shop schedule by means of LiSA package can be conducted with the use of the following methods [2]:

– Branch & Bound,
– Brucker's Job-Shop B&B,
– Dispatching Rules,
– Shifting Bottleneck
– Iterative Improvement,
– Simulated Annealing,
– Threshold Accepting,
– Tabu Search.

Each method allows modification of algorithm parameters in order to change their impact on effectiveness of scheduling. Any given problem can be modelled in the form of rank matrix (sequence), disjunctive graph or the Gantt chart (Fig. 3).

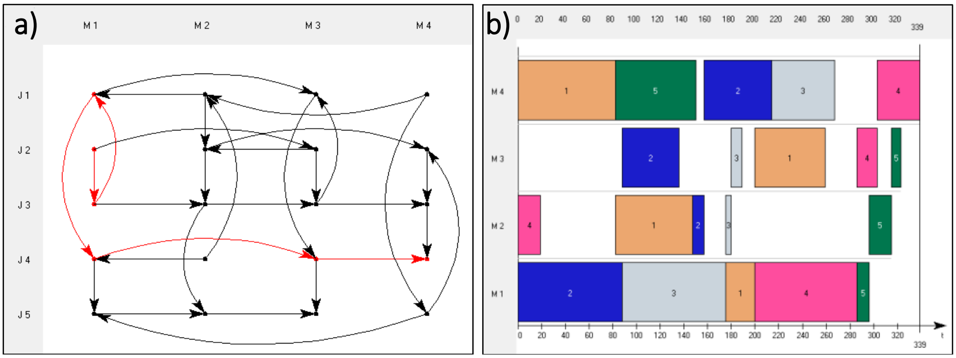

Fig. 3. Models for shop problems in LiSA: a) disjunctive graph, b) Gantt chart [source: own study]

5. EFFECTIVENESS OF TASK SCHEDULING ALGORITHMS

The evaluation of task scheduling algorithms used by LiSA software was based on actual manufacturing data. Four technological processes carried out in a machinery park consisting of 13 machine tools (the machines were ordered according to technology). In order to carry out the analysis, the data had to be suitably prepared, *i.e.* proper indices were ascribed to particular processes (jobs), machines and operations. The indices corresponded to the numbers used in LiSA software. All data is shown in Tables 1–4.

Tab. 1. Route sheet for process 1 [source: own study]

Technological process 1 **Name in LiSA:** job J1								
Operation No.	Machine	**Operation No. (LiSA)**	**Machine No. LiSA**	Operation	t_s [h]	t_c [h]	$t_s + t_c$ [h]	t for 100 units
10	WCC80	**1**	**1**	Centring and facing	0.3	0.03	0.33	3.3
20	TUM25	**2**	**4**	Turning	0.4	0.55	0.95	55.4
30	FYC26	**3**	**6**	Slotting	0.5	0.04	0.54	4.5
40	WKA25	**4**	**9**	Drilling	0.4	0.04	0.44	4.4
50	Met. work.	**5**	**10**	Metal working operations	0.15	0.12	0.27	12.15
60	TUD40	**6**	**3**	Finish turning	0.5	0.15	0.65	15.5
70	SWB25	**7**	**12**	Grinding	0.5	0.15	0.65	15.5

Table 2. Route sheet for process 2 [source: own study]

Technological process 2 **Name in LiSA:** job J2								
Operation No.	Machine	**Operation No. (LiSA)**	**Machine No. LiSA**	Operation	t_s [h]	t_c [h]	$t_s + t_c$ [h]	t for 100 units
10	WCC80	**1**	**1**	Centring and facing	0.3	0.03	0.33	3.3
20	TUD50	**2**	**2**	Turning	0.4	0.12	0.52	12.4
30	FWD25	**3**	**7**	Slotting	0.3	0.02	0.32	2.3
40	FYC26	**4**	**6**	Slotting	0.5	0.01	0.51	1.5
50	SWB25	**5**	**12**	Grinding	0.5	0.2	0.7	20.5
60	TUD40	**6**	**3**	Thread turning	1.5	0.18	1.68	19.5

Table 3. Route sheet for process 3 [source: own study]

Technological process 3 **Name in LiSA:** job J3								
Operation No.	Machine	**Operation No. (LiSA)**	**Machine No. LiSA**	Operation	t_s [h]	t_c [h]	$t_s + t_c$ [h]	t for 100 units
10	WCC80	**1**	**1**	Centring and facing	0.5	0.08	0.58	8.5
20	PHW12S	**2**	**5**	Turning	0.15	0.2	0.35	20.15
30	TUD50	**3**	**2**	Slotting	0.4	0.1	0.5	10.4
40	TUD50	**4**	**2**	Slotting	0.4	0.11	0.51	11.4
50	TUD50	**5**	**2**	Grinding	0.4	0.25	0.65	25.4
60	TUD40	**6**	**3**	Thread turning	1.5	0.45	1.95	46.5
70	FYC26	**7**	**6**	Slotting	0.5	0.08	0.58	8.5
80	SZX160LC	**8**	**11**	Grinding centring holes	0.2	0.02	0.22	2.2
90	SWB25	**9**	**12**	Grinding	0.5	0.29	0.79	29.5
100	Matrix	**10**	**13**	Grinding thread	1.5	1.9	3.4	191.5

Table 4. Route sheet for process 4 [source: own study]

Technological process 4 **Name in LiSA:** job J4								
Operation No.	Machine	**Operation No. (LiSA)**	**Machine No. LiSA**	Operation	t_s [h]	t_c [h]	$t_s + t_c$ [h]	t for 100 units
10	WCC80	**1**	**1**	Milling	0.4	0.03	0.43	3.4
20	TUD40	**2**	**3**	Turning	0.4	0.06	0.46	6.4
30	FND32	**3**	**8**	Milling	0.25	0.04	0.29	4.25
40	Met. work.	**4**	**10**	Metal working operations	0.15	0.01	0.16	1.15
50	SWB25	**5**	**12**	Grinding	0.5	0.18	0.68	18.5

5.1. Mathematical model

The collected data describing the realised processes and indexation allowed developing the mathematical description, which was subsequently implemented into LiSA software. The columns of the matrix represent processors (the number of technological machine) and rows denote the number of the job (realised technological process).

The mathematical description comprises the following elements:

– set of machines M:

$$M = \{M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8, M_9, M_{10}, M_{11}, M_{12}, M_{13}\}, \qquad (4)$$

– set of jobs J:

$$J = \{J_1, J_2, J_3, J_4\}, \qquad (5)$$

– matrix SIJ, containing information on the use of machines during particular production processes:

$$SIJ = \begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \end{bmatrix} \qquad (6)$$

– matrix PIJ, containing processing times:

$$PIJ = \begin{bmatrix} 3 & 0 & 16 & 55 & 0 & 5 & 0 & 0 & 4 & 12 & 0 & 16 & 0 \\ 3 & 12 & 20 & 0 & 0 & 2 & 2 & 0 & 0 & 0 & 0 & 21 & 0 \\ 9 & 47 & 47 & 0 & 20 & 9 & 0 & 0 & 0 & 0 & 2 & 30 & 192 \\ 3 & 0 & 6 & 0 & 0 & 0 & 0 & 4 & 0 & 1 & 0 & 19 & 0 \end{bmatrix} \qquad (7)$$

– matrix MO, describing the order of operations on particular machines:

$$MO = \begin{bmatrix} 1 & 0 & 6 & 2 & 0 & 3 & 0 & 0 & 4 & 5 & 0 & 7 & 0 \\ 1 & 2 & 6 & 0 & 0 & 4 & 3 & 0 & 0 & 0 & 0 & 5 & 0 \\ 1 & 3 & 4 & 0 & 2 & 5 & 0 & 0 & 0 & 0 & 6 & 7 & 8 \\ 1 & 0 & 2 & 0 & 0 & 0 & 0 & 3 & 0 & 4 & 0 & 5 & 0 \end{bmatrix} \qquad (8)$$

The document containing mathematical model in the presented format can serve as input file for LiSA. The process of data input comprises the following steps:

1. In *Problem type* the user defines the analysed problem by means of three-field notation.
2. Then, in *Parameters* window the user describes the analysed process, by filling in the data for particular matrices (Fig. 4).
3. Next, a required scheduling algorithm is selected in the window *Algorithms*, where it can be moreover edited.
4. The obtained results are displayed after selecting *View*.

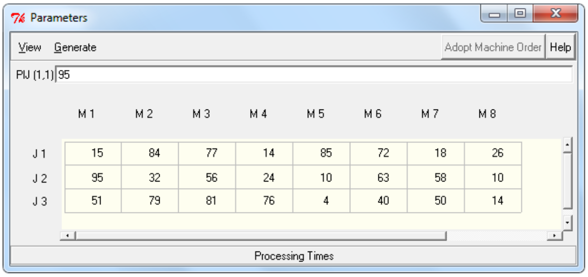

Fig. 4. Data input procedure – defining processing times [source: own study]

5.2. Effectiveness of selected production task scheduling algorithms

In order to evaluate the effectiveness of selected task scheduling algorithms, they were used to solve the following problem (the Graham notation):

$$J \mid \mid C_{max}$$

The scheduled problem concerned the job shop system with no additional constraints, where the objective criterion was to minimise the schedule length. The latter is the criterion that is routinely introduced to analyse optimisation of production task scheduling algorithms.

One exact and three heuristic algorithms were applied in the analysed scheduling. The optimisation analysis involved assessing the impact of priority rules on scheduling results. The values parameters of implemented algorithms were unchanged and set to default. The results of scheduling are presented in Table 5.

Tab. 5. Results for task scheduling problem

Method	Rule	C_{max} [h]
Branch & Bound	LPT	356
	RANDOM	356
Dispatching Rules	LPT	428
	SPT	365
	FCFS	375
	RANDOM	359
Simulated Annealing	–	356
Tabu Search	–	356

In the analysed case, where the production process consists of four technological processes, methods based on both exact and approximate algorithms produced excellent effects. As a result, a 356 h schedule was determined.

As observed in Dispatching Rules the selection of priority rule has great impact on the schedule length. The difference between the longest and shortest schedule length amounts to 69 h. Fig. 5 shows Gantt chart for the optimal solution. The sequence of jobs is presented in the form of task scheduling matrix (Fig. 6). It ought to be noted that in this particular case the total schedule length depends heavily on the operations of technological process 3, which are characterised by long operation times. It is therefore justified to claim that the time of job 3 affects the realisation of other tasks.

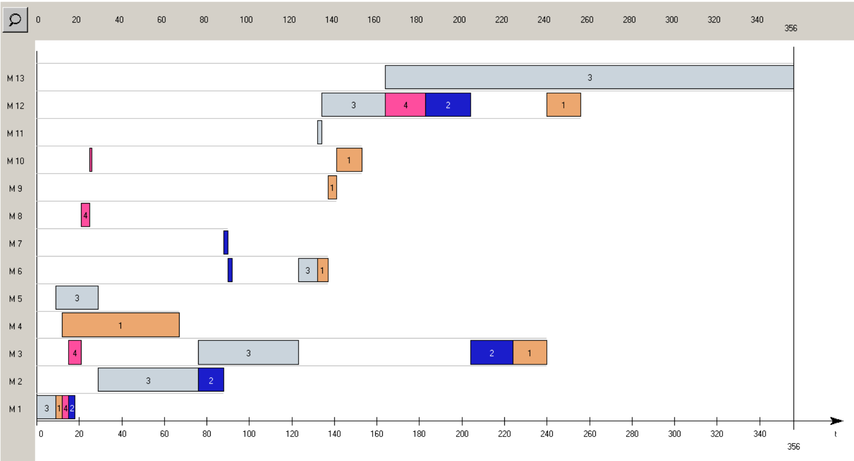

Fig. 5. Task schedule – Gantt chart [source: own study]

	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13
J 1	2		14	3		9			10	11		15	
J 2	4	5	13			7	6					12	
J 3	1	3	5		2	8					9	10	11
J 4	3		4					5		6		11	

Fig. 6. Task scheduling matrix [source: own study]

6. SUMMARY

Production task scheduling is of great significance in the present market. Although designing a feasible schedule is frequently complex and problematic, a well-developed one allows tackling problems regarding order realisation. Hence, computer software is applied to aid production scheduling process. Computer-aided scheduling facilitates the work of any production plant and offers an array of solutions to different problem variants.

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ontology, machine learning, logic predicate

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COMPUTER SYSTEM FOR AUTOMATED ONTOLOGY BUILDING BASIC CROCUS

Abstract

The article exposes the approach developing a computer system of automated ontology building based on creation of architecture system ontology synthesis CROCUS (Cognition Relations or Concepts Using Semantics) software model. The basic modules of the system and its operations are described. The choice of software tools for implementation was described. Example of SDK decision for system realization was substantiated. The using of this system allows filling the domain ontology in automatic mode.

1. INTRODUCTION

The analysis of researches and develops in the branch of intellectual information systems and Internet services gives a ground to suggest that such soft/hardware decisions:

– realization of the ontology synthesis system as a subsystem of the Internet portal system [1];
– using OWL as a knowledge presentation language;

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– using HTN and OWL-S as structures of the automated knowledge base planning language;
– Java API for Protégé OWL as the API and the library processing classes, in particular for the machinery studying (reinforcement learning) of the OWL-ontology and knowledge bases;
– Link Grammar Parcer as an instrument of the grammatically-semantic analysis of English text documents;
– Apache-PHP-MySQL as a software tool to build a web-portal based user interface;
– we get as a web service for automatized access to search engines with a query, formed from the keywords;
– SWRL as a logical new knowledge output language with deductive and inductive methods;
– WordNet as the basic glossary of English.

An ontology in OWL language contains a high-level meaning automation of the subject area. A high-level ontology provides:
– a logical output of new knowledge with the addition of new messages with the context;
– the verification of the validity of obtained statements;
– the evaluation of the probability of the message sources;
– the ensuring of the knowledge base logical integrity.

Extensive researches are conducted in the field of information technologies, especially artificial intelligence. The advances are strengthened by the creation of wide range of software and universal and specialized computer equipment that uses it. All this is accompanied by the rapid and intensive formation of the new scientific terminology that is not always commonly acknowledged. Therefore to avoid ambiguity we should give the basic definitions of concepts used in this paper.

The notion of 'knowledge' remains most common and least clearly defined yet. In this paper, we assume that knowledge is useful information. Unlike the information that is measured as media volume needed for its storage, knowledge should be measured as a benefit of using corresponding information. Knowledge acquisition can in principle take place only when and where there is its (potential) carrier – an intellectual agent which has information about its current and desirable state as a goal, achievement problem and motivation, and a strategy (plan) to achieve its goals. Only then the information can be used to solve these problems and thus serve as knowledge to their carrier – an intelligent agent.

We are considering ontology as formal explicit representation of common terminology and its logical interdependence for a certain subject domain. An ontology formalizes an intensional of the domain – e.g. a set of rules in terms of formal logic, while its extensional is defined in the knowledge base as a set of facts about instances of concepts and relationships between them. The process of filling the knowledge base called knowledge markup (further – KM), or ontology population (further – OP), methods and tools for automatic (semi-automatic) ontology structure development – ontology learning (OL). OL methods in turn are based on the methods of natural language processing (NLP) [2] and machine learning (ML). Far less attention is paid to the approaches developed in the field of automated planning (AP). Knowledge acquisition (KA) in particular from text documents using the NLP methods is perhaps the only way for automatic construction of ontology, which however cannot replace an OL as a scientific discipline, remaining its key instrument. A role of ontology makes a fundamental difference between OL and KA because for OL it is not only the tool but also a target and a performance criterion for methods and tools developed during OL researches.

The method of recognizing the logic content of the natural text document i.e. natural language understanding (NLU) is based on an information technology of semantic text analysis, i.e. text mining (TM), which in turn can be approximately determined as the process of identification information that can be useful for solving certain tasks [3]. On the other hand, the research area TM includes NLU in the part where it acts as a scientific discipline – linguistic tool for translation natural language (NL) documents to formal knowledge representation languages for further formal analysis. NLU in turn considered as a section of NLP [4] (Fig. 1).

Currently TM is an actively developing scientific discipline. It has not well developed institutions (no universally recognized textbooks, lectures, chairs on this subject) and therefore is in a somewhat uncertain status. Some experts interpreted TM too broadly and include in it all IT techniques which deals with NL texts, others understood TM too narrowly as a particular case of statistical data analysis – data mining (DM), yet others tend to believe this discipline extension or replacement of the information retrieval (IR) discipline. In most cases, a statement of the problem depends on the subject domain in which it is formulated. TM includes very different approaches to this problem by a level of analysis – a simple classification using a syntactic parser and identification the specific values of the semantic structures as provided, for example, in a quite advanced project GATE, up to complex predictive analysis, aimed at finding a solution of the problem. It is the second approach is considered in this paper – an intelligent content recognition (understanding) NL text as a main source of knowledge today.

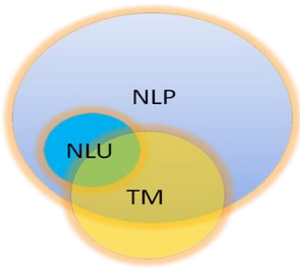

Fig. 1. Interference of scientific disciplines in natural text processing – TM includes NLU in field of targeted logical analysis [source: own study]

1.1. Java API Protégé-OWL

The machinery education is provided with the means of Java API Protégé-OWL. These means contain libraries of classes, which realize methods to work with OWL-structures like reading and addition. Therefore, the means of machine learning are working in addition to the OWL-ontology. It takes templates of grammatically semantic structures to recognize statements (the first order predicates) into the research and/or educated texts including new elements as the result of such recognition. Link Grammar Parcer divides a grammatically correct approving sentence into interconnected pairs of words. LGB contains a table that has all the conformities between grammar constructions of English and syntax-semantically links between words (intellections). LGP API allows to link this table to OWL-ontology, so the table can adapt in the process of learning the given object area dynamically.

Java API Protege-OWL [5] based means of machinery education contain a generalized description of the semantic link, which serves as the template for generating new types of semantic link during studying. In addition, it forms appropriate vectors and indications of these links to form and identify semantic links in a text. Herewith, properly classes of links and their properties adding to the OBP. Exemplars of those classes are for the description of existing and new classes of an ontology by their use as first rank predicates.

1.2. Ontology learning

The process of ontology learning [6] is widely discussed lately. But all elaborated approaches do not take into account the problem of reaching an optimal structure and dimension of an ontology. It is known that computational complexity of graph processing algorithms not allow to work (at least in real time scale) with especially large ontologies, for example in case of solving tasks of eliminating knowledge inconsistency. Therefore extremely important not simply add all accessible relevant knowledge data to an ontology but refine existing knowledge structures inside defined optimal volume. This task must follow some criteria of optimality most valuable of which is data usefulness, applicability or, other words, knowledge pertinence.

To estimate data usefulness as the main criteria of optimality it is possible to count a frequency of mention of connected with it concepts and relations in ontology. This is a formal evidence of data importance, because ontology represents sphere of agent interests if and only if learning procedure will be correct enough. Such approach was considered in our previous work.

More precise approach must take into account the main task of agent's activity or, to be more specific, hierarchy of tasks and a gain from its solving as the most adequate criterion of information usefulness. It is possible because an ontology should contain an explicit specification of that task hierarchy. Moreover, if a first dimension of an ontology structure is a taxonomy, second must be built as a hierarchical task network (HTN) (Fig. 2).

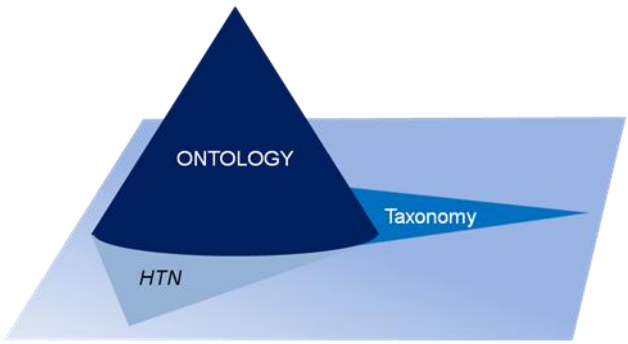

Fig. 2. Two different dimensions an ontology

An ontology has two different dimensions – as a taxonomy of concepts and as a hierarchical task network (HTN) [7].

Thus ontology learning process is based on NLP procedures with aim to find out subtasks of the agent's main task, appropriate task solving strategies and their components – resources, actions (operators), methods, preconditions, effects, dependencies and other restrictions. It is performed on different levels of coverage of text – from separate found term definitions up to the whole message meaning as a problem solving recipe. In any case all new information or supplements an optimal strategy represented in an ontology, or cannot do it and is rejected as unnecessary.

Learning process in details consists of next stages:

– a task from own ontology, which is appropriate to the task described in a message, extracted from NL text document, must be selected;
– new approach taken from message is applied temporarily to solve the selected task;

– a maximum expected utility of a new strategy is estimated and compared to previous one;
– if an utility value growing, the ontology is corrected, otherwise message data is stored in a knowledge base as a reference information about it's source.

Agent also learns different task solving patterns – decision making using different heuristics. In one of them for simplicity each task could be represented as partially observable Markov decision process (POMDP) that is a generalization of the standard completely observable Markov decision process that allows estimate optimal strategy using imperfect (incomplete) information about the state of the system. Such formalism possess well developed solving algorithms therefore is useful for implementation.

ZMN ontologies make sense only as the part some intellectual system. Optimal decisions in our opinion are that, where such an intellectual system [8-10] in the information search system for which an adaptive ontology is an instrument for information research, analysis and classification on the one hand, which uses search instrumentalities to provide data for its filling, new predicates and rules synthesis, learning new means and semantic links on the other. An intellectual system of information searching based on the adaptive ontology, material science knowledge base, a database of scientific publications became such a decision.

A developed architecture of the ontology synthesis system was realized with the usage of selected and descripted means and program-technically decisions as a CROCUS (Cognition Relations Or Concepts Using Semantics) [11].

2. THE PROBLEM FORMULATION

2.1. New knowledge evaluation

All the procedures are needed to evaluate the knowledge contained in the analyzed message. As has been mentioned above it depends on message context which is explicitly expressed in an ontology of the agent and optimal strategy of reaching its goal that it contains. The evaluation method is based on the expected value of perfect information – $EVPI$:

$$EVPI = EV \mid PI - EMV, \tag{1}$$

where: EMV – is the probability weighted sum of possible payoffs for each alternative;

$EMV = \max_i \sum p_j R_{ij}$ (2), $\sum_i p_j R_{ij}$ (3), is the expected payoff for action i ; $EV \mid PI$ – the expected or average return if we a priory have "perfect" (i.e. new) information for best i choice:

$$EV \mid PI = \sum_i p_j (\max R_{ij}) \tag{4}$$

To estimate new knowledge $EVPI$ we must have the value of EMV for each solving approach (action for (3)) to each task from HTN of our ontology and with aim to obtain them all we must create and solve appropriate POMDP task:

$$EMV_i \equiv U(S_i) = R(S_i) + \gamma \cdot \max_{A_{ik}} \sum_k P(S_i, A_{ik}, S_j) U(S_j) \tag{5}$$

Equation (5) describes the reward for taking the action giving the highest expected return. Additional information decreases model uncertainty therefore expected common reward (utility) will be not less than without such information.

Using them for particular domain model it is possible to evaluate expected utility for both cases: with new information and without it.

2.2. Reliability evaluation

All obtained information is verified for its consistency and if any contradictions appear a logical conflict is solving by rejecting data with less reliability of its source. In such case the reliability of the source D also decreases according to appropriate formula:

$$D_{n,i+1} = \frac{D_{n,i}}{(2-s)} + \frac{1-D_{n,i}}{2} \cdot s$$

where: s – the truth of the statement that takes the value 1 if the statement is true or 0 – otherwise, i – step number confirmation/denial of the truth of the one statement of n-th source.

The purpose of this article is to develop a computer system building automated ontology base.

3. MAIN PART

3.1. CROCUS system

The overall concept of CROCUS [12] is introduced at the (Fig. 3). A subsystem of the ontology education uses educational texts of annotations of scientific publications from article DB. The system forms a plural of key words to fill the DB in. It chooses the main metadata about the publications in the defined subject area in Internet (ScienceDirect, CiteSeer, Wiley Online Library, Springer) including their annotations, which become the core of analysis and ontology learning.

The essence of the knowledge extraction method from the natural text document is into building of the intellectual agent activity strategy – an informational model of the recognition subject of its specification based on dedicated from recognized text document data. A plan is considered to be a specific optimal strategy realization of some task, which has an intellectual agent within the subject area.

The plan is built with the same with informational model formal knowledge representation language – a database of an intellectual agent. Considering that, such a knowledge base is already an overall plan of intellectual agent functioning, build basing on the natural text recognition is a sub-plan. It means that it is a specification of an overall plan and it bases on it. A value of information, received as a result of recognition the context of a text document is determined as increasing of the updated intellectual agent functioning plan expected utility.

Scientific publications range for the relevance to the users informational demands, for the conformity to ontology, which displays these demands. An analysis of each annotation as natural text is made, builds its image in the terms of ontology as predicates and rules in this purpose. These predicates and rules are added in the knowledge base of the system and the expected utility of an intellectual agent is calculated again. A system puts those publications nearer to the beginning of the list, which data including leads to the greater reliability change with such a type of ranging.

A system can adopt to the users requirements by saving his preference system in the DB. Each user can perform an education of his ontology. The system saves the data about this process, leads the session statistics, provides the possibility to correct the education errors and does backtracking to previous versions of an ontology.

CROCUS system modules are shown at the (Fig. 3). A client has a possibility to control the priority of document ranging, to correct their order in the list of the most important (relevant to the client informational requirements) document and classify them with the help of graphic interface. The most important documents are used for ontology education and building of the efficient sets of key schemas and new, received from Internet, articles (their metadata including annotation) insert into the DB of publications with the link with preferences of the user and other prerequisites of the document receiving. First of all, its sources.

An annotation processing happens after its previous processing, conversion into the massive of predicates as a result of grammatically-syntax analysis of Link Grammar Parser. Formed annotation models are supplemented with semantically near ontology predicates – the context of this annotation. Supplemented annotation models are compared between themselves to calculate the semantic length between their semantic weight midpoints and so the nearest by content documents are chosen with their further ranging and classification.

3.2. Main functions of CROCUS

An interactive automatic building of the problem area ontology. Searching, saving and classification (ranging) of scientific publications as in interactive semiautomatic as in automatic mode.

Each of these functions is realized with its base set of functionality modules but a part of them was a double appointment. CRONUS is realized as an object oriented paradigm by using Java as a hierarchy of code classes, which copies call each other with determined at that moment parameters or they interact through throw events and/or handlers. Most of them have a Swing graphical interface and AWT libraries. All the connected libraries have an open source status. Project has a full functionality and has all the necessary means for its development (evolution). A functional assignment of the main CROCUS system modules is shown at the (Fig. 3).

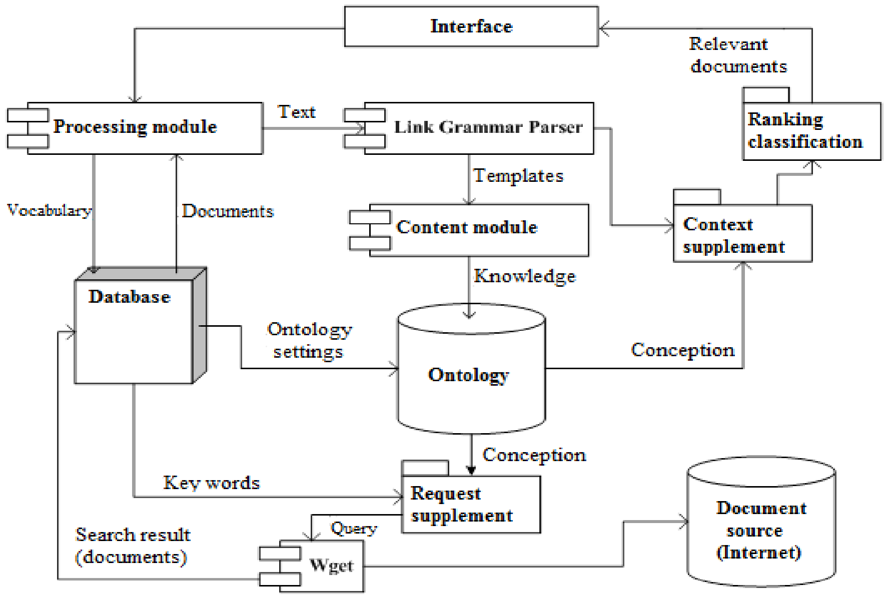

Fig. 3. CROCUS modules [source: own study]

As an implementation of presented KD concept the intellectual information retrieval system CROCUS (Cognition Relations Or Concepts Using Semantics) was created. The system was built on the basis of Java Protégé-OWL API, using OWL-DL as a knowledge representation language. For providing of recognition new do-main concepts at interactive learning mode the WordNet API was included in the system. Through the use of DBMS MySQL it is possible for the CROCUS system to store, process and use during learning process a statistics for many domains and many users simultaneously and independently. The main interface of the CROCUS application is presented at (Fig. 4).

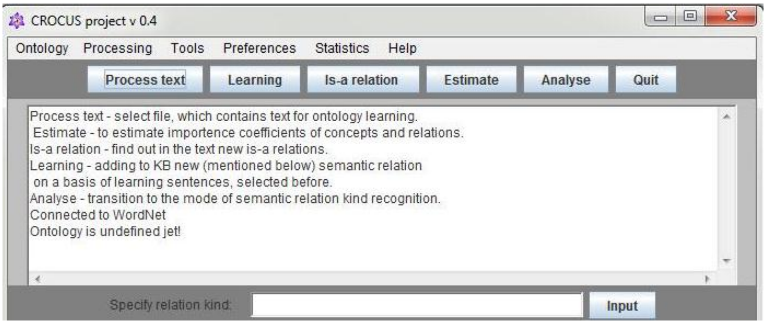

Fig. 4. The main window of CROCUS user interface [source: own study]

It performs two main interdependent functions: learn an ontology in both super-vised and unsupervised modes, and search new knowledge in annotations of scientific articles using ontology with aim to recognize it and estimate measure of its importance.

3.3. Functionality of CROCUS modules

The basic system control element in CROCUS is ControlGUI module (user graphical control interface). This module has a graphical interface by which user can execute procedures, which are provided by the system functionality. Module has the main menu and its main functions are in the toolbar. Control output is carried out at the appropriate text panel. There is an output field and an input field at the underside of the main window to specify the semantic link type at the process of ontology learning using learning sentences (Fig. 4**)**.

Despite the importance of the effective dialog between system and user, a great attention during developing was to the graphical interface design, its intuitiveness and pithiness with a functional completeness of project tasks realization. In addition, there is a possibility to zoom interface to expand its functionality. Despite the intense competition between the similar projects, a great importance was to create a recognizable logotype, which will be replied to the content of the word CROCUS. An experience of such foreign projects confirms an efficiently of such an approach (Protégé to work out with OWL-Ontology, project GATE, etc.). That is why all the windows in dialogue with user are decorated with CROCUS logotype – an illustration of 6-petal saffron (crocus) flower. Professional designers developed an image and the design of main windows interface.

System has an internationalization of whole text dialogues. User can choose a comfortable interface language from four available. There is no problem in language addition. A dialog language file MessagesBundle_xx_XX.properties has to be translated, where XX – the code of a language (RU – Russian, UA – Ukrainian etc.).

To choose the dialogue language you have to choose a subparagraph 'language' into the paragraph of the main menu 'Preferences'.

3.4. Justification of the SDK choose

A using of SDK common libraries gives a chance to avoid unjustified overrun of time, finances and human resources for their redevelopment. Therefore, there is a wide list of investigated currently working analogue projects in this work. Most of them use the concept of open source code and free licensing. The leading developers groups provide their projects with API (Application Programming Interface) means, so the functionality of these objects may be efficiently used by cataloged and well-documented procedures and functions with appropriate settings.

Co-authorship of SDK developments worked out principles of software application usage with different license agreements [12–16]. In addition, they can take part in support and development of existence projects, so each developer has a possibility to get and install these project or libraries and use them as he or she wants. Such internet portals as SourceForge.net contain all the necessary instrumentals for documentation and support projects of every level of difficulty, readiness, access level and popularity between users. Developers actively use special foundation servers, which provide collective (let it be 1000 developers) software developing. The most popular foundation server is Git. It can be installed separately as individual or corporative server and it is possible to use a global GitHub server.

Researches show, that most of the develops in text documents natural processing, almost all the develops in ontology learning are performed on Java. Moreover, Java is dominating between projects languages at SourceForge resource.

A decisive argument to Java usage is an accessibility of Protégé-OWL Java API of Stanford University (USA), because Stanford Center for Biomedical Informatics Research became a flagman of practice developments in OWL SDK-s.

Projects made by Java:

- Gate [http://gate.ac.uk/] – a couple of text documents processing means to find a new knowledge;
- owlapi.sourceforge.net – another one Java project, which is an OWL documents processing Java classes library with broad functionality;
- Pellet [http://clarkparsia.com/pellet/] – a logical output machine to realize thinking (new knowledge output) from OWL 2.0 knowledge base.

4. CONCLUSIONS

Therefore, this work shows an approach to develop an automatized basic ontology building. An architecture of ontology synthesis system as CROCUS (Cognition Relations Or Concepts Using Semantics) software model was created. The main system modules and their appointment were described. A decision of SDK for system realization was substantiated. A usage of such a system can fill an ontology of subject area automatically.

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R&D projects, Fuzzy AHP, TOPSIS

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COMPUTER AIDED TEAM BUILDING FOR RESEARCH AND DESIGN PROJECTS

Abstract

Building teams has a fundamental impact for execution of research and development projects. Often the success of the project depends on the competence of employees implementing these projects. Therefore, it becomes essential to build the team where skills complement each other in terms of knowledge, personality and practical skills. On the other hand an important element is the process of assessing the candidate. The person dealing with recruitment often bases its decisions on intuition / subjective impression and they tend to be unreliable. The article presents a proposal to use Fuzzy AHP and TOPSIS methods in team building for R&D projects on the basis of employees skills using for this process the most well-known tool, namely spreadsheet.

1. INTRODUCTION

Employee team building is one of the first stages of execution of an R&D project. This process is essential for correct execution of the whole project, quite often implemented for the first time. Quality of jobs assigned depends on experience and personalities of cooperating team members within the R&D project, while correct implementation in accordance with approved plan depends on project leaders. Work sharing, controlling the essential aspect of the project, as well as monitoring progress at various stages, are the key milestones of R&D

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project management. “This is the art that requires the ability to function in many job roles and to understand the importance of the ‘human factor’ for the success of the project” [8]. “Individuals decide on everything – this statement repeated multiple times is always true when it comes to implementation of R&D projects” [9]. Described in the article simulation was carried out in a spreadsheet. Based on this experience, the authors plan to create a dedicated IT tool [12].

This publication has two sections – theoretical and practical. The article in chapter one and two presents the concept of R&D projects and describes individuals – the fundamental job roles in regards to implementation of an R&D project. The next two chapters present Fuzzy AHP and TOPSIS methods and describe the use of presented methods in relation to the process of team building in R&D projects.

2. RESEARCH AND DEVELOPMENT PROJECT – DESCRIPTION

The definition of a project has been known for a hundred years. “Already in the ancient times great monuments were built on the basis of detailed unique technical and organisational plans, which specified in details the tasks and management arrangements of contractors work” [16]”. The word project originated from Latin word ‘proiectus’ back then meant ‘to put forward’ which is explained by modern researchers as an intended development of a proposal. Nowadays, the term ‘project’ can be defined as “an endeavour made within the organisation, which is a new and extraordinary idea, different from routine activities, that the organisation has not dealt with ever before [19]”. James P. Lewis describes project as ‘a one-off job, which has a certain commencement date and deadline, clearly defined aims, scope and (in general) a fixed budget [13]”. The reference literature often assumes that a cause of project commencement is a personal need or a given assignment from a client [22]. In the aforementioned definitions of the project, the authors emphasize that the main goal of a project is to achieve an aim, which is a defined result, and they skip the uncertainty and risk issues within the project implementation. It means that the general definition of the project shall not be used to describe research and development project. The authors of this article have chosen, for further consideration, one type of projects – research and development projects that are describe the source literature as R&D projects.

“The research and development activity is a systematically conducted creative work, undertaken in order to increase knowledge (...), as well as to discover new ways to apply this knowledge. It covers three types of research: basic research (theoretical and experimental work basically non-targeted, to provide particular practical uses) and applied research (research work conducted in order to gain new knowledge that has particular practical use), as well as development research (that consists of application of the existing knowledge in order to develop new or significant improvement of existing products, processes or services) [8]". The above mentioned definition is similar to the definition recommended by the OECD from Frascati's book [21].

A research and development project is defined as implementation of a particular goal with a risk factor, not always precisely set out, in most of the cases allowing to obtain new knowledge about the reality that surrounds us for whose achievement we have the necessary resources, including highly qualified team of contractors, specified amount of time and knowledge regarding all the requirements [9].

The management of research and development project is a sustained search of causes for success and roots of failures [3]. The management consists of a chain of decisions, which lead to meeting the goals specified during the defining of objectives stage. "In accordance with the principles of implementation and management theory, the process of R&D project management consists of four basic relationships occurring during definition and implementation of the project. These are the following: planning, organising, motivating and controlling [9]". The management of R&D projects is classified as an adaptive and extreme way of project management, as goals of R&D projects are not precisely set out and can be modified during the project implementation [25].

3. TEAMS IN RESEARCH AND DEVELOPMENT PROJECTS. DESCRIPTION OF POSITIONS AND SKILLS.

Members of the team should have appropriate education and experience to carry out their tasks. They should also easily be able to cooperate, to lead and have other qualities for effective team work in the given research and development project.

The reference literature distinguishes three strategies of team building:

- creation of an R&D department in a company and designated project teams within this department, continuously working on assigned tasks,
- creation an independent team sin a company, whose members spare most of their time working on the project,
- the individuals chosen for implementing the project are those, who carry out their main duties in different departments, and they work on the particular project when they have free time.

As has been demonstrated in a research conducted by A. Gryzik, A. Knapinska, A. Tomczynska, R&D activities are most effectively carried out within a separate R&D unit, created in a company. It is more difficult to implement projects, when members of a team have numerous responsibilities, work in more than one team, or work on a large number of projects [5].

The main personnel that is necessary for R&D projects implementation are, inter alia, an author, a project manager, tasks managers and individuals responsible for implementing [9].

"The author is an individual that developed a project, which is original and has cognitive values" [17]. This individual has right to undertake decisions in regards to, e.g. circumstances of project implementation, or determining public announcement of results of the whole R&D project. It is commonly assumed that the author specifies individual and cognitive values of the whole project, and thereby she or he has a key role in its implementation. A popular event occurring in manufacturing companies is hiring author, also as a manager of research and development project.

The manager of R&D project, is often in the companies that implement R&D projects, also called a project leader or a project manager. The reference literature, in the subject of project management skills and features, is very comprehensive. It describes both "hard" and "soft" skills of an individual, employed in this capacity, as well as project management styles, which depend on the way the company does business. This literature also very often indicates the wide range of tasks, which must be completed by a manager. Jobs most frequently carried out by a project manager include:

– planning tasks, activities and results by creating, inter alia, appropriate work share amongst members of a team, schedules, budgets,
– choosing and organising the team,
– establishing and maintaining relationships with stakeholders,
– team building of all the employees that are working on the project;
– monitoring of project progress,
– identifying and direct solving of problems, or searching for ways to resolve them,
– dealing with the crisis and conflict management,
– decision-making or giving recommendation to stop the project in case when achievement of the set objectives is not possible [18, 9, 5].

The project manager skills are also described by four global standards:

– PMCDF – Project Manager Competency Development Framework (Project Management Institute),
– NOS PM – National Occupational Standards for Project Management (Engineering Construction Industry Training Board),
– AIPM PCSPM – Professional Competency Standards for Project Management (Australian Institute for Project Management),
– ICB – IPMA Competence Baseline (International Project Management Association) [5, 8, 9, 24].

The most popular standard is the ICB-IPMA standard. It lays down three groups of skills, which each individual on a project manager position shall have. “Behavioural competencies are associated with the expected attitudes and behaviours, as well as values presented by the manager. This includes, for example, leadership, motivation, self-control, assertiveness, openness, creativity, crisis management, compliance with ethical principles, etc. Technical skills enable starting a project, management of implementation and its successful completion. Their fundamental meaning is emphasized, however simultaneously, it is pointed out that they are not sufficient to eliminate the possible risks during the project implementation. Contextual competences are associated with the wider context in which the project is done, for example, the process of implementation, personnel, occupational health and safety managements, finance, law” [5]. Additionally, due to the fact that more and more research and development projects being implemented in international consortia, it is recommended that the project manager has the ability to operate in a multicultural environment, which means, inter alia, knowledge of foreign languages and, if necessary, even knowledge of the history and culture of other countries.

Task manager is an individual that has essential knowledge to carry out a particular activity and, additionally, he manages team of subordinated employees, performing assigned jobs. In general, he shall have similar qualifications and a project manager. However, his scope of activity and power is limited only to defined task to fulfil. Individuals responsible for implementing are those, who perform assigned jobs in R&D project. „The composition of a team decides on results and effectiveness on this team, where members have range of duties that are well established, related to the traits of their personalities” [23] . It is described by M. Belbin, who distinguishes in his works types of personalities that could be assigned to appropriate job roles. In R&D projects useful are individuals like creator, explorer of sources, engine and assessor [2]. It is often proven in practice that the most effective are teams whose members differ from each other, e.g. in their origin, education, experience, qualifications and personality traits.

Tab. 1. Personality traits of the best project managers according to the senior management of a given organization [1]

Personality traits most often indicated as the qualities of the best project managers	Personality traits pointed out very rare as the quantities of the best project managers
meticulous, conscientious	independent
energetic	conventional
undertaking control; leader	modest
self-confident, open	theoretical
reasonably evaluating situation	worried, becoming easily emotional
convincing, emphatic	

The ability and effectiveness of activity of the whole project team depends greatly on complementing each other in the team. In his work S. Gregorczyk writes with co-authors that general requirements regarding team members may include:

- susceptibility to the project management influence,
- team work skill,
- ability to cooperate with other team members with different level of education and experience,
- high level of technical skill,
- problem solving and results achieving orientated,
- high self-evaluation and ability to acknowledge mistakes and failures [4].

4. FUZZY ANALYTICAL HIERARCHY PROCESS AND FUZZY TOPSIS METHOD

FAHP (Fuzzy Analytic Hierarchy Process) – the method of fuzzy analytic hierarchy process is based on AHP method, which is widely used in development of decision-making models. FAHP uses experts opinions in order to establish the weighting factors that determine the validity of features and, additionally, eliminates the features of least importance, when it comes to question of linear ordering of objects [13]. The importance of a feature in this case is established on the basis of fuzzy opinions of experts, so-called, soft opinions (soft opinions), which are more viable than hard opinions (hard opinions) [14].

TOPSIS Method (Technique for Order Preference by Similarity to an Ideal Solution) is a statistical process leading to linear ordering of objects described by metric and non-metric features – professional order [14]. This method is used to establish order and rank of various alternatives [10]. The mail goal of the TOPSIS method is that determines a solution with the shortest distance to the ideal solution and the greatest distance from the negative-ideal solution [19].

5. FUZZY AHP AND TOPSIS

The assessment process of strategic factors for selection of personnel essential to implement the R&D project, was based on the fuzzy analytical hierarchy process that is the method used to solve multi-criteria problems with decision-making. This process was implement in various business situations studying the selection of excellence from the performances of multiple companies' [6, 7].

In this direct case - this method was conducted according to four stages. In stage 1, on the basis of survey sent out to 30 research and development project managers, implemented within manufacturing companies, established in Poland, the criteria of skills assessment for the position of project manager. In the survey the five grades of evaluation in the Likert Scale, where 5 is very important, 4 – important, 3 – neutral, 2 – unimportant and 1 – criteria is irrelevant, had been specified, criteria which were considered to be the most important. The effectiveness of the conducted survey was 73% (the feedback contained 22 surveys with answers). The results were presented in Table 1.

Project manager competency criteria analysis

	Technical competencies	**Number of Scoring**				
		5	**4**	**3**	**2**	**1**
C1	project management effectiveness	14	6	2	0	0
C2	project requirements	13	8	1	0	0
C3	risk and responsibility	10	8	4	0	0
C4	timeliness	11	9	0	0	2
C5	interpersonal communication,	6	7	6	1	2
C6	knowledge of foreign languages	15	5	1	0	1
C7	analytical thinking	9	7	3	0	3
	Behavioral competencies	**Number of Scoring**				
		5	**4**	**3**	**2**	**1**
C1	leadership qualities	12	10	0	0	0
C2	involvement and motivation	5	17	0	0	0
C3	assertiveness	10	7	3	1	1
C4	creativity	15	2	2	1	2
C5	effectiveness	11	8	2	1	0
C6	conflict management	13	6	2	1	0
C7	flexibility and availability	15	5	2	0	0
	Contextual competencies	**Number of Scoring**				
		5	**4**	**3**	**2**	**1**
C1	project oriented	8	10	3	1	0
C2	business, economic indicators	12	10	0	0	0
C3	personnel management	5	13	1	2	1
C4	health, safety and environment	7	14	0	0	1
C5	knowledge of financial and legal policy	3	6	8	3	2

Fig. 1. Stage 1: determination of criteria for assessing competence for the position of Project Manager [source: own study]

Based on the theoretical description of the method of Fuzzy AHP and TOPSIS presented in the article by A. Łuczak and F. Wysocki [10] and C. Kahraman, U. Cebeci and Z. Ulukan [7], consecutively in the stage 2, the following steps were carried out:

Step 1. Developing a hierarchical structure for problems with multiple criteria for objects assessment Developing structure is made through comparison of pairs of tasks of lower priority. On each level of hierarchy the importance of critical elements is determined by pairwise comparisons, using in this process the fuzzy 9-grade evaluation scale (Table 2). These comparisons are analysed in respect of its importance in the making of decision. Using the scale, the comparisons of importance of lower priority are made, in regards to main objective and tasks in the scope of every lower priority objective (Table 2). The pairwise comparisons of importance of critical elements on each level of hierarchy are conducted by professionals (decision makers) who are directly involved in meticulous decision-making process.

Tab. 2. The 9-grade evaluation scale of importance of pairwise elements [11]

The superiority of importance of critical elements	**Explanation**	**Priority Scales** $(\tilde{a} = (l, m, u))$
Equivalence	Both factors contribute equally to achieve the objective.	$\tilde{1} = (1,1,1)$
Poor or moderate	Importance does not convince or poor priority of one factor over another factor.	$\tilde{3} = (1,3,5)$
Important, fundamental strong	Fundamental or strong meaning, or strong priority of one factor over other factors.	$\tilde{5} = (3,5,7)$
Vast or very strong	Vast meaning or very strong priority of one factor over other factors.	$\tilde{7} = (5,7,9)$
Total	Total meaning or total priority of one factor over others.	$\tilde{9} = (7,9,9)$
For comparisons compromising between values stated above	Sometimes a numerical interpolation of compromising opinions must be carried out for lack of appropriate vocabulary to describe them. That is the reason for using intermediate values between two adjacent grades.	$\tilde{2} = (1,2,4)$ $\tilde{4} = (2,4,6)$ $\tilde{6} = (4,6,8)$ $\tilde{8} = (6,8,9)$
Transitivity of grades	If a factor A has assigned one of the above grades, during a comparison with a factor B, then factor B has opposite value, when being compared to A factor.	Opposition of above values

	C1			C2				C6			C7		
C1	1,00	1,00	1,00	3,00	5,00	7,00	...	5,00	7,00	9,00	3,00	5,00	7,00
C2	0,14	0,20	0,33	1,00	1,00	1,00		5,00	7,00	9,00	1,00	3,00	5,00
...								...					
C6	0,11	0,14	0,20	0,11	0,14	0,20		1,00	1,00	1,00	0,14	0,20	0,33
C7	0,14	0,20	0,33	0,20	0,33	1,00		3,00	5,00	7,00	1,00	1,00	1,00

Fig. 2. Stage 2: calculation of weighting factors for the features under the technical criterion [source: own study]

Step 2. Determination of the priority of criteria and features by assigning them weighting factors, derived from fuzzy analytic hierarchy process (FAHP). The results obtained are described in Figure 2, 3 and 4.

	C1			C2				C6			C7		
C1	1,00	1,00	1,00	1,00	3,00	5,00	...	1,00	1,00	1,00	1,00	3,00	5,00
C2	0,20	0,33	1,00	1,00	1,00	1,00		3,00	5,00	7,00	1,00	3,00	5,00
							...						
C6	1,00	1,00	1,00	0,14	0,20	0,33	...	1,00	1,00	1,00	0,20	0,33	1,00
C7	0,20	0,33	1,00	0,20	0,33	1,00		1,00	3,00	5,00	1,00	1,00	1,00

Fig. 3. Stage 2: calculation of weighting factors for the features under the behavioural criterion [source: own study]

	C1			C2			C3			C4			C5		
C1	1,00	1,00	1,00	1,00	3,00	5,00	1,00	3,00	5,00	1,00	3,00	5,00	1,00	3,00	5,00
C2	0,20	0,33	1,00	1,00	1,00	1,00	1,00	3,00	5,00	1,00	3,00	5,00	1,00	3,00	5,00
C3	0,20	0,33	1,00	0,20	0,33	1,00	1,00	1,00	1,00	0,20	0,33	1,00	1,00	3,00	5,00
C4	0,20	0,33	1,00	0,20	0,33	1,00	1,00	3,00	5,00	1,00	1,00	1,00	1,00	1,00	1,00
C5	0,20	0,33	1,00	0,20	0,33	1,00	0,20	0,33	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Fig. 4. Stage 2: calculation of weighting factors for the features under the context criterion [source: own study]

The third stage, according to the indicated article [14], the values of synthetic feature were determined, using fuzzy TOPSIS method (Figure 5 and 6). Next, in the stage 4, the data was put in linear order and prospective candidates for a R&D project manager were typologically classified, according to the synthetic feature value (Figure 7).

CANDIDATE	Technical competencies							Behavioural competencies							Contextual competencies						
	C1				C5			C1				C5			C1				C5		
	a	b	c		a	b	c	a	b	c		a	b	c	a	b	c		a	b	c
K1	60	70	80	...	40	50	60	60	70	80	...	40	50	60	40	50	60	...	40	50	60
...					...							...							...		
K5	80	100	100		60	70	80	80	100	100		80	100	100	40	50	60		40	50	60
weighting factor	0.10				0.06			0.02				0.02			0.09				0.04		

Fig. 5. Stage 3: determination of synthetic feature value using the fuzzy TOPSIS method – step 1 [source: own study]

CANDIDATE	Technical competencies			Behavioural competencies			Contextual competencies		
	C1		C5	C1		C5	C1		C5
K1	0.627	...	0.000	0.457	...	0.315	0.000	...	0.000
...			...			...			...
K5	1.000		1.000	1.000		1.000	0.000		0.000

Fig. 6. Stage 3: determination of synthetic feature value using the fuzzy TOPSIS method – step 5 [source: own study]

Eventually, on the basis of data of all candidates, in the first place, for the R&D project should be employed candidate no. 5. In case indicated candidate will not undertake this job, the offer of candidate no. 1 shall be considered.

CANDIDATE	Technical competencies			Behavioural competencies			Contextual competencies		
	C1		C5	C1		C5	C1		C5
K1	average - upper level	...	below threshold	average - upper level	...	below threshold	below threshold	...	below threshold
...			...			...			...
K5	high level		high level	high level		high level	below threshold		below threshold

Fig. 7. Stage 4: Linear ordering of data and typological classification of prospective candidates according to synthetic feature values [source: own study]

6. CONCLUSION

In this study the evaluation of skills priority and particular candidate for the position of the R&D project manager was conducted, with the use of two-stage methodology based on FAHP and TOPSIS methods. Such complimentary approach eliminates weaknesses of FAHP and TOPSIS methods with their autonomous use, and ensures development of relatively simple and effective tool for making decisions regarding choosing the best candidate. The proposed approach helps to resolve examined critical problem in the hierarchical structure in more reliable way, as it includes various criteria, sub-criteria and alternatives. All begins from development of survey and opinions of experts, usage of FAHP method, which allows finding relative weigh of assessment criteria meaning in decision-making hierarchy. Subsequently, TOPSIS method uses these weighs to establish candidates classification. The use of these methods allows finding the best candidate, because it defines criteria weights, evaluates them and on the basis of these data, choses optimum. It is necessary to remember that even the most thoroughly selected sets of competencies, will not replace direct contact with prospective candidate. A proposed method has analytical approach, focusing on carefully selected criteria, which allow development of the best research team, based on employees criteria.

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“GHOSTWRITING” PROCEDURE

(based on guidelines of the Ministry of Science and Higher Education, Poland)

Introduction

Reliability is one of the foundations in the education. Readers should be assured that the author’s results of work are transparent, fair and honest. Authors should present works in such a way whether they are the direct authors, or used in support of a natural or legal person. Therefore, the provide information about entities that contribute to the formation of publication (their substantive or financial contribution, etc.) is necessary. It is a sign of good morals and corporate social responsibility. Opposite behaviors are the phenomenon of “ghostwriting” and “guest authorship”.

“Ghostwriting” and “guest authorship”

“Ghostwriting” is the concealment participation of a person having a significant contribution to the formation of publication. If the author's contribution in the formation of the publication is negligible or even not taken place, and it is still included as an author or co-author – then we have to deal with the phenomenon of “guest authorship”.

Procedure

In order to prevent the “ghostwriting” and “guest authorship” cases authors of the publication should reveal the contribution of individual authors in the creation of the publication. They should provide information about the authorship of ideas, assumptions, methods, etc. used for the development of publication. The main responsibility for the article bears author.

Moreover the authors should present information about sources of funding of publications, contribution of research institutions, associations and other entities (“financial disclosure”).

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