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UTILISATION OF EVOLUTION ALGORITHM IN PRODUCTION LAYOUT DESIGN

Abstract

The need for flexibility of layout planning puts higher requirements for utilisation of layout and location problem solving methods. Classical methods, like linear programming, dynamic programming or conventional heuristics are being replaced by advanced evolutionary algorithms, which give better solutions to large-scale problems. One of these methods are also genetic algorithms. This article describes the genetic algorithm utilisation in the production layout planningunder the terms of the digital factory concept.

1. REQUIREMENTS FOR THE PRODUCTION LAYOUT PLANNING

Current pressure on rapid innovations in the factory places increasing requirements also on the manufacturing and logistics systems design from the point of view of reduced laboriousness, consumption of time and costs for the whole system of technological design and, at the same time, on growth of quality, complexity and ability to testify the outputs generated from this process (Mičieta, Biňasová & Haluška, 2014).

Based on the mentioned reasons it is possible to sum up the following fundamental requirements on the process of technological design (Krajčovič, 2011):

- rapid design of new solutions,
- maintenance of systematic approach in design,
- manufacturing systems design as part of digital factory concept,

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- interactive design of a new manufacturing/logistics system,
- possibility of ongoing monitoring and assessment of proposed solution variants,
- implementation of optimisation approaches to design the time and spatial structure of the manufacturing system,
- proper visualisation and presentation of design outputs,
- possibility of dynamic verification of a proposed solution.

From the viewpoint of spatial arrangement of manufacturing and logistics structures, the following decision criteria are important (Krajčovič et al., 2013):

- minimisation of transport-related outputs and costs,
- minimisation of the areas needed,
- provision of occupational hygiene and safety,
- flexibility and the possibility of changes in the future,
- favourable conditions for team work,
- minimisation of reserves and continuous time,
- simple material flow,
- connection to an external logistics chain,
- possibility to flexibly optimise the arrangement in compliance with the changing production program.

2. APPROACH TO MANUFACTURING SYSTEMS DESIGN IN DIGITAL FACTORY CONCEPT

The design process itself has to respect the fundamental principles of the manufacturing systems design. With regard to the requirements for increase in the resultant design quality and decrease in the design time, it is necessary to enrich the classical approaches to the manufacturing and logistics systems with implementation of new progressive approaches and computer technologies (Li & Meerkov, 2009).

The process of manufacturing systems design has to run in the following phases (Fig. 1):

1. Preparation and analysis of input data: The basis resource of information needed for design is, first of all, the database from construction and technological preparation of production. Data for the manufacturing and logistics systems design can be divided into two basic groups:
   a) Numerical data – are used, first of all, to describe conditions in which the system will operate and are the basic input for output analyses of the manufacturing and logistics system. In compliance with a digital factory concept, numerical data are structured in three key areas (Hnát, 2012):
      - Information about products which will be made and transported in the manufacturing system (product types, piece lists, construction parameters, planned production volumes, etc.),

– Information about processes of their production (operations, manufacturing and assembling processes, used technologies, time norms, etc.),
– Information about resources for their manufacture (manufacturing machines and equipment, tools, workers, transport and handling machines, handling units, storage premises, etc.).

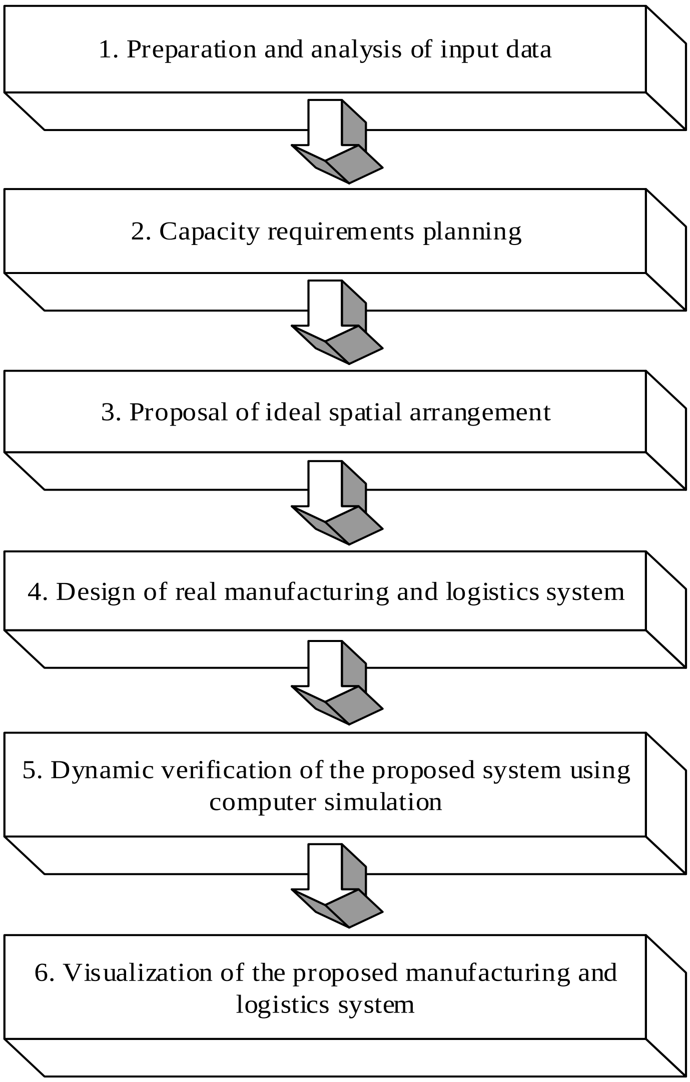
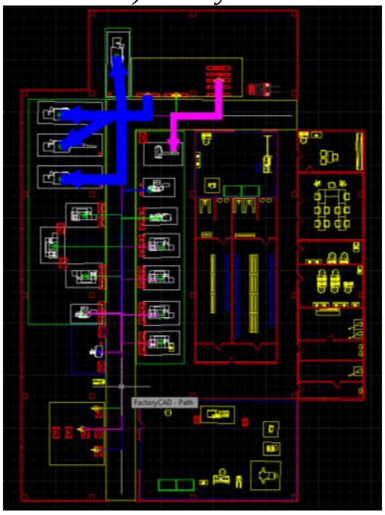


Fig. 1. Methodology of manufacturing system design in digital factory concept

b) Graphical data – represent visual display of individual elements of the manufacturing and logistics system which are used mainly in layout design and modelling and simulation of the resultant system (Furmann & Štefánik, 2011).

2. Capacity requirements planning: Before we start designing spatial solution of a manufacturing or logistics system, we have to decide which resources (production machines and equipment, transport, handling and storage devices, handling units, and the like), from the viewpoint of types and number, will be needed to ensure particular manufacturing and logistics processes in a designed system. Capacitance calculations serve this purpose. To calculate capacity needs, the designer has to know individual operations and activities of the manufacturing system, their quantity, time consumption norms for individual operations and available time for individual categories of resources (Ďurica et al., 2015).
3. Proposal of ideal spatial arrangement: When we know the need of individual resources of the designed system, material flows and other connections among individual elements, we can begin with designing an ideal spatial arrangement of the manufacturing or logistics system. In this phase of the proposal, no real spatial requirements of workplaces, no input-output places of the system and any other restrictions are considered (e.g. spatial restrictions). Proposing an ideal arrangement, it is advantageous to use optimisation methods and algorithms (graphical, analytical and heuristics methods). In this phase, evolutionary algorithms are also used (Hančinský & Krajčovič, 2014).
4. Design of real manufacturing and logistics system: Further stage of the solution of proposal layout of the manufacturing and logistics system is performed exclusively in a software environment (Fig. 2). Software environment for creation of real layout enables the designer, in a very short time, to verify more variants of detailed solution of either manufacturing or logistics system for which he uses tools for analysis, assessment and optimisation of the layout from the viewpoint of material flows and logistics (Dulina & Bartánusová, 2014). The designer can then make changes in the layout continuously; simultaneously with every change the designer receives the feedback about change of material flow parameters in the system, which enables him interactively and in a very short time to improve spatial arrangement of the designed system. Currently there are more software solutions and packets to support a 2D/3D design of layout solutions of manufacturing and logistics, e.g. VisTABLE, Factory CAD/FLOW, Autodesk Factory Design Suite, MALAGA, MPDS4 Factory Layout, EON Planner, etc.

a) 2D layout



b) 3D model

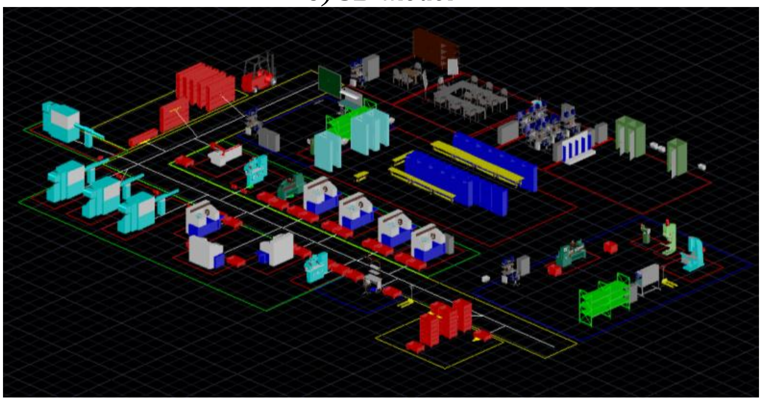


Fig. 2. Example of real layout design in FactoryCAD/FLOW

5. Dynamic verification of the proposed system using computer simulation: A lot of problems and risks occur at design and operation of complex manufacturing and logistics systems. Great numbers of variants and complexity of their assessment do not give a designer or manager a possibility to choose the best solution. These systems are commonly designed on the basis of narrowed views and criteria. It is just the modelling and simulation which provide the managers with a possibility of “dry run testing“, how the proposed manufacturing and logistics system will operate and evaluate its optimality on the basis of costs and efficiency parameters (Trebuňa et al., 2014). The importance of simulation grows mostly with a growing system complexity. Computer simulation is in this case the only tool which allows,

also in complex systems, “a view to the future” with high accuracy and expressive power (Mičieta, Dulina & Malcho, 2005). The simulation application enables industrial factories to save a large sum of money. Great advantage is at present the strong software support for simulation of manufacturing and logistics systems (Arena, Simple++, Witness) and its integration into software solutions of the digital factory concept (DELMIA Quest, Tecnomatix Plant Simulation).

6. Visualization of the proposed manufacturing system: To meet the needs of a team proposal, visualisation and presentation of a layout plan for the manufacturing or logistics system design, it is appropriate to connect the software for the manufacturing and logistics systems design with the advanced hardware and software solutions, such as (Fig. 3):
   a) Planning table: This solution is suitable for a team proposal and optimisation of the layout plan and they simultaneously provide sufficient mobility of the system design. In combination with an additional data projector or monitor, it enables a parallel optimisation of the layout arrangement in a 2D display and visualisation of solution in 3D environment.
   b) Virtual reality (VR): Virtual reality is a type of human-computer interface that aims at creating the illusion of the user being immersed in a computer generated environment, providing a more direct communication link between users and the problem environment modelled by the computer system. In this case, designed manufacturing system is displayed using HMD (head mounted display) or CAVE (Computer assisted virtual environments) devices, fully in 3D environment (Strapek, Hořejší & Polcar, 2016).
   c) Augmented reality (AR): Research in the area of augmented reality focuses on development of technologies which allow the connection of digital content with real world in real time. In contrast to virtual reality which drags the user completely into synthetic environment, augmented reality enables to see three-dimensional virtual objects inserted into a real environment.

a) planning table *b) virtual reality* *c) augmented reality*

Fig. 3. Forms of visualisation of designed manufacturing system

3. GENETIC ALGORITHMS

Genetic algorithms are based on the principle of natural evolution, which was described in Darwin's book "On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life" (1859). In the seventies of the twentieth century, J. H. Holland proposed the idea of genetic algorithm as an abstraction of appropriate genetic processes (Saleh & Hussain, 2013). A decade later, genetic algorithms became one of major rapidly developing fields of informatics and artificial intelligence. Fig. 2 shows the basic procedure of genetic algorithm, which was divided into two main sections – evaluation and evolution (Misola & Navarro, 2013).

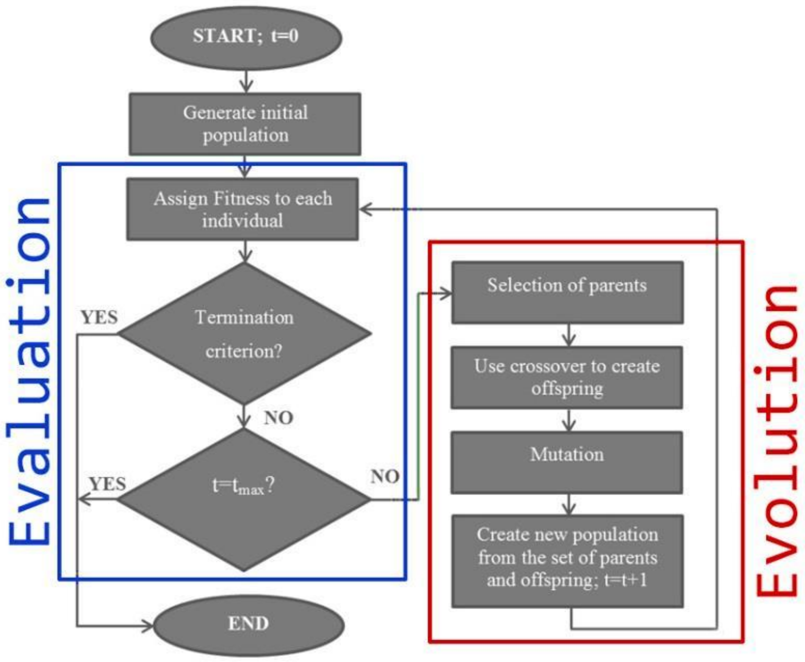


Fig. 4. Genetic algorithm

After generating the initial population, which can be created randomly, or based on historical/empirical data, the evaluation section takes place. The first step is to evaluate each individual in relation to the solved problem. Within genetic algorithms, we call the function that evaluates individuals as "fitness function". The basic principle of genetic algorithm is that individuals with better fitness must be unconditionally preferred in selection to next generation. However, with certain probability, it is possible for every solution to be selected. This ensures the diversity of the population.

The next steps after determining the fitness of all individuals in current population are two decision blocks, where the first evaluates, if the termination criterion is met (e.g. cost is below the specified value) and the second checks, if the maximum number of generations is not exceeded. If none of the above applies, the evolution section takes place. Within the evolution, the algorithm must first select the parents. As we mentioned, higher fitness means higher probability of individual being chosen. Several methods for choosing parents are known, we particularly can mention these(Yang et al., 2008):

- Roulette mechanism with fitness-proportionate selection,
- Roulette mechanism with rank selection,
- Stochastic universal sampling,
- Tournament mechanism,
- Elitism.

After determining the parents, genetic operators (Fig. 3) are applied, to create offspring. Crossover is an analogy to chromosomal recombination and reproduction in biology on which they are based. It is a genetic operator, which is responsible for mutual exchange of parts of chromosomes. Mutation is a genetic operator used to maintain genetic diversity of the population. Within mutation, one or more alleles in the chromosome are altered from their initial state. The main goal of mutation is to prevent algorithm from being stuck in the local extreme by preventing excessive similarity of individuals.

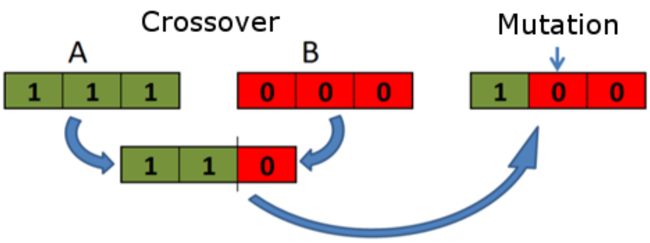


Fig. 5. Genetic operators – crossover and mutation

After application of genetic operators, new population is created, where both offspring and parents can be present, depending on the rules used within evolution. Subsequently, evaluation section calculates new fitness values and decides if another iterationis needed.

The main advantages of genetic algorithms include (Xu et al., 2011):

- They work with a population of possible solutions, thus it is less probable for the algorithm to end at a local optimum.
- They do not require any special knowledge about target function, they are universal.

- Genetic algorithms have very good results with problems with a large set of possible solutions.
- Versatility for a variety of optimisation problems.

Disadvantages include:

- They do not find optimal, but feasible solution.
- The implementation of the algorithm, the representation of solutions and the formulation of evaluation function can be difficult.

4. LAYOUT PLANNING USING GENETIC ALGORITHMS

Currently, system for plant layout design is being developed at the Department of Industrial Engineering at the University of Zilina, utilising genetic algorithms.

Own genetic algorithm for layout planning consist of (Fig. 4):

- specification of solution requirements and input data entry,
- layout optimisation (GA core),
- termination of the GA procedure (termination conditions).

At this stage, input and results are transferred between Matlab and Excel spreadsheet (Krajčovič & Hančinský, 2015), where simple user interface was created. In the spreadsheet, we input parameters such as number of machines, dimensions, types and probabilities of genetic operators or intensities between workstations/machines (Fig. 5).

After setting the input parameters we run the layout generator, coded in Matlab/GNU Octave language. The algorithm creates initial solutions in a specified quantity and performs evolution. The chromosome structure was determined as $2*n$, where n is the number of machines. Therefore, we store information about X and Y coordinates of each machine inserted into the layout. Mechanisms for machine overlap correction and desired layout dimension maintenance were also incorporated. After the run, following data are transferred back to Excel (Fig. 6):

- X-Y coordinates of each machine,
- fitness value of proposed solution,
- graphic interpretation through block layout.

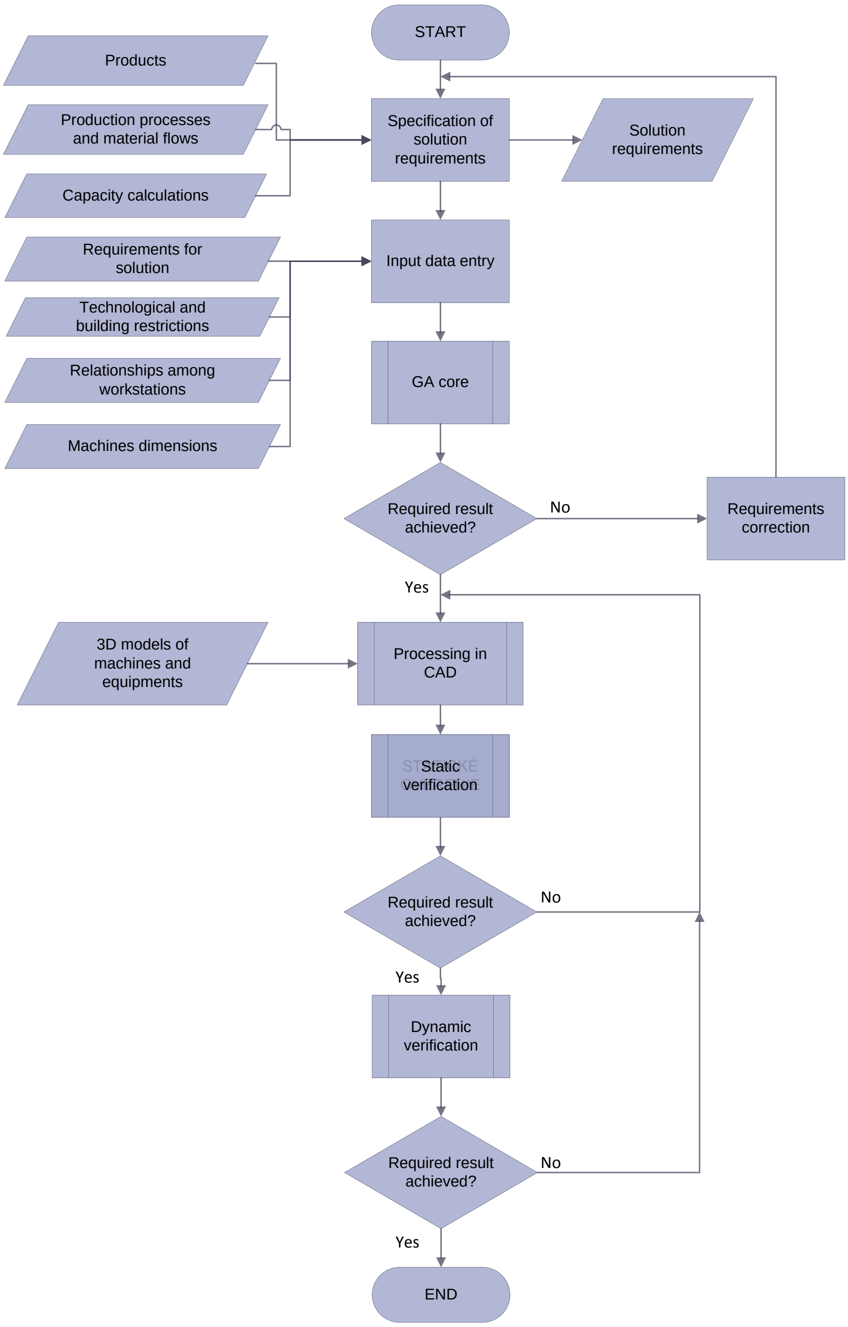


Fig. 6. Procedure of production layout design using genetic algorithm

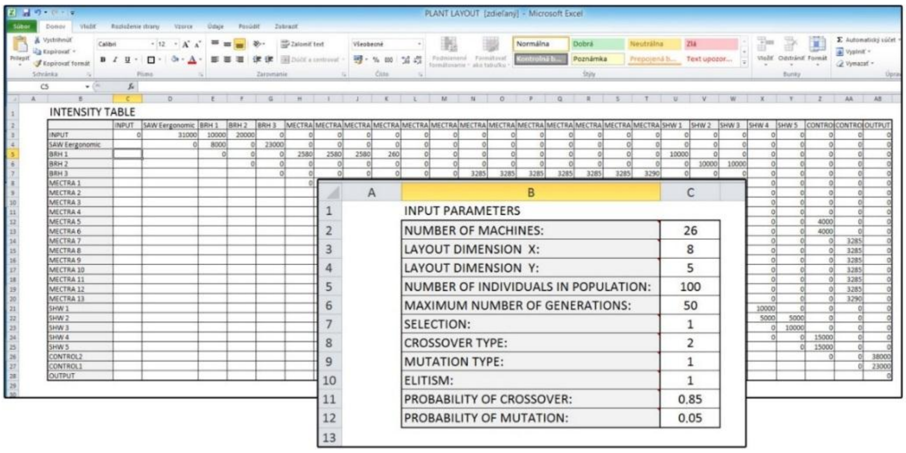
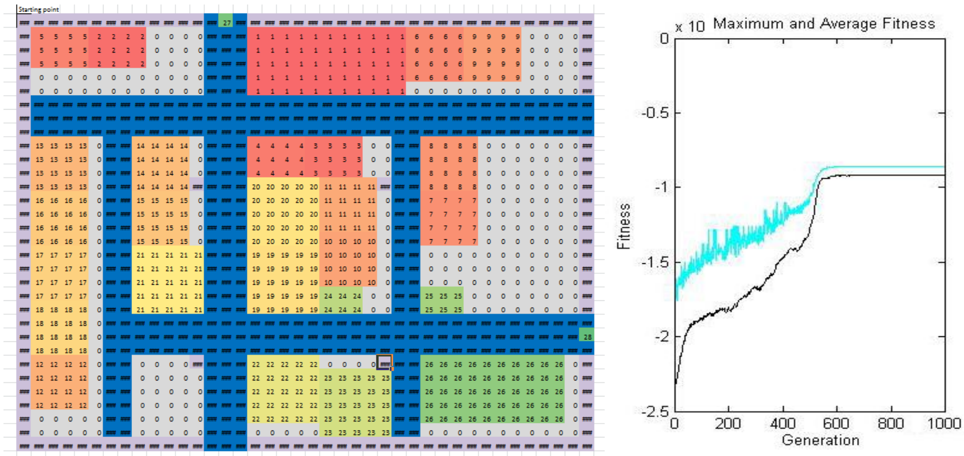


Fig. 7. Input sections of spreadsheet



a) graphic interpretation (block layout) *b) fitness value chart*

Fig. 8. Results of genetic algorithm

Block layout generated in Excel is converted to AutoCAD software (Fig. 7), where not only the obtained plant layout can be constructed, but also thanks to installed FactoryCAD/FactoryFLOW extensions, we can insert 3D models of machines in *.JT format, thus creating 3D model of machine layout and evaluate various aspects of the solution, such as material flow, aisle congestion, area structure or the possibility of milk run implementation with included tools. Also, thanks to SDX (Simulation Data eXchange) format, it is possible to evaluate obtained layout dynamically in another software solution by Siemens – Plant Simulation (Rakyta et al., 2016).

Thanks to these functionalities, we can not only get a possible layout solution, but also evaluate it both statically, and dynamically, which provides us with an advantage over solutions where only simple non-interactive block layout is created.

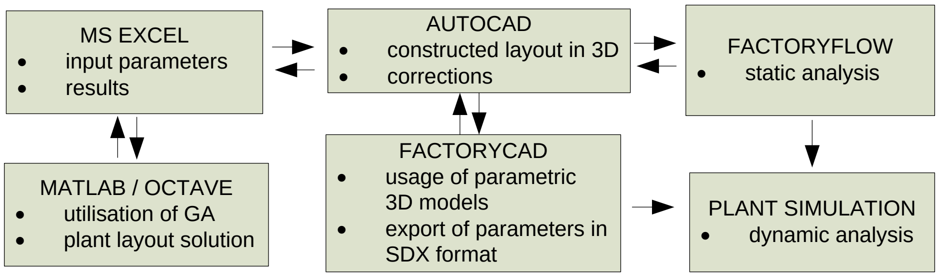


Fig. 9. Proposed integration of plant layout design utilising genetic algorithms

5. CONCLUSION

This paper describes the utilisation of genetic algorithm in the layout design of production systems. Authors' workplace addresses mentioned issues within the development of the digital factory concept and advanced industrial engineering methods (Altuntas & Selim, 2012). Described approach connects the algorithmic solution of the spatial arrangement problem (utilising genetic algorithms) with both static (FactoryFLOW) and dynamic (Plant Simulation) verification and also a graphical representation of the proposed production system (AutoCAD, FactoryCAD). The benefits of application of genetic algorithms are manifested mainly when solving large-scale problems of spatial arrangement, where genetic algorithms can effectively and more quickly converge to solution than traditional algorithms for spatial arrangement optimisation (Gašová, Gašo & Štefánik, 2017).

Described layout design procedure provides:

- Reduction of the time needed to design the spatial arrangement of the large-scale production system.
- Increase of the design quality through the implementation of appropriate configuration of boundary conditions to the algorithm,
- Complex verification of an obtained spatial arrangement solution through static and dynamic verification of the proposed system.
- Cost reduction in a designed production system.
- Visualisation of the spatial arrangement through a 3D model of the production system, which can be further presented and utilised with the use of progressive computer technologies, such as virtual and augmented reality.

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mathematical model of vehicle, multibody system simulation,
dynamic simulation

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DESIGN AND DYNAMICS MODELING FOR ELECTRIC VEHICLE

Abstract

This paper descript software for vehicle simulation and mathematical models that describe the motion of the vehicle. A dynamic simulation model of vehicle was developed using Matlab/Simulink and SimDriveline toolbox. The model has a configurable structure that is suitable to simulation with multiple levels. The powertrain system model developed using Simulink and SimDrivline could also be used as a generic, modular and flexible vehicle modeling platform to support the integration of powertrain design and control system optimization.

1. INTRODUCTION

The dynamic behavior of vehicles can be analysed in several different ways. One way may be a simple spring mass system, through a three-degree of freedom (DoF) model, to a large degree of complexity using a multibody system simulation package such as MSC ADAMS or Modelica. Vehicle models are often simulated with advanced controller designs provided as software in the loop (SIL) with controller design software such as Simulink, or with physical hardware in the loop (HIL). The subject of modeling in Simulink and SimDriveline

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was presented in (Tomasikova, Nieoczym & Brumercik, 2015; Tomasikova, Brumercik & Nieoczym, 2015). The issues of structural modeling and electric vehicle dynamics using Simulink are described in several publications. In (Cheng, Dong & Dong, 2013) powertrain model of a series-parallel, multiple-regime plug-in hybrid electric vehicle (SPMR-PHEV) was introduced. Simulation and control system was developed using rule-based load-leveling energy management strategy (EMS) under the MATLAB/Simulink and SimDriveline environment. The powertrain system model developed using Simulink and SimDrivline could also be used as a generic, modular and flexible vehicle modeling platform to support the integration of powertrain design and control system optimization.

A dynamic simulation model of electric vehicle (EV) was developed using Matlab/Simulink and SimPowerSystem/SimDriveline toolbox. The EV model has a configurable structure that is suitable to simulation with multiple fidelity levels. This advantage will combine simulation models associated with deployment and test for different controllers to a single platform. It has multiple running rates and different solvers for subsystems in order to speed up simulation. The electrical system model is capable to simulate power electronics behavior both on average and switching level. An automated mechanical transmission (AMT) model and its controller were developed for heavy duty application, such as a city bus (Zhou , Shen & Liu, 2014).

Mousavi, Saman, Pakniyat & Boulet (2014) focuses on the modeling, simulation and control of a two-speed transmission for electric vehicles which has seamless gear shifting specification. The transmission incorporates two-stage planetary gear sets and two braking mechanisms to control the gear shifting. The dynamic model is developed by using the kinematic equations of the planetary gear trains and the Euler-Lagrange equations to derive the equations of motion. The mathematical model is validated by using the SimDriveLine library of MATLAB/Simulink.

During construction work related to vehicle modeling, there are problems with formalizing the physical processes occurring in the vehicle. A test vehicle was created to validate the mathematical model. It ‘s experimental research and demonstration vehicle – Research Concept Vehicle (RCV) (Wallmark & Nybacka, 2014). The vehicle is intended as a platform to implement, validate, and demonstrate research results from different research projects carried out at KTH. In (Fang et al., 2013; Pawlus, Hovland & Choux, 2015) characterized the driveline modelling techniques for development of new control algorithms. This paper presents the analysis of the current driveline modelling methods through comparison simulations in Matlab. A driveline model including the tyre dynamics is developed and its effectiveness has been demonstrated by simulations.

2. VEHICLE MODEL

Vehicle model is created in Matlab-SimDriveline. The blocks represent basic parts of vehicle like engine, gear, differential, tires. The model contains elementary information about vehicle geometry – dimensions and center of gravity position. These information about vehicle are sufficient for mathematical description of vehicle.

Key features:

- Common gear configuration models, including planetary, differential, and worm gears with meshing and viscous losses.
- Clutch models.
- Vehicle component models, including engine, torque converter, and vehicle dynamics models.
- Models of translational elements.
- Ideal and non-ideal model variants, enabling adjustment of model fidelity.

2.1. Engine block

The engine model is specified by an engine power demand function $g(\omega)$. The function provides the maximum power available for a given engine speed ω. The block parameters (maximum power, speed at maximum power and maximum speed) normalize this function to physical maximum torque and speed values.

The engine power is nonzero when the speed is limited to the operating range

$$\omega_{min} \leq \omega \leq \omega_{\max} \tag{1}$$

The absolute maximum engine power $Pmax$ defines ω_0 such that $Pmax = g(\omega_0)$. Define $w \equiv \omega/\omega_0$ and $g(\omega) \equiv Pmax \cdot p(w)$.

Then $p(1) = 1$ and $dp(1)/dw = 0$.

The torque function is:

$$\tau = (Pmax/\omega_0) \cdot [p(w)/w] \tag{2}$$

Generic engine uses a third-order polynomial form:

$$p(w) = p_1 \cdot w + p_2 \cdot w_2 - p_3 \tag{3}$$

In typical engines, the p_i are positive. This polynomial has three zeros, one at $w = 0$, and a conjugate pair. One of the pair is positive and physical; the other is negative and unphysical:

$$\omega_{\pm} = {}^{1}/_{2}\left(-p_2 \pm \sqrt{p_2^2 + 4\, p_1 p_2}\right) \tag{4}$$

For the engine power polynomial, there are restrictions on the polynomial coefficients p_i, to achieve a valid power-speed curve. These restrictions are detailed below. If you use tabulated power or torque data, corresponding restrictions on *P(ω)* remain.
Set:

- $w = \omega/\omega_0$ and $p = P(\omega)/P_0$,
- $w_{min} = \omega_{min}/\omega_0$ and $w_{max} = \omega_{max}/\omega_0$.

Then engine speed is restricted to a positive range above the minimum speed and below the maximum speed:

$$0 \le w_{min} \le w \le w_{max} \tag{5}$$

The engine power at minimum speed must be nonnegative: $p(w_{min}) \ge 0$. If you use the polynomial form, this condition is a restriction on the p_i:

$$p(w_{min}) = p_1 \cdot w_{min} + p_2 \cdot w_{min}^2 - p_3 \cdot w_{min}^3 \ge 0 \tag{6}$$

The engine power at maximum speed must be nonnegative:

$$p(w_{max}) \ge 0.$$

If you use the polynomial form, this condition is a restriction on:

$$w_{max}\colon w_{max} \le w_{+}.$$

For the default parametrization, Generic Engine provides two choices of engine, each with different engine power demand parameters (Table 1).

Tab. 1. Engine power demand parameters

Power demand coefficient	**Engine type**	
	Spark ignition	**Diesel**
p_1	1	0.6256
p_2	1	1.6948
p_3	1	1.3474

2.2. Gear block

The Simple Gear block represents a gearbox that constrains the two connected driveline axes, base (B) and follower (F), to co rotate with a fixed ratio that you specify. You can choose whether the follower axis rotates in the same or opposite direction as the base axis. If they rotate in the same direction, ω_F and ω_B have the same sign. If they rotate in opposite directions, ω_F and ω_B have opposite signs.

Simple Gear imposes one kinematic constraint on the two connected axes:

$$r_F \omega_F = r_B \omega_B \tag{7}$$

The follower-base gear ratio $u_{FB} = z_F / z_B$, where z is the number of teeth on each gear. The two degrees of freedom reduce to one independent degree of freedom. The torque transfer is:

$$u_{FB} T_B + T_F - T_{loss} = 0 \tag{8}$$

In the ideal case moment of losses in the system $T_{loss} = 0$.

In a nonideal gear pair, the angular velocity, gear radii, and gear teeth constraints are unchanged. But the transferred torque and power are reduced by:

- Coulomb friction between teeth surfaces on gears, characterized by efficiency η,
- Viscous coupling parametrized by viscous friction coefficients μ:
-

$$T_{loss} = T_{Coul} \cdot tanh\left(\frac{4\omega_{out}}{\omega_{th}}\right) + \mu\omega_{out} , \tag{9}$$

$$T_{Coul} = |T_F| \cdot (1 - \eta) . \tag{10}$$

where: T_{loss} – moment of losses in the system,
T_{Coul} – moment on coupling.

Conditions (Jeong & Lee, 2000):

- Constant Efficiency: in the constant efficiency case, η is constant, independent of load or power transferred.
- Load-Dependent Efficiency: in the load-dependent efficiency case, η depends on the load or power transferred across the gears.

For either power flow:

$$T_{Coul} = u_{FB} T_{idle} + kT_F, \tag{11}$$

Factor k is a proportionality constant. Coefficients η is related to T_{Coul} in the standard, preceding form but becomes dependent on load:

$$\eta = T_F/[u_{FB}T_{idle} + (k + 1)T_F]\,. \tag{12}$$

This block has limitations, also:

– Gear inertia is assumed negligible,
– Gears are treated as rigid components.

Differential gear block represents a gear mechanism that allows the driven shafts to spin at different speeds. Differentials are common in automobiles, where they enable the various wheels to spin at different speeds while cornering. Ports S, D1, and D2 represent the driving and driven shafts of the differential. Any of the shafts can drive the remaining two.

The block models the differential mechanism as a structural component based on Simple Gear and Sun-Planet Bevel Simscape™ Driveline™ blocks. Fig. 1 shows the block diagram of this structural component.

Differential imposes one kinematic constraint on the three connected axes:

$$\omega_D = \pm(1/2)u_D(\omega_{S1} + \omega_{S2})\,, \tag{13}$$

with the upper (+) or lower (–) sign valid for the differential crown to the right or left, respectively, of the center-line. The three degrees of freedom reduce to two independent degrees of freedom. The gear pairs are (1,2) = (S,S) and (C,D). C is the carrier.

The *sum* of the lateral motions is the transformed longitudinal motion. The difference of side motions $\omega_{S1} - \omega_{S2}$ is independent of the longitudinal motion. The general motion of the lateral shafts is a superposition of these two independent degrees of freedom, which have this physical significance.

One degree of freedom (longitudinal) is equivalent to the two lateral shafts rotating at the same angular velocity ($\omega_{s1} = \omega_{s2}$) and at a fixed ratio with respect to the longitudinal shaft.

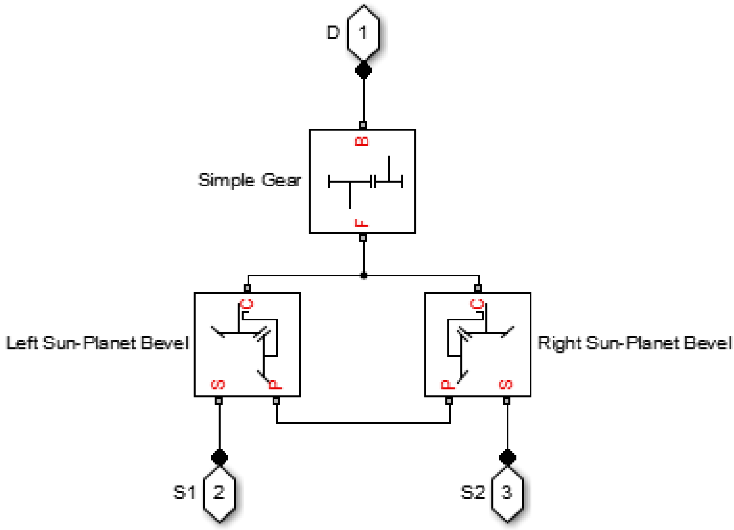

Fig. 1. The structural component of differential block

The other degree of freedom (differential) is equivalent to keeping the longitudinal shaft locked ($\omega_D = 0$) while the lateral shafts rotate with respect to each other in opposite directions ($\omega_{s1} = -\omega_{s2}$).

The torques along the lateral axes, T_{S1} and T_{S2}, are constrained to the longitudinal torque T_D in such a way that the power flows into and out of the gear, less any power loss N_{loss}, sum to zero:

$$\omega_{S1}T_{S1} + \omega_{S2}T_{S2} + \omega_D T_D - P_{loss} = 0 \tag{12}$$

When the kinematic and power constraints are combined, the ideal case yields:

$$u_D T_D = 2(\omega_{S1}T_{S1} + \omega_{S2}T_{S2}) / (\omega_{S1} + \omega_{S2}) \tag{13}$$

2.3. Tire block

The Tire Block models the tire as a rigid wheel-tire combination in contact with the road and subject to slip. When torque is applied to the wheel axle, the tire pushes on the ground (while subject to contact friction) and transfers the resulting reaction as a force back on the wheel. If you include the optional tire compliance, the tire also flexibly deforms under load. Table 2 defines the tire model variables. Forces and Characteristic Function: a tire model provides a steady-state tire characteristic function $F_X = f(\kappa, F_Z)$, the longitudinal force F_x on the tire, based on vertical load F_z and wheel slip κ

Tab. 2. The tire model variables

Parameter	Description
r_w	Wheel radius
v_x	Wheel hub longitudinal velocity
u	Tire longitudinal deformation
Ω	Wheel angular velocity
Ω'	Contact point angular velocity = Ω if u = 0
$r_{w\Omega'}$	Tire tread longitudinal velocity
$v_{sx} = r_{W\Omega} - v_x$	Wheel slip velocity
$v'_{sx} = r_{W\Omega'} - v_x$	Contact slip velocity = v_{sx} if u = 0
$\kappa = v_{sx}/\lvert v_x\rvert$	Wheel slip
$\kappa' = v'_{sx}/\lvert v_x\rvert$	Contact slip = κ if u = 0
v_{th}	Wheel hub threshold velocity
Fz	Vertical load on tire
Fx	Longitudinal force exerted on the tire at the contact point.
$C_{Fx} = (\partial F_x/\partial u)0$	Tire longitudinal stiffness under deformation
$b_{Fx} = (\partial F_x/\partial \mathring{u})0$	Tire longitudinal damping under deformation
Iw	Wheel-tire inertia
T_{drive}	Torque applied by the axle to the wheel

Each tire in The Pacejka “Magic formula” (Pacejka, 2005) is characterized by 10–20 coefficients for each important force that it can produce at the contact patch, typically lateral and longitudinal force, and self-aligning torque, as a best fit between experimental data and the model. These coefficients are then used to generate equations showing how much force is generated for a given vertical load on the tire, camber angle and slip angle. A problem with Pacejka's model is that when implemented into computer code, it doesn't work for low speeds (from around the pit-entry speed), because a velocity term in the denominator makes the formula diverge (Kucera, Lukac, Jurak & Brumercik, 2009).

The Magic Formula is a specific form for the tire characteristic function, characterized by four dimensionless coefficients (B, C, D, E), or stiffness, shape, peak, and curvature:

$$\begin{gathered} Fx = f(\kappa, Fz) = \\ = Fz \cdot D \cdot sin(C \cdot arctan[\{B\kappa - E \cdot [B\kappa - arctan(B\kappa)]\}]) \end{gathered} \tag{14}$$

A more general Magic Formula uses dimensionless coefficients that are functions of the tire load. A more complex set of parameters *p,I* entered in the dialog box, specifies these functions:

$$Fx0 = Dx \cdot sin(\,Cx \cdot arctan[\,\{\,Bx\kappa x - Ex[\,Bx\kappa x - arctan(Bx\kappa x)\,]\,\}\,]\,) + SVx \tag{15}$$

where: $df_z = (F_z - F_{z0})/F_z$,

$\kappa_x = \kappa + S_{Hx}$,

$C_x = p\_Cx1$,

$D_x = \mu_x \cdot F_z$,

$\mu_x = p\_Dx1 + p\_Dx2 \cdot df_z$,

$E_x = (p\_Ex1 + p\_Ex2 \cdot df_z + p\_Ex3 \cdot df_z^2)[1 - p\_Ex4 \cdot sgn(\kappa_x)]$,

$K_{x\kappa} = F_z \cdot (p\_Kx1 + p\_Kx2 \cdot df_z) \cdot exp(p\_Kx3 \cdot df_z)$,

$B_x = K_{x\kappa}/(C_x D_x + \varepsilon_x)$,

$S_{Hx} = p\_Hx1 + p\_Hx2 \cdot df_z$,

$S_{Vx} = F_z \cdot (p\_Vx1 + p\_Vx2 \cdot df_z)$.

S_{Hx} and S_{Vx} represent offsets to the slip and longitudinal force in the force-slip function, or horizontal and vertical offsets if the function is plotted as a curve. μ_x is the longitudinal load-dependent friction coefficient. ε_x is a small number inserted to prevent division by zero as F_z approaches zero.

The block uses a representative set of Magic Formula coefficients. The block scales the coefficients to yield the peak longitudinal force F_{x0} at the corresponding slip κ_0 that you specify, for rated vertical load F_{z0}.

Numerical values are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Tab. 3. Formula coefficient

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

2.4. Vehicle body block

This block models a vehicle with two axles in longitudinal motion. The axles can have different wheel counts. The vehicle wheels are assumed identical in size. The vehicle axles are parallel and form a plane. The longitudinal *x* direction lies in this plane and perpendicular to the axles. The vehicle motion is

determined by the net effect of all the forces and torques acting on it. The longitudinal tire forces push the vehicle forward or backward. The weight *mg* of the vehicle acts through its centre of gravity *(CG)*. Figure 2 and Table 4 define the vehicle motion model variables.
This are the motion equations:

$$m\,\dot{V}_X = F_X - F_d - mg\sin\beta \tag{16}$$

$$F_X = n(F_X f + F_X r) \tag{17}$$

$$F_d = \frac{1}{2}\,C_d\rho A(V_X - V_W)^2 \tag{18}$$

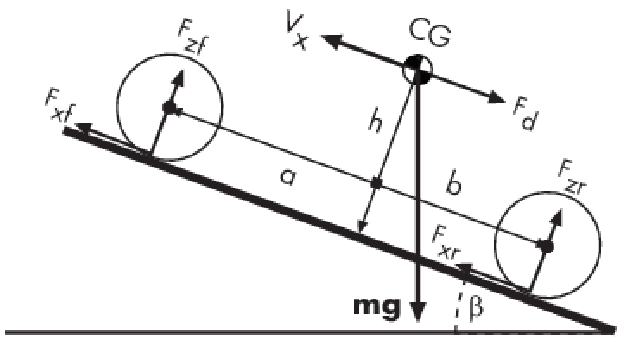

Fig. 2. Scheme of the vehicle model

Zero normal acceleration and zero pitch torque determine the normal force on each front and rear wheel:

$$F_{zf} = \frac{-h\,(F_d + mg\sin\beta + m\,\dot{V}_X) + b\,mg\cos\beta}{n(a+b)} \tag{19}$$

$$F_{zr} = \frac{+h\,(F_d + mg\sin\beta + m\,\dot{V}_X) + a\,mg\cos\beta}{n(a+b)} \tag{20}$$

Tab. 4. The vehicle motion model variables

Parameter	Description
β	Incline angle
h	Height of vehicle CG above the ground
a, b	Distance of front and rear axles, respectively, from the normal projection point of vehicle CG onto the common axle plane
v_x	Longitudinal vehicle velocity
v_W	Headwind speed
n	Number of wheels on each axle
F_{xf}, F_{xr}	Longitudinal forces on each wheel at the front and rear ground contact points, respectively
F_{zf}, F_{zr}	Normal load forces on the each wheel at the front and rear ground contact points, respectively
A	Effective frontal vehicle cross-sectional area
C_d	Aerodynamic drag coefficient
ρ	Mass density of air ρ = 1.2 kg/m^3
F_d	Aerodynamic drag force

The Vehicle Body block lets you model only longitudinal dynamics, parallel to the ground and oriented along the direction of motion. The vehicle is assumed to be in pitch and normal equilibrium. The block does not model pitch or vertical movement. As such, the equations assume that the wheels never lose contact. This constraint can result in negative normal forces.

Vehicle model in SimDriveline is simplified 4 wheels car (Figure 3). We can measure and explore some dynamic properties of vehicle like vehicle velocity, normal forces on tire, wheel rpm. The model is limited. We can simulate only driving in direct direction, not turning. The Tire (Magic Formula) block assumes longitudinal motion only and includes no camber, turning, or lateral motion.

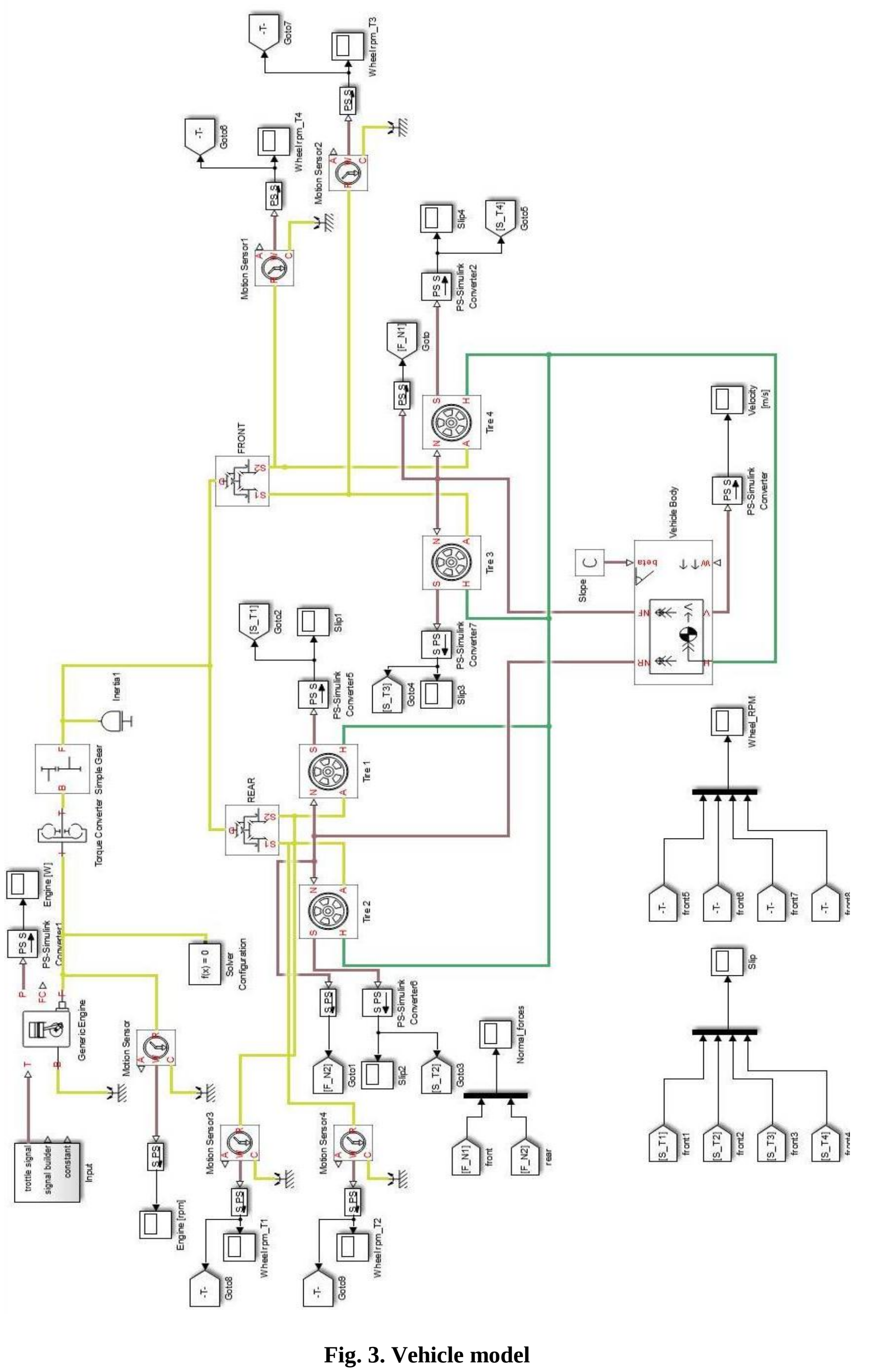

Fig. 3. Vehicle model

3. CONCLUSIONS

The methodology for designing the propulsion and driving system using the Simulink program has been presented. The analyzed driving system was divided into functional components: engine, clutch, gearbox and powertrain with rubber wheels. For each component, key features and model limitations were identified. The basic formulas and the mathematical relationships used in modeling have been demonstrated. Mathematical formulas are written in a parametric manner using coefficients. The coefficients values are given for the calculation of the propulsion engine, the driving wheels and the dynamic effects on the vehicle. The equations described above allow for quick analysis of the output when changing certain coefficients. A model vehicle built from Simulink blocks. This model takes into account the kinematic dependence on vehicle units and enables analysis of dynamic vehicle characteristics. Limitation of the described model is the analysis of its motion on the straight line.

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MDE, DSL, learnability

Kamil ŻYŁA[*]

SIMPLIFIED GRAPHICAL DOMAIN-SPECIFIC LANGUAGES FOR THE MOBILE DOMAIN – PERSPECTIVES OF LEARNABILITY BY NONTECHNICAL USERS

Abstract

Increasing number of technologically advanced mobile devices causes the need for seeking methods of software development that would involve persons without or with highly limited programming skills. They could participate as domain experts or individual creators of personal applications. Methods based on models might be the right answer, thus the author conducted workshops and surveys concerning perspectives of graphical modeling languages for the mobile domain. Research revealed that nontechnical users declared high learnability of simplified ones as well as the majority of them correctly read models in such languages.

1. INTRODUCTION

Development as well as expansion of mobile devices is very dynamic. Not only design and hardware is changing, but also available functionality. For example, mobile phones evolved from simple devices for texting an making voice calls to multithread context-aware microcomputers continuously utilizing Internet connection and processing a lot of multimedia content. Also, other devices like smart watches, TV sets and multimedia centers in cars, started to provide some of their functionality.

Forrester (Taylor, 2015) predicted that by the end of 2016, 4.8 billion people globally will use a mobile phone, and 46% of population will use a smartphone.

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According to Gartner (Meulen & Forni, 2016), global sales of smartphones to end users totaled 373 mln units in the 3rd quarter of 2016. Both sources predict growth of mobile services market. These create demand for new methods of mobile software development, that takes into account also nontechnical users. It is gaining importance as the number of such people surrounded by technically advanced devices is still growing. Authors of scientific publications started mentioning about involving nontechnical persons as domain experts or creators of simple personal as well as business applications (Angeles, 2017; Kawasaki, 2016; Viedma, 2010; Kapitsaki, Kateros & Pappas, 2015; Mohamad el al., 2011).

Author assumes in this paper that nontechnical person is a person which is unable (or with significant difficulties) to create software utilizing classical programming languages and methods. Those difficulties might be the result of intellectual deficiencies or lack of proper education.

Another notion that needs explanation is learnability. It could be understood as "...a quality of products and interfaces that allows users to quickly become familiar with them and able to make good use of all their features and capabilities" ("Definition – learnability", 2017). This is coherent with e.g. ISO 9241-11 standard defining learnability as "time of learning" (Abran, Khelifi, Suryn & Seffah, 2003).

Graphical modeling languages are the tools within model-driven engineering (MDE) that could help to involve nontechnical people into software development process. They could be used to create platform-independent models that could be later transformed into running applications by code generation (Brambilla, Cabot & Wimmer, 2012; Kesik & Żyła, 2011). Despite some doubts concerning claimed benefits of using MDE tools (Hutchinson, Rouncefield & Whittle, 2011; Mohagheghi & Dehlen, 2008) and the small number of fully-mature tools, experience gained at the Lublin University of Technology (Żyła & Kesik, 2012; Kesik, Żyła & Nowakowski, 2014; Żyła, 2013, 2015; Rieger, 2017) show that MDE tools might play an important role for people without programming skills.

Modeling languages for the mobile domain, chosen for the purpose of research described in this paper, could be divided into 3 categories. The 1st category concerns languages that are similar to 3G programming languages, although they provide simplified syntax – some irrelevant technical details are hidden. Nevertheless they still operate on the level of instructions and require some programming skills. The 2nd group concerns general purpose graphical modeling languages oriented on defining interactions among objects. They require at least basic object-oriented programming skills, as they operate on the level of objects and invocations of methods. The last category concerns simplified graphical domain-specific languages based on high-level components performing complex actions (activities) and flows among them.

2. AIM OF THE STUDY

The number of mobile devices in common people surroundings is constantly increasing, which makes the need for programming or managing (orchestrating) them by nontechnical persons harder to avoid. The same trend concerns also technical aspects of intelligent houses, smart cities, etc. As the result, the problem of choosing a proper tool (language) suitable for nontechnical users emerges. Thus it is particularly important to recognize, what type of solution is less problematic for such target group.

Analysis of tools available on the market revealed that simplified graphical domain-specific languages might be the solution to at least some of above-mentioned problems. The question is what is the opinion and preferences of nontechnical persons.

With such problem statement in mind, the following research questions were formulated:

1. What kind of modeling language is easier to learn and use by nontechnical persons?
2. Whether simplified graphical modeling languages are suitable for creating personal as well as simple business applications?

3. MATERIALS AND METHODS

In order to answer the formulated research questions, short workshops on modeling software for mobile devices were conducted. English was the working language. They were designed for persons without previous experience in developing software for mobile devices or an IT background (like computer science studies or in a related field; training in software engineering, modeling languages, programming languages, etc.). After the workshop, participants were asked to voluntarily fill in an anonymous survey.

A single workshop lasted a few hours, and each person could participate in only one workshop. The main workshop topics were: mobile systems for reporting life-threatening situations (what those systems are, why they are needed, how they work and how they should work) and graphical modeling of mobile reporting systems (why modeling could be useful, what tools are available and how to use them, how to read models, how to communicate using models). Participants were also working with exemplary models depicting functionality related to processing the report.

Typical deficiencies of nontechnical persons are inability to handle too many technical details and ease of discouragement, which was also mentioned in (Żyła, 2015). Due to the specificity of the respondents, survey needed simplifications concerning technology choices as well as the number and character of questions.

After analyzing a short list of modeling languages available for the mobile domain, three of them were chosen. Each of them represented a distinguishable class (group) of solutions described in the introduction. 1st group was represented by Unified Modeling Language (UML) as an industrially recognized tool (Arisholm, Briand, Hove & Labiche, 2006); 2nd group by App Inventor (AI) as a tool well recognized by the community (Kowalczyk, Turczynski & Żyła, 2016; "MIT App Inventor", 2017); and 3rd group by AergiaML as a tool designed for nontechnical persons that tries to be an answer for disadvantages of former tools (Żyła, 2015). Models made in those solutions were equivalent – they held the same information, sufficient to fully describe the behavior of an application. Such level of details allows for the code generation resulting in platform-specific executable file with the application or its source code.

The anonymous survey was divided into the following parts:

1. Personal background:
   Age, country of origin, information regarding studies, experience in creating and modeling mobile applications.
2. Tasks:
   - T1: Mark from 1 to 6 how easy it is for you to learn and use UML.
   - T2: Mark from 1 to 6 how easy it is for you to learn and use App Inventor.
   - T3: Mark from 1 to 6 how easy it is for you to learn and use AergiaML.
   - T4: What is depicted by the presented model made in UML?
   - T5: What is depicted by the presented model made in App Inventor?
   - T6: What is depicted by the presented model made in AergiaML?
3. Questions:
   - Q1: Do you think that AergiaML allows you to focus on the idea of application and you are not distracted by too many technology-specific details?
   - Q2: Do you think that you would be able to learn AergiaML in a degree that allows to create applications fulfilling your everyday needs?

The following examples depict the level of complexity of models in the survey tasks T4–T6: acquiring location of a mobile device before submitting a report, collecting data from the form before submitting a report, managing photos in a gallery.

4. RESULTS AND DISCUSSION

A group of 67 English-speaking persons participated in the workshops. 29 of them filled in an anonymous survey. Among respondents were students and graduates in medicine, administration, sociology, foreign relations, policy making, management and environmental engineering. They originated from more than 12 countries, including Poland, Czech Republic, Germany, Portugal, Russia, Ukraine, USA, Canada, Republic of Korea and Indonesia. None of them had ever created software on his/her own or learned how to use UML, App Inventor, or any other solution. Their age structure is presented in Figure 1.

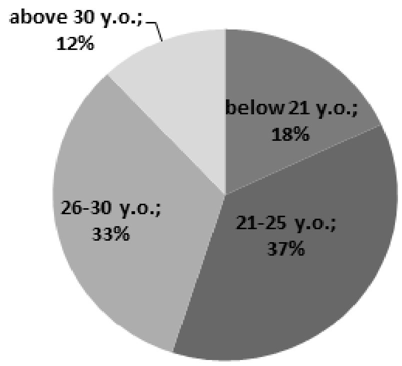

Fig. 1. Age structure of the survey respondents

Respondents, by solving tasks T1–T3, indicated AergiaML as a language that is easiest to learn and use – the average mark being 4.86. UML received the average mark being 3.24, and App Inventor the average mark being 3.21. Distribution of marks is presented by Figures 2–4 (the higher the mark, the better).

Fig. 2. Distribution of marks – App Inventor

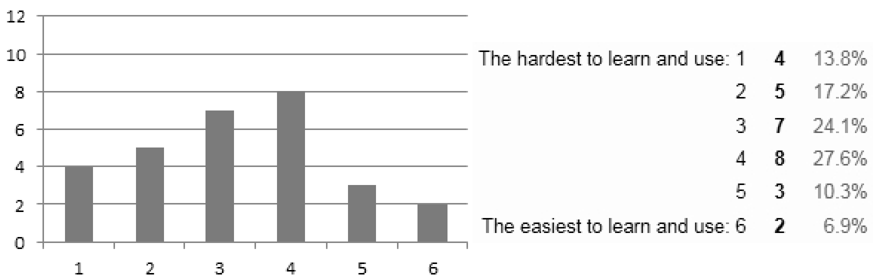

Fig. 3. Distribution of marks – UML

Fig. 4. Distribution of marks – AergiaML

The Wilcoxon signed rank test shows that there is no statistically significant difference between declared ease of learn and use of UML and App Inventor (two-sided test p-value of 0.5055; the hypothesis was that the score of UML would be higher than App Inventor). However, there is a statistically significant difference between UML or App Inventor and AergiaML, in favor of the latter (p-value of 0.0007 and 0.0004; the hypothesis was that the score of AergiaML would be higher than any of the two other). Due to multiple testing, the standard significance level of 5% was corrected, using Bonferroni, to 0.016. Calculations were performed using R environment.

When it comes to recognizing what is depicted by the model (tasks T4–T6), the McNemar test shows that the percentage of correct responses for App Inventor and AergiaML was statistically significantly greater than for UML (p-values of 0.0154 and 0.0003; the hypothesis was that the percentage of correct responses for App Inventor or AergiaML would be greater than for UML). However, the percentage of correct responses for App Inventor was not statistically significantly greater than for AergiaML (p-value of 0.1445; the hypothesis was that the percentage of correct responses for App Inventor would be greater than for AergiaML). Due to multiple testing, the standard significance level of 5% was corrected, using Bonferroni, to 0.016. Calculations were performed using R environment (Żyła, 2015).

Respondents also answered questions Q1 and Q2. 79% of them declared that AergiaML allowed them to focus on the idea of application and they were not distracted by too many technology-specific details. In case of Q2, 59% of respondents declared that they would be able to learn AergiaML in a degree that allows to create applications fulfilling their everyday needs. High rate of unsure persons, might be the result of no prior experience concerning software development. The distribution of answers is presented in Figures 5 and 6.

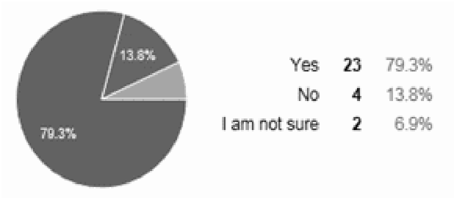

Fig. 5. Distribution of responses to question Q1

Fig. 6. Distribution of responses to question Q2

5. CONCLUSIONS

In order to determine perspectives of learnability of simplified graphical domain-specific languages for the mobile domain by nontechnical users, a series of workshops were conducted. Highly diversified (origin and education) group of 29 participants without prior knowledge in creating software, after participating in workshops, filled in anonymous surveys.

Analysis of the surveys revealed that nontechnical persons indicated simplified graphical domain-specific languages as a category of languages that is the easiest to learn and use. It was confirmed by highest (although statistically not significant) rate of correct answers concerning functionality of models. Moreover respondents indicated that such languages are suitable for creating personal and simple business application, as they allow to focus on the idea of an application and they could be learned to an extent that allows to individual creation of applications.

Obtained results allows to suggest that it is worth to investigate languages that are based on components that perform complex activities (e.g. saving something to a database, getting access to a GPS sensor), where the role of a user is to show how those components interact by connecting them in chains of complex actions, executed in a particular order. Such approach might be highly useful when involving nontechnical people in a process of software development.

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A MODEL OF KNOWLEDGE ACQUISITION IN THE MAINTENANCE DEPARTMENT OF A PRODUCTION COMPANY

Abstract

The knowledge acquisition model proposed in this paper is designed to assist with the acquisition of knowledge in a company possessing its own maintenance department. The model is built on the basis of knowledge bases. The authors focus on basic information required for maintenance department operation and expert archiving of technical documentation. Three main areas are covered by the model: knowledge acquisition and formalization, knowledge systematization and knowledge retrieval by problem or field. It is assumed that the implementation of the model coupled with an electronic knowledge acquisition report and with an application for information retrieval will bring benefits for the company.

1. INTRODUCTION

In a knowledge-based company, the need to minimize manufacturing costs encourages the management of not only material and financial resources but of intangible resources too. Intangible resources include explicit knowledge available in the procedures and operating instructions that is necessary to preform business processes in a company, pointing to external and internal sources (Falkenberg, Woiceshyn & Karagianis, 2003). One can also distinguish tacit knowledge that is accumulated in the minds of workers, supported by their

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hands-on experience. For this reason, there is a need to acquire and accumulate this type of resource in the form of simple knowledge bases. Some experts working for a company may show a reluctance to share their knowledge because they may be afraid of losing their position resulting from years of experience. The exchange of explicit knowledge within a company is mainly done through informal communication, which reduces the quality of this knowledge (Padzich, 2004) and does not allow for duplication.

In the realities of a manufacturing company, knowledge acquisition can lead to establishment of conditions supporting the work of the maintenance department. Maintenance services have specialized knowledge of machinery maintenance and repair. Owing to their participation in the process of restoring machinery efficiency, the specialists are able to determine the type of a fault and its location, name the cause of the fault, and to identify shortcomings or design mistakes that may affect failure frequency. Correct archiving of maintenance reports and further classification of key information from this area lead to optimization of processes related to maintenance and care of the machinery stock. Proper knowledge management brings a number of benefits for the company. They result from an easier access to knowledge for employees and reduction of erroneous activities. This, in turn, leads to faster completion of tasks and cost minimization.

The knowledge acquisition model proposed in the paper was created based on the company's databases and technical documentation. One of the tools supporting knowledge acquisition is an electronic report. When drafting it, the authors focused on the basic knowledge useful for maintenance work, proper archiving of documentation containing the characteristics of a fault along with a brief description of repair actions. In the case of devices that make part of an already existing stock of machines, it is possible to develop modernization solutions to eliminate the mistakes of the design engineer. Consequently, three main areas should be included in the model:

- knowledge acquisition and its formalization,
- knowledge systematization,
- knowledge retrieval depending on the problem or the field of knowledge/project.

This paper describes the types of knowledge available in a production company and its sources. The knowledge acquired during the design of modernization and operation of machines is described. A research model is developed based on the characteristics of work of a specified production company with its own maintenance department based in Lubuskie Province. For the purpose of streamlining the work, the structure of an electronic reports dedicated to maintenance services is proposed together with examples of how it can be supplemented. The conclusions point to potential benefits of the proposed solution.

2. KNOWLEDGE IN A COMPANY

According to Bernaert and Poels (Bernaert & Poels, 2011), we can distinguish four types of knowledge depending on the identification of acquired information: know what (structural knowledge based on models), know why (interpretation of collected information), know how (knowledge of activity procedure), know who (identification of individuals who could help in problem solving).

The implementation of new tasks is based on interdisciplinary knowledge that is born in the minds of experts. It is argued that companies suffer from gaps in the exchange of information and experience gained from projects and that "the accumulated knowledge is dissipated and unprofitable after the project completion" (Wąsowicz, 2013). It is necessary to focus on the identification of sources of knowledge: explicit knowledge that is accessible and simple to transfer and tacit knowledge that is difficult to express and formalize (Piotrowska, 2012). The acquisition of explicit knowledge is based on the transfer of knowledge in a written or oral form. The problem is to systematize and write down tacit knowledge that requires engaging and motivating the workers (Beyer, 2011). In this case, it is important to extract the knowledge from the worker's mind by means of metaphors or hypotheses and to transform it into explicit form (externalization) (Nonaka, Ryoko & Konno, 2000).

Hands-on experience acquired during project implementation, testing and research, complaint analysis, informal discussions and brainstorming is considered to be the underlying source of tacit knowledge (Mendryk, 2011). Explicit knowledge comprises information contained in paper and electronic form – expert systems, guides, books, standards, design support software, manufacturing or the Internet, intranet etc. The external sources include: applicable laws, quality and safety standards, customer requirements, material specifications, competitive characteristics, customer or supplier feedback, expert consultation, and research analyses (by external R&D units). The internal sources include: reports, forms, instructions, intranets, simulations, analyses or technical documentation.

The organization of knowledge, storing it and making the repository available lead to repeating good practices and encourage the development of joint solutions. Through knowledge transfer, organizations can provide employees with access to the resources needed to implement innovative projects. In network environments (of work groups), white collar workers have different roles and tasks; often, they are scattered over different departments, branches and units. Nowadays standard models based on bilateral and personal exchange of knowledge cannot exist any longer. In advanced models, the management of innovative projects is based on information technologies. It is necessary to define the knowledge transfer process using IT and to show the synergies between project requirements, knowledge competencies of the partners and IT tools (Dąbrowski & Patalas – Maliszewska, 2016). The core business benefits of sharing knowledge include the reduction of (Gasik, 2011, Tabaszewska, 2008) project implementation time, costs, the number of complaints or employee training. In addition, this leads to faster generation of innovative processes in the company, the development of new areas for business activity, the improvement of employee motivation and development of the entire organization (Maier, 2002).

3. KNOWLEDGE ACQUIRED FROM DESIGN AND MACHINERY OPERATION

3.1. Knowledge acquired from design, modernization

Sometimes maintenance department workers use parts available in on the premises to design simple devices for the company or for improved work ergonomics. When designing or modernizing the maintenance services – similarly to the R&D staff – select optimum solutions based on their own experience and knowledge acquired from the co-operating departments (technology, quality, control, HR, supplies and production) (Śliwa & Patalas-Maliszewska, 2016) or from external sources (tests, consultations, opinions). When solving a new problem (similar to previous one but described by other boundary conditions), experts create solutions (tacit knowledge) based on explicit knowledge accumulated in technical documentation, operating procedures, guidebooks, etc. It is necessary to use methods enabling the codification of the applied knowledge and preserving it in a continuous form. The methods supporting the acquisition of tacit knowledge include (Śliwa & Patalas-Maliszewska, 2015):

- filling in knowledge acquisition forms (Fazlagić, 2014),
- the making of video recording showing actions taken by an experienced worker,
- talk to an expert about the topic/ problem and steps to take,
- the engagement of experts from external companies,
- the creation of a place where knowledge workers can report/record their observations,
- registering logs generated in the course of creative work of an expert, e.g. by CAD programmes,
- schematic designs of processes and models in the form of associations, visualizations, holograms, cyber-world etc.

The sources of explicit knowledge in production companies include (Skarka, 2007):

- systems such as CAD/CAM/CRM, etc.,
- standards, customer requirements,
- books, textbooks, brochures, manuals, leaflets,
- expert knowledge bases,

– internal designs and documentation bases,
– internal knowledge bases such as intranet, wiki…,
– vademecum for staff (repository of manuals, brochures informing about behavioural procedures, guidebooks for novice workers).

The acquisition of knowledge by maintenance department workers resulting from simple actions when working on the designs, infrequently conducted in co-operation with other departments, takes place in the course of :

– concept development,
– conducting tests,
– creation of design and technological documentation – determining work specification,
– creation of machine operation manuals,
– creation of machinery specification, operation and maintenance documentation,
– training of machine-operating workers.

3.2. Knowledge acquired during machinery operation

The operation of a stock of machines requires implementation of actions under the maintenance process. The chief responsibility of the maintenance department is to maintain machines in a state of operational reliability and to ensure continuity of the production process. The tasks of the maintenance services include:

– performing maintenance and repair works such as: maintenance works resulting from the operation and maintenance documentation, i.e., lubrication, oiling, machine parts exchange after a given number of man-hours; machine operation adjustment,
– removal of failures,
– monitoring and analysis of the record of machine operation parameters (e.g. temperatures of subassemblies, cooling liquids, lubricants, oils, machine parts vibration, noise level),
– keeping a record of the number of spare parts available in the store,
– contact with the suppliers of parts for key subassemblies,
– development of maintenance and repair works schedule based on operation and maintenance documentation and production schedule,
– modernization of the technical infrastructure of a company,
– being in contact with Office of Technical Inspection units, in particular: keeping a record of equipment available at the Office of Technical Inspection (UDT); organization of routine tests; performing actions connected with acceptance tests of new devices (in the case of outsourcing) and maintenance works on equipment reported to the UDT; coordination and supervision of works and resulting recommendations.

To perform the above tasks, maintenance department works must have skills in the following areas: the ability to read operation and maintenance documentation , analysis of the technical condition of machines and devices, selection of suitable spare parts. Also important is the knowledge of the design and maintenance of machines and devices (knowledge from the field of mechanics, automatics, robotics, electronics). The next one is knowledge about the methods of performing repair and maintenance works on machines and devices and environmental protection (in case of environmental-hazard failure and when utilizing operational materials).

The acquired knowledge and skills result to a large extent from repair works performed by maintenance services. Due to its practical nature, the acquired knowledge should be classified as tacit knowledge. Some of it is stored by workers in databases, programs and systems supporting maintenance work. Their structure proposed by Rybińska and Sekieta (Rybińska & Sekieta, 2009) is shown in Fig. 1.

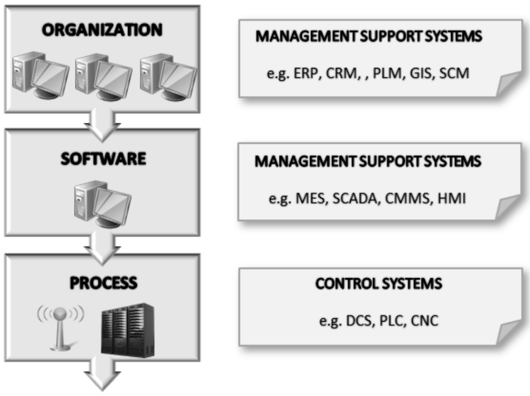

Fig. 1. Structure of IT tools supporting individual process layers (Kosicka & Mazurkiewicz, 2015)

The business layer contains, among others, systems for the management of resources, supplies and suppliers, and their tasks include the support of decision-making and planning of current activities. The operational layer supports maintenance in the managing of production processes through special systems. All kinds of maintenance data from repair and maintenance works are archived in computer systems and can be used for generating reports.

On the Polish market there are applications supporting the work of maintenance services in production companies. These applications consist in the management of data and their number, and are mainly dedicated to larger maintenance departments that take care of extended machinery stocks. These are sample programs: CMMS.net (http://cmms.net), KMS Maintenance (http://www.komtech.pl), MESO CMMS (http://www.utrzymaniemaszyn.pl) and Maintpartner products (http://maintpartner.fi/index.php/en/). These software are often modular, with many features and attributes to complement, which, on the one hand, may prove to be an asset but, on the other, the excessive-formalization and multiplicity of options poses the need to introduce new employees to their duties and motivate them to implement these programs, without pointing to key elements.

Due to the realities of work, time constraints and intensive inspections of machines at downtimes, the engineers do not control the reports generated by the maintenance services. The reports are often in paper form, and the information contained therein is not used again. They are mainly used for archiving, job accounting and are dispersed in many places (maintenance engineers office, maintenance services documentation, workshops). For this reason, it is important to choose the most important information about work with machines or installations. The data must be sorted out, linked together and, finally, offer a tool enabling easy search alongside a brief description of the actions taken or reasons that makes a compendium of knowledge gained from hands-on experience.

As a result of machinery maintenance and day-to-day work, workers increase their knowledge in four areas: process and work control, machine operation and work ergonomics, repair ergonomics and actual availability of machine parts. The increase in knowledge of machine operation ergonomics occurs when the machine is operated for a longer period of time (e.g. the worker proposes feeder position adjustment or a minor upgrade of the shield system or soundproofing). Repair ergonomics is significant to determine the availability of particular subassemblies. For instance, when a manufacturer provides additional engine gears. Despite no need to work using specific parameters, repair and fault identification are easier. As regards actual availability of parts, it involves verification of the and cost and time of components provided by manufacturers, components manufactured on request from specific materials, and components that are hard to get on the market. Then it is possible to propose a different technological solution or the use of substitutes. The control of processes and operation indicates key machine components that require monitoring. Focus is put on the need to provide additional sensors at stands responsible for the correctness of performed processes or statistics.

4. PROPOSED MODEL

The maintenance department of a manufacturing company should have an IT tool for systematization, quick identification and search of knowledge about workstations, equipment, machinery or installations. This need arises from the observed penetration of knowledge regarding machine design and maintenance. In response to the problem connected with knowledge acquisition and the often chaotic archiving of documents in manufacturing companies, a model of application based on knowledge bases is proposed for locating knowledge and information flow from the maintenance department. It is also assumed that access to specified information is given to external units within the company and outside it. The model is shown in Fig. 2.

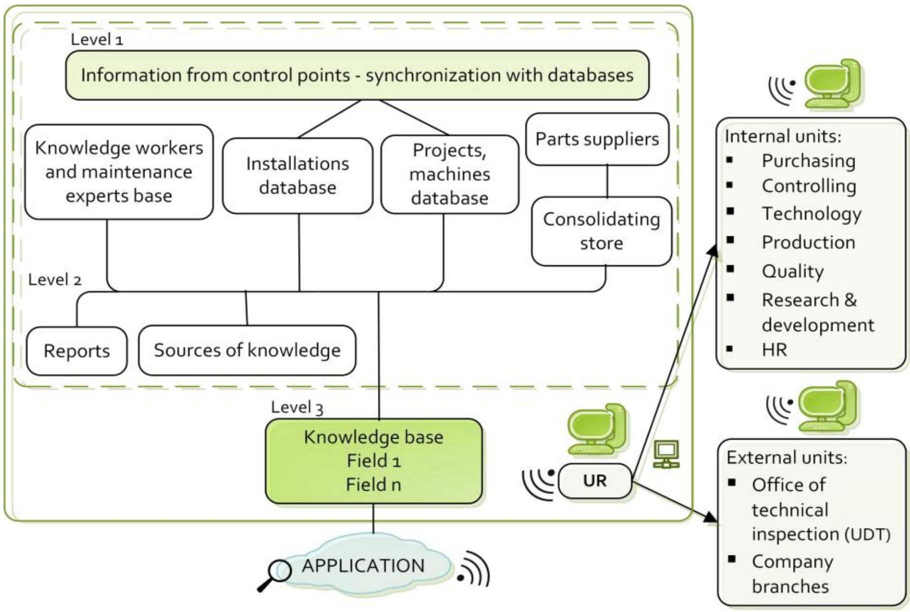

Fig. 2. Model of knowledge management system in a maintenance department

The proposed model illustrates the relationship between the main modules of the support system for acquiring and sharing knowledge in the maintenance department of the analysed manufacturing company. Structure of model complexity refers to the definition and relationship between: data (level 1), information (level 2) and knowledge (level 3) (Grabowski & Zając, 2009). Data and information contained in the knowledge bases (marked by a dashed-line rectangle) supplementing the program are entered and edited by maintenance department workers. The implemented tool is based on linking the existing technical documentation of a machine, device or workstation with modernization, repairs and machine parts used for this purpose. This is due to the fact that the machine is described by information contained in a report (presented later in the paper), illustrating the chronology of works at the same time.

The information in the reports is supplemented by authorized maintenance department workers. Optionally, the maintenance services are provided with mobile devices (computers, tablets and smartphones) with a report template.

The task leader and maintenance engineer should approve information synchronized with the knowledge base every single time in order to maintain control over the quality of entered data and their verification, or to reject unnecessary information. Upon approval, the engineer decides whether certain attributes should be made available or not to workers of other department or a co-operating unit treated as a knowledge client.

The application created on the basis of the presented model would act as a search engine automatically cooperating with e-reports. It would be placed in an external cloud computing environment that offers access to different knowledge bases depending on the client (recipient).

To determine boundary conditions, a series of assumptions were made concerning the analyzed real company based in Lubuskie Province:

- industry branch: automotive,
- type: a big production company,
- range: an international corporation with foreign capital,
- with its own maintenance department,
- the number of maintenance workers: 6 engineers, about 16 labourers,
- supplied media: gas, electricity, water, air, closed cycle of coolant.

The maintenance department uses an application for the structuring and dividing the knowledge connecting the access to bases and sources located within the organization (set B0):

B1: Knowledge workers and experts base,

B2: Designs base – machines, devices or production, assembly and logistical processes supporting lines,

B3: Media supplying installations knowledge base,

B4: Reports base (repairs, preventive maintenance, maintenance),

B5: Sources of knowledge,

B6: Spare parts base (specification of parts in the consolidating store),

B7: Machine parts suppliers

At the same time, the company’s maintenance department could be authorized to access external databases with a similar data structure that belong to the company's branch. Ideally, it is also important that the model involves cooperation with the local Office of Technical Inspection. The possibility of downloading data on the validity period of technical inspection and operational admittance of a machine, tank, hoist, etc. would be an additional advantage of the proposed model, because it would relieve the worker of continuous updating of records or remembering to schedule upcoming inspections.

The designs base includes both operation and maintenance documentation necessary for proper machine operation as well as extended design documentation containing technical drawings, spare parts lists and manuals. It is also assumed that the base is used for archiving the documentation produced during the upgrade or installation of an additional module or component.

The other type of technical documentation refers to the media supplying installations and includes the documentation of basic equipment, e.g. in the case of a compressed air network such equipment comprises compressors, tanks, driers and filters, as well as designs and technical specifications of the accessories supporting the supply of a given medium, e.g. pipeline type, measuring points, cut-off points.

Elements allowing to organize knowledge are introduced and edited by a maintenance department worker who runs a given project, supervises or approves of maintenance services actions. The key elements here are “designs base” and “installations knowledge base,” where every component, i.e., action taken, is described by the attributes from Section P0. The electronic report on the actions of the maintenance services is shown in Figure 3, where the blue sections suggest the possibility of association with a reference or attachment.

P1: Worker

This indicates a person who performs the task and hence enters the data. There is also a function of automatic reading of the worker’s ID after logging to the application.

P2: Manufacturer

P3: ID

This indicates a topic (name of a machine read by its rating plate or scanned bar code),

P4: Knowledge source – basic

This indicates an access path to the location of electronic documentation (attachment), if necessary with the hard-copy description of material.

P5: Knowledge sources – created

This indicates an access path to the documentation produced while solving the problem (attachment), i.e., description, modernization, technical documenttation, etc.

P6: Problem

Indicates a specified unit or machine part by its ID, name.

P7: Solution

This indicates a problem-solving action from a closed list of entries such as exchange, installation (e.g. of a module), repair (of existing part), maintenance (e.g. oiling), etc.

P8: Parts ID

If the entry ”exchange” occurs in Section P7, the availability of an element for exchange is checked in the consolidating store and, if available, it is fetched in a required number.

P9: Justification

This indicates a justification for the solution described by entries such as burnout, nick, breakage, unscrewing, loosening, wear, protection etc.

P10: Notes

This section is completed at the worker's own discretion. It can contain a hint or reference to the operational instructions (attachment).

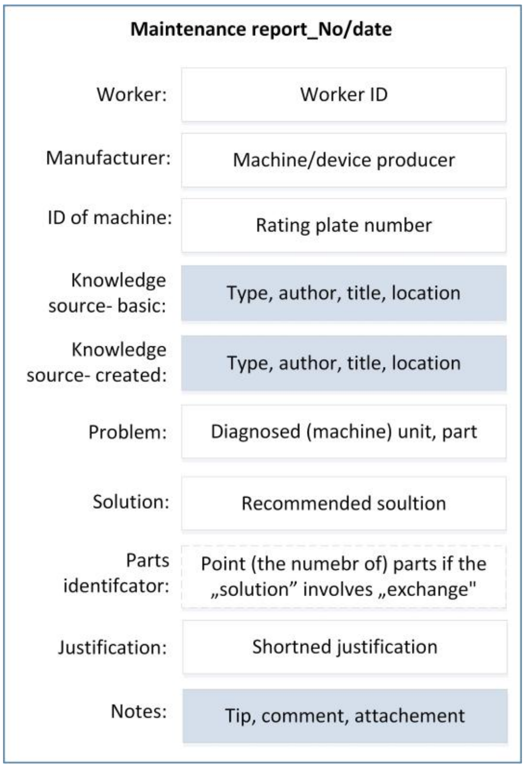

Fig. 3. Electronic report made by maintenance services

The final result of the work of the application is a knowledge search engine displaying the results by type (optionally by hyperlinks) in response to the key entered in the coupled knowledge bases.

The search results include:

– designs denoted under specified entry,
– media supplying installations denoted under specified entry,
– internal workers (so-called experts) – figures in the report,
– sources of knowledge – basic – list of hard-copy and electronic materials available in the company – representation of explicit knowledge sources,
– created sources of knowledge – representation of externalized tacit knowledge in the company (e.g. formulation of instructions for action).

In addition, it is assumed that materials are sorted by knowledge type, i.e., base affiliation, edition and addition order in an alphabetical order.

One example of a completed electronic report refers to the real problem of the enterprise under investigation and to the way it was resolved.

A production line worker reported on the splashing of the cooling water of the CNC machine cutter, which caused discomfort (splashed goggles) and an excessively wet floor around the station, which should be cyclically drained to the grate. Activities taken by the maintenance services included: CAD cover design, material selection, cover design and mounting, and then obtaining the CE certificate from the machine's manufacturer. The modernization was undertaken by the maintenance services following consultation with the manufacturer of a CNC machine. The completed report is presented in Fig. 4.

Maintenance report_56/01_02_2017

Worker:	2032
Manufacturer:	ANSYX
ID of machine:	M-502633
Knowledge source- basic:	ANSYX – CNC_M502633 dokumentacja techniczna.pdf
Knowledge source- created:	ANSYX_CNC_Osłona.dwg, Jan Kowalski
Problem:	Cooling unit (of cutter)
Solution:	Installation (of cover)
Justification:	Protection (of worker)
Notes:	Modernization after manufacturer's approval: ANSYX – CNC_M502633_CEcertyfikat.pdf

Fig. 4. Example of a filled-in maintenance services e-report

The solution is useful for quick and easy sorting out of key documentation collected in the maintenance department. It helps with analysing the history of activities undertaken by the maintenance services. It can be a source of knowledge for new employees by providing information such as: problem-solution-justification.

5. CONCLUSION

Production companies must implement knowledge management supporting tools that take account of the source of knowledge and its two types (tacit and explicit knowledge). The maintenance department must use methods that support the formalization of knowledge, its acquisition, collection and conscious exchange with co-workers. The systematic collection of information about the operations performed on machines, installations and equipment such as repairs and upgrades, the workers can significantly improve the quality of their work, save time dedicated to filling in and rewriting information from the reports. The accumulated knowledge is also a source of information for new workers, which leads to shorter times of their training and their getting used to new duties and taking actions on their own. The implementation of a computer application based on the proposed model enables quick and easy search of the necessary information by combining the available technical documentation with the history of operations performed by the machine. It also indicates workers who solve problems in a given category, which allows to select the person responsible for actions that must be taken. Archived knowledge can also be useful for verifying expectations when ordering a similar machine or improving simple workstations for the company's own purposes by maintenance department workshops.

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NEW EXTRUSION PROCESS FOR PRODUCING TWIST DRILLS USING SPLIT DIES

Abstract

The paper presents a new extrusion process for producing twist drills using split dies. The design of the dies is described, where the profile of the flute-forming element is the same as the profile of the flute on the plane inclined to the drill axis at an angle equal to the helix angle. The proposed method for the extrusion of twist drills by the new type of dies is verified by numerical modeling. Three cases of the extrusion process are modelled, each with a different position of the flute-forming element relative to the axis of the drill. The paper investigates the effect of the position of the flute-forming element on the angle of inclination of the flutes and the cross-section shape of the drill. Numerical modeling is performed using DEFORM-3D.

1. INTRODUCTION

Extrusion processes are widely used in the manufacture of a broad range of products for various industries. The most common methods of extrusion are forward and backward extrusion. There are also special types of extrusion, including KoBo extrusion, hydrostatic extrusion, and Conform extrusion. Extrusion is mainly applied in the production of long products of varying cross-section (Fang, Zhou & Duszczyk, 2009; Jiang, 2015; Cristobal, Ramírez, Ruiz, Ortiz & Jacobo, 2017). Extrusion processes are also used to produce more

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compact products such as combustion engine pistons (Dong & Chen, 2008). Currently a growing interest in screw extrusion can be observed. Screw extrusion is a process by which the material is pushed through a helical hole in the die. The material leaving the die moves with a helical motion which is a combination of progressive and rotational motion. Screw extrusion is used in the manufacture of such components as twist drill, rotors of pumps, helical gears, etc. (Kim, Kubota & Yamanaka, 2008; Hwang & Chang, 2014; Bulzak & Pater, 2013).

Twist drills can be extruded through single and split dies. Extrusion through unitary dies consists in pushing the material through a die with a helical channel whose contour corresponds to the shape of the twist drill (Liekmeier, 1992). In the case of split dies, the material is pushed through two dies with oblique protrusions that form helical flutes and give the drill its helical shape (Bulzak & Tomczak, Pater, 2014, 2016). Split dies can be designed in two ways, as schematically shown in Figure 1. In the first method, the geometry of the flute-forming elements (protrusions) corresponds to the contour of the flute in plane n_1 perpendicular to the drill axis (Figure 1a). In the second method, the geometry of the flute-forming element is consistent with the contour of the flute in plane n_2 normal to the flute (Figure 1b). This article presents the results of numerical simulations of the process of extrusion of twist drill in which tools with flute-forming elements normal to flutes were used.

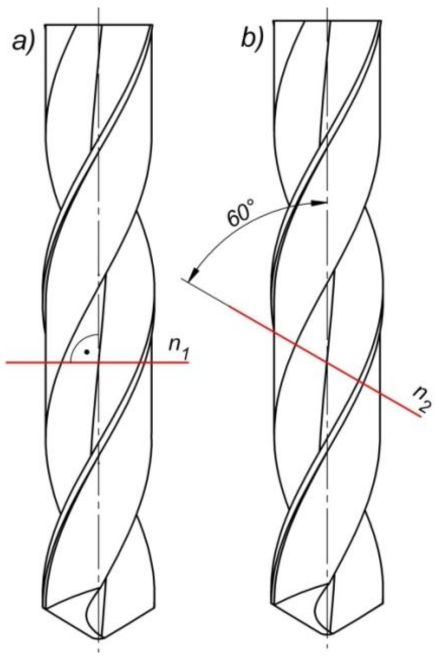

Fig. 1. Schematic of the position of the contour of the flute-forming element relative to the twist drill axis – description is provided in the text

2. METHOD AND GOAL

Similarly as in the case of milling of twist drill, the position of the flute-forming element relative to the extruded twist drills can be defined based on the position of point *S*, which marks the point of intersection between the axes of the flute-forming protrusion and the twist drill. The position of point *S* is defined by two values: *x* and *y*. The schematic of the position of the flute-forming element is shown in Figure 2. The present article reports the results of numerical simulations of the process of extruding twist drills for the following positions of point *S* : 1) $x = 0.5y$; 2) $x = y$; 3) $x = 1.5y$.

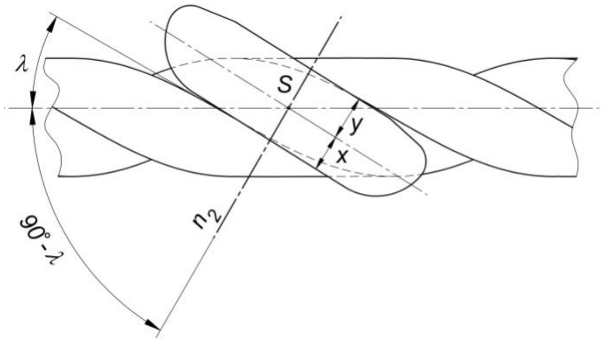

Fig. 2. Schematic of the position of the flute-forming element relative to the extruded twist drill

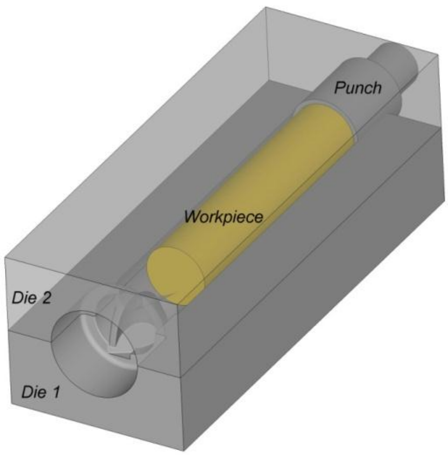

Fig. 3. Geometric model of extrusion of twist drills using split dies

Numerical simulations based on the finite element method were performed using Deform-3D software. In order to carry out the numerical simulations, three geometric models of the process of extrusion of twist drills were constructed, one of which is shown in Figure 3. A ∅27 × 120 mm billet, whose initial temperature was 1150°C, was modelled using tetragonal finite elements. It was assumed that the tools were ideally rigid and their temperature was constant at 300°C. The material model of the workpiece material (DIN – 102Cr6) was gleaned from the library of the software used. The heat exchange factor between the material being formed and the tool was assumed to be 10 kW/m^{2}K, and that between the environment and the material was 0.2 kW/m^{2}K. The friction on the contact surface between the workpiece and the tools was described by the constant friction model, with the assumed friction coefficient m = 0.5.

3. RESULTS OF NUMERICAL SIMULATIONS

Based on the simulations, the effect of the position of the flute-forming element on the course of the extrusion process and the dimensional accuracy of the obtained twist drill was determined. Fig. 4 compares the transverse profiles of the twist drill extruded at variable point *S* positions. By far the greatest compliance with the theoretical profile was achieved for the twist drill profile extruded with point *S* exactly at the center of the flute ($x = y$). A good match with the theoretical profile was also obtained with point *S* positioned near the margin ($x = 0.5y$). When point *S* was positioned at $x = 1.5y$, there was a large discrepancy between the CAD profile and the FEM profile in the area of the rear surface of the flute. The remaining part of the flute differed only slightly from the theoretical contour in the area of the drill margin.

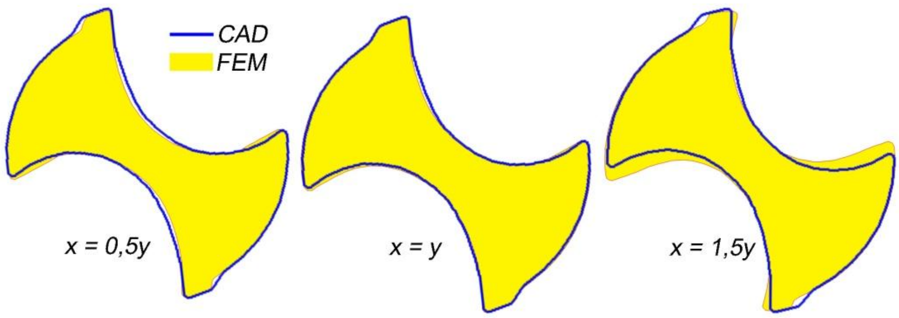

Fig. 4. A comparison of the profiles of twist drills extruded at different positions of point *S* with the theoretical profile

The position of the flute-forming element also has a significant impact on the helix angle λ. A comparison of the geometries of twist drills extruded at different positions of point *S* is shown in Figure 5. The largest helix angle λ was obtained when the position of point *S* was defined as $x = 0.5y$. As the distance x increased, the helix angle λ of the extruded twist drills became smaller.

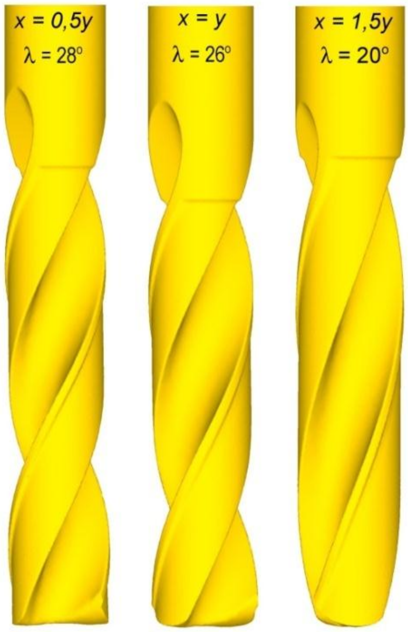

Fig. 5. Geometry of twist drills extruded at different positions of point S

The helix angle λ depends on the axial velocity $V_z$and the circumferential velocity V_θ of material flow. Figure 6 shows the distribution of the axial velocity $V_z$of material flow. In the first two cases ($x = 0.5y$; $x = y$), the velocities of the material exiting the die were similar. A marked difference was found for the third position ($x = 1.5y$), where the velocity of the material exiting the die was lower than in the other two cases.

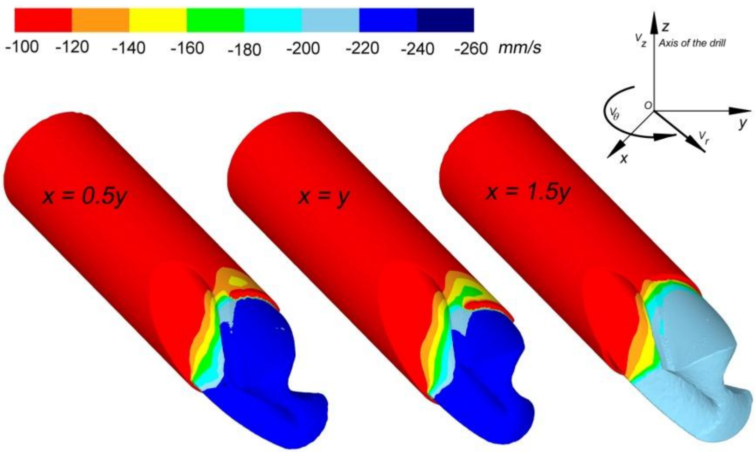

Fig. 6. Distribution of velocity of material flowing in the axial direction V_z

The position of the flute-forming element also affects circumferential velocity V_θ which is responsible for the twisting of the extruded drill. Maps showing the distribution of circumferential velocities of material flow are shown in Figure 7. An increase in distance x led to a reduction in circumferential velocity of material flow. This reduction was very small for $x = 0.5y$ and $x = y$. A significant drop in flow velocity of the material was observed for $x = 1.5y$, which was reflected in the fact that the drills extruded at this position of point S had the smallest helix angle.

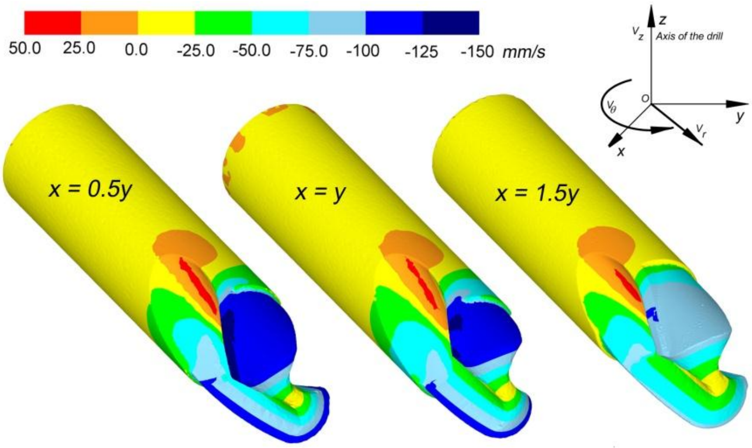

Fig. 7. Distribution of velocity of material flowing in the circumferential direction V_θ

Fig. 8 shows numerically determined distribution of the plastic strain for the investigated cases of twist drill extrusion. In the cross-sections of the obtained twist drills, the largest plastic strains were concentrated at the web of the twist drill. The value of strain decreased in the peripheral part of the cross section of the twist drill. Strain on the surface of the flute for $x = 0.5\ y$ and $x = y$ was the greatest in the margin area. For $x = 1.5y$, the largest values of plastic strain were found at the edge of the land.

The curves of forming and expansion forces determined using the finite element method are shown in Figures 9 and 10, respectively. For all cases, an increase in the extrusion force was observed, which resulted from the cooling of the workpiece. The expansion force, after reaching the maximum value, decreased along with the decreasing height of the billet placed in the die container. The force parameters for the extrusion force and the expansion force for the die parameters x = 0.5 y and x = y were similar. When x = 1.5 y, both the extrusion force and the expansion force reached smaller values. In the process of split-die extrusion of twist drills, this is a typical situation, i.e. the extrusion force decreases along with a decrease in the helix angle of the extruded twist drill.

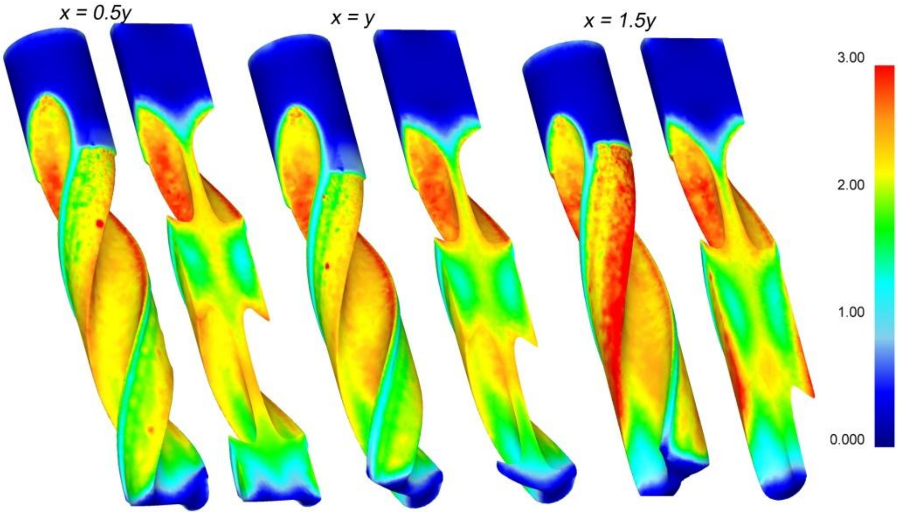

Fig. 8. Distribution of effective strain

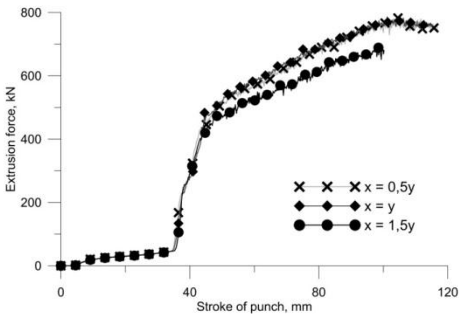

Fig. 9. A curve of punch extrusion forces

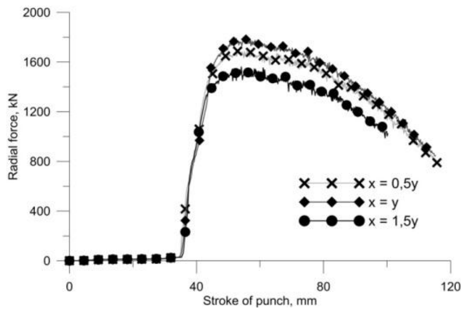

Fig. 10. A curve of expansion forces acting on the die

4. RESULTS OF EXPERIMENTAL TESTS

The positive simulation results led the research team to verify them under laboratory conditions.Fig. 11 shows the dies and the apparatus used in the experiments. Experimental tests were carried out using Pb1 lead as model material. In the experiments, extruded rods with a diameter of 27 mm and length of 120 mm. The experiments were conducted using a PYE 160 universal hydraulic press. The numerical and experimental results confirm that twist drill can be formed by extrusion process using new design split dies.

Fig. 11. Apparatus for split-die extrusion of twist drills

Twist drill blanks with a diameter of ∅ 30 mm formed during the experimental study are shown in Fig. 12. The obtained twist drills were characterized by reproducibility of dimensions, including screw thread pitch. No problems were encountered during the removal of the blanks from the die cavity. Also, no defects were found on the surface of the drill during removal of the forgings from the die cavity. The fact that the twist drills could be properly removed from the die cavity without the need to unscrew them from the die confirms the correctness of the assumptions of the newly proposed method of extrusion of these tools. The helix angle of the twist drills obtained in the process is consistent with the angle calculated numerically using FEM simulations.

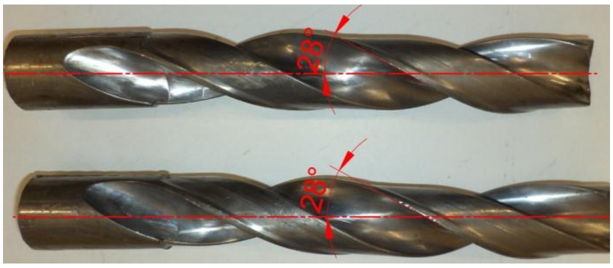

Fig. 12. Twist drills obtained in the experiments

5. CONCLUSIONS

The numerical and experimental investigations performed in this study lead to the following conclusions:

- twist drills can be extruded using dies with a flute-forming element positioned normally to the flute;
- dies with a flute-forming element positioned normally to the flute allow easier removal of the twist drill from the die cavity, especially in the margin area;
- an increase in distance x, which describes the position of the flute-forming element, results in an increase in the helix angle λ of the extruded twist drills;
- the contour of the flute is best reproduced when $x = y$; for $x = 1.5y$, the contour of the flute deviates the most from the theoretical contour;
- the smaller the helix angle λ, the smaller the extrusion forces;
- the experimental studies conducted using the model material confirmed the results of the theoretical FEM studies.

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Pedicle screws, FEA, CAD, 3D modeling

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NUMERICAL ANALYSIS OF SPINAL LOADS IN SPONDYLOLISTHESIS TREATMENT USING PEDICLE SCREWS – PRELIMINARY RESEARCH

Abstract

The aim of this experimental study was to analyse the influence of lumbar stabilisation used in the treatment of spondylolisthesis on the biomechanical properties of the human lumbar spine. FEM models were built on the basis of pre-surgical CT scans, routinely used in medical practice. MIMICS software was used to process the results of the neuroimaging study and to create 3D models. Two models were built: with and without a stabiliser. A static load analysis was performed for a normal upper-body load. The simulations allowed to determine the stresses in the individual discs for both models, with and without the transpedicular stabiliser.

1. INTRODUCTION

There is probably no other system in the human body that plays as important a role for human health and a long and active life as does the spine. The spine forms a kind of axis for the human body, and its specific structure protects the brain and the spinal cord from shocks and injuries. A healthy spine promotes the proper

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function of the nervous system, which has a great impact on a person's general health and wholesome life. The spine is built of alternating layers of hard bony structures called vertebrae and elastic elements called intervertebral discs. This system is stabilized and supported by soft tissues: joints, ligaments and muscles. Structured in this way, the vertebral column allows the body to move and simultaneously transfer loads generated by body weight and bodily activities (Zubrzycki & Smidova, 2014; Zubrzycki, Karpiński & Górniak, 2016).

As clinical practice shows, the most common spinal conditions are those that affect the lumbar spine. This region is exposed to the largest loads, compared to the thoracic and cervical spine. Approximately 30% of orthopaedic patients are lumbar cases. Almost all instabilities are due to muscular imbalance, disc degradation, and intervertebral degeneration. They all lead to the deepening of the lumbar lordosis and misalignment of the lumbar spine relative to the sacrum. These problems are most often caused by mechanical loads. With age, the ligaments get stretched, which results in loosening of the joints, and the gradual loss of muscle efficiency additionally contributes to instability in the motor segments (Yugang et al., 2015).

A typical stress fracture of the spinal bony structures and one of the most common lumbar disorders is spondylolisthesis. This disease is a form of chronic instability of the lumbar spine. It involves slippage or displacement of the column of vertebrae over a vertebra below it (or the sacrum). In the lumbar region, spondylolisthesis, in most cases, occurs at the L5-S1 level of the spine and, less frequently, at levels L4-L5 and L3-L4. The most common complaints are related to the irritation of and subsequent damage to the nervous system or to a pathology of facet joints (Gzik, Joszko & Pieniążek, 2012; Ciupik et al., 1997).

2. ANATOMY AND PHYSIOLOGY OF THE SPINE

The spine is the moving axis of the body and the neck, which is located in the midsagittal plane on the dorsal side of the body. It stretches from the base of the skull to the lower end of the trunk, forming, together with the ribs and the breastbone, the axial skeleton of the body. The spine is made up of 33 to 34 unpaired, symmetrical vertebrae stacked on top of each other to form the spinal column. The vertebral column in divided into five regions (Fig. 1):

- cervical (C1–C7) – 7 vertebrae,
- thoracic (Th1–Th7) – 12 vertebrae,
- lumbar (L1–L7) – 5 vertebrae,
- sacral (S1–S7) – 5 vertebrae,
- coccygeal (Co1–Co4 / Co5) – 4–5 vertebrae.

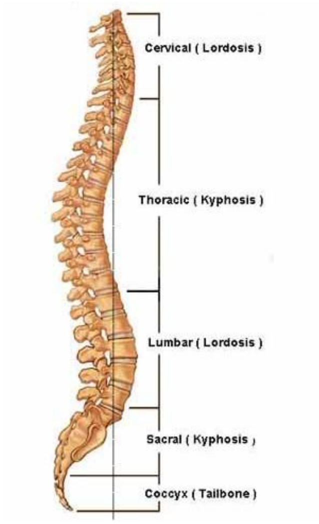

Fig. 1. Lateral view of the spinal column [19]

The spine becomes stronger and more resistant the further down it goes as the vertebrae become larger and more strongly built. This type of structure provides high rigidity and durability, while allowing for flexibility. Owing to this, the spine can fulfil its three basic functions: to protect the spinal cord, to protect the locomotor system and to support the body (Woźniak, 2003; Bochenek, 2010; Karpiński, Jaworski & Zubrzycki, 2016).

2.1. Curvature of the spine

In an adult body, when viewed in the sagittal plane, the spine is seen to have two types of curves: lordosis – with anterior convexity (convex forward) and kyphosis – with posterior convexity (concave forward). Starting from the top of the vertebral column, the following four curves can be distinguished: cervical lordosis, thoracic kyphosis, lumbar lordosis and coccygeal kyphosis. Together, they give the spine its characteristic double-S shape. Cervical lordosis transitions smoothly into thoracic kyphosis and there is a similar smooth transition between thoracic kyphosis and lumbar lordosis. By contrast, the transition between the last, fifth lumbar vertebra and the sacrum is more prominent and is known in the literature as the lumbosacral angle. The last intervertebral disc forms an outward curve or a promontory (although the latter term is more often used to refer to the upper edge of the sacral bone) (Woźniak, 2003; Będziński, 1997; Mańko, Zubrzycki & Karpiński, 2015).

The shape of the spine as described above is a specific feature of human beings, a result of verticalisation of the body. The spinal curves bring the centre of gravity into a straight line that projects onto the base of support outlined by the feet.

When the projection of the centre of gravity of the body falls outside the outline of the feet, a person loses balance. The situation is different in animals, in which the centre of gravity of the body projects forward of the feet. This also applies to apes and monkeys, which assume an upright position only occasionally (Woźniak, 2003; Bochenek, 2010).

3. SPONDYLOLISTHESIS

Spondylolisthesis is a disease defined as a displacement of a vertebra (together with all the vertebrae lying above it) with respect to a vertebra inferior to it. Spondylolisthesis most often affects the L5–S1 and L4–L5 levels. Most authors believe that the lumbar spine, as a result of having assumed a vertical position in the course of evolution, is a mechanically weak point of the human locomotor (musculoskeletal) system, which is why spondylolisthesis most commonly occurs just in this region of the spine. Spondylolistheses of other spinal regions are rare. In the general population, the incidence of spondylolisthesis is estimated to be around 5%. The name of the condition comes from the Greek words "spondyl" – the spine and "olisthesis" – slippage. Spondylolisthesis was first described in 1782 by the Belgian obstetrician Herbinaux, who associated the unnatural displacement of the spine forward relative to the bones of the sacrum with problems during delivery (the shifted body of the L5 vertebra reduced the patency of the pelvic birth canal). Since then, spondylolisthesis has been the focus of many orthopaedic, neurological and biomechanical studies (Bartochowski, 2011; Aruna, 2002; Vadapalli, 2004; Ciupik et al., 1997; Awłasewicz, Kędzior & Krzesiński, 1997; Maurel, Lavaste & Skalli, 1997).

3.1. Determining the grade of slip in spondylolisthesis

The severity of a spondylolisthesis is assessed using the Meyerding classification:

- grade I: displacement of neighbouring vertebrae by less than 25% of the vertebral body width,
- grade II: displacement by up to 50% of the vertebral body width,
- grade III: displacement by up to 75% of the vertebral body width,
- grade IV: displacement greater than 75% or total displacement of adjacent vertebral bodies relative to one another (Yugang et al., 2015).

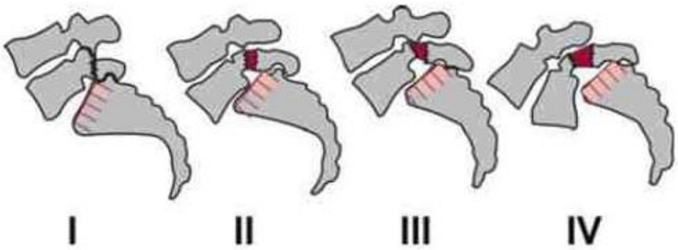

Fig. 2. The spondylolisthesis grading scale

To calculate the percentage of vertebral slip, the following formula is used:

$$P = A / B * 100\% \quad (1)$$

P – percentage of displacement;
A – length of the overhanging part of the superior vertebral body;
B – total width (anteroposterior length) of the vertebral body;

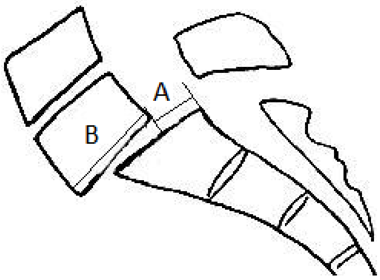

Fig. 3. Determination of grade of slip

3.2. Treatment methods

Treatment of spondylolisthesis is based on conservative and operational procedures. The doctor decides what treatment to use based on observation of the patient, radiographic assessment and the progression of the disease. The purpose of treatment is to achieve stability of the spine and prevent neurological disorders (Bartochowski, 2011). One of the main methods of treatment is to insert specially designed stabilisers called pedicle screws (Fig. 4).

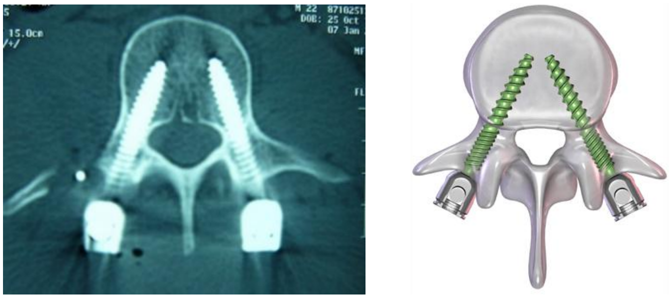

Fig. 4. Examples of use of transpedicular screws

4. DEVELOPMENT OF NUMERICAL MODELS OF VERTEBRAE

Numerical models and numerical strength tests were performed based on the results of CT scans obtained in studies done in cooperation with the Independent Public Teaching Hospital No 4 in Lublin. The tests were anonymous. The geometry of the vertebrae and their anatomical alignment were extracted using Mimics and SolidEdge software. CT images were taken in accordance with the DICOM standard. Data consisted of 226 tomograms made at a resolution of 1.25 mm. The subject was a 21-year-old man with a second grade L5-S1 spondylolisthesis.

Due to the localization of the slip, further investigations were focused on the region of the spine comprising L3, L4 and L5 vertebrae and the sacral bone (Fig. 5).

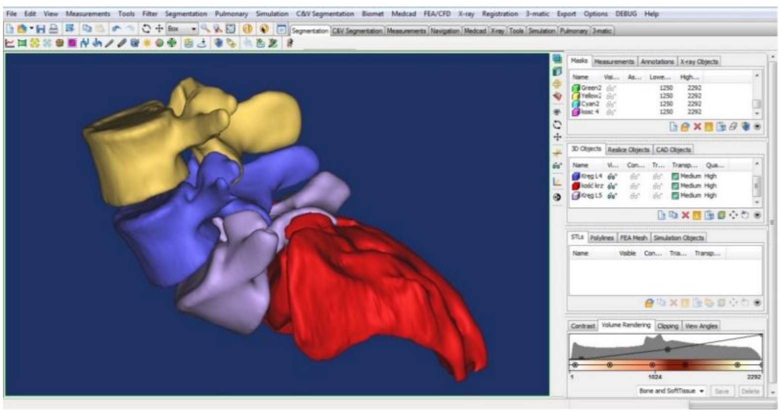

Fig. 5. Models of L3, L4, L5 vertebrae and the sacral bone (Mimics)

4.1. Simplification of numerical models of intervertebral discs and the spine before surgery

Because the CT images did not visualise intervertebral disc structures, it was necessary to create simplified models of the discs (Mańko et al., 2015; Zubrzycki & Braniewska 2017). To capture the shape of the discs and the relations between discs and vertebrae, it was necessary to simplify the earlier obtained vertebral models by levelling their upper and lower surfaces (removing the anatomical unevenness of these surfaces). After completing these steps, the Assembly module was used to develop a final model of the investigated region of the spine (Fig. 6) (Zubrzycki & Smidova, 2014).

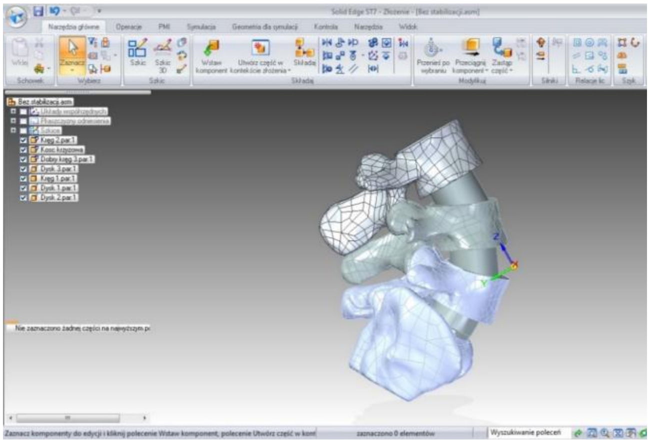

Fig. 6. Numerical model of the investigated spine segment

Numerical stress distribution tests were performed for this model.

The next step of the experiments was to develop a numerical model of a pedicle screw stabiliser. For this purpose, fixation of the screws and the entire structure of the stabiliser were designed. This article presents a simplified model of a stabiliser with straight rods. Due to the preliminary nature of the study, the curvature that should normally be given to the rods was omitted. The model of the investigated fragment of the spine with the stabiliser is shown in Fig. 7.

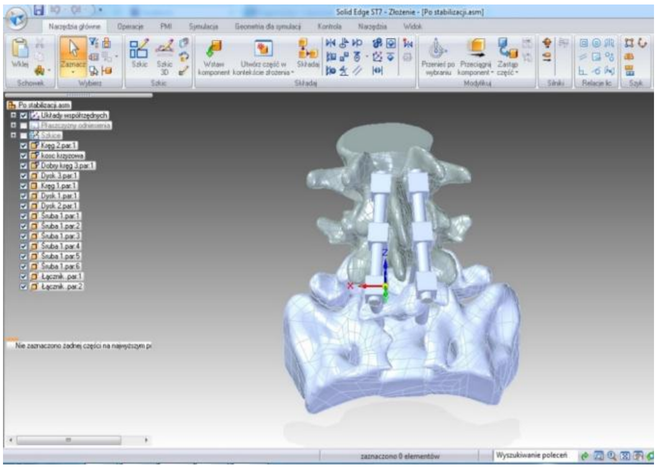

Fig. 7. Numerical model of the spine with a stabiliser

The spine was stabilised using the following elements: 6 transpedicular screws and 2 connectors. The screws had a diameter of 8 mm and a length of 55 mm and were made of Ti 6Al 4V titanium. Previous research had shown that 8 mm diameter screws could be safely used to fix the L3 vertebra. The connector had a diameter of 6.5 mm and a length of 70 mm and was made of Ti6Al 4V titanium. The screws were inserted into the vertebra at an angle of 130° relative to the xz plane, at an angle of 5° relative to the yz-axis on the left side and -5° relative to the yz-axis on the right side.

5. NUMERICAL STRENGTH TESTS

Numerical strength tests were performed using Finite Elements Analysis (FEA). The tests were performed for two cases:

1. An anatomical spine with a diagnosed spondylolisthesis,
2. A “postoperative” spine with an implanted transpedicular stabiliser.

5.1. Test assumptions

Strength analysis was performed for an upper-body load of 500 [N] applied to the top part of the L3 vertebra, which allowed us to determine the state of stress in the individual vertebrae. The model fixation was applied to the sacral bone. The material of the vertebrae and discs was assumed to be isotropic. The properties of the vertebrae and discs were determined on the basis of an analysis of available research reports (Awłasewicz et al., 1997; Maurel et al., 1997; Yugang et al. 2015; Gzik et al., 2012). The parameters are given in the table below.

Tab. 1. Properties of materials used during FEM analysis

Material	Young's Modulus [MPa]	Poisson's ratio
Vertebra	10000	0.3
Intervertebral disc	100	0.4
Screws and connectors (Ti 6Al 4V Titanium)	104800	0.31

The first test was an analysis of the physiological lumbar region using the input data as given in 5.1. The obtained stress distribution data are presented in the figures below. FEM analysis was performed according to the Huber–von Mises hypothesis.

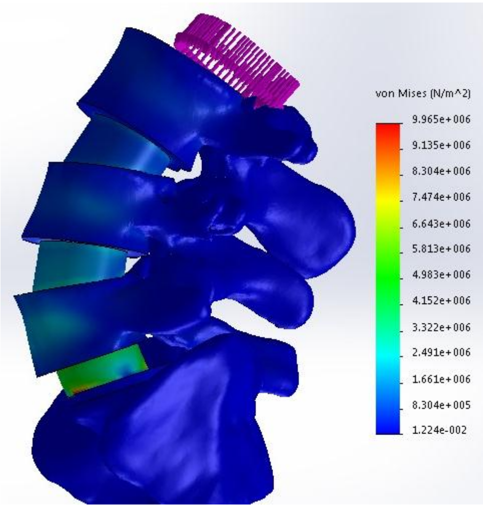

Fig. 8. Stress distribution in the model without a stabiliser – general view

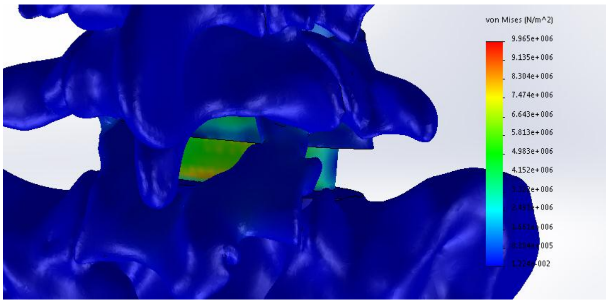

Fig. 9. Stress distribution in the model without a stabiliser – details

It is easily seen in the figures above that the stresses concentrate in the posterior and anterior parts of the intervertebral disc between the L5 vertebra and the sacral bone (9.135 MPa). In the vertebrae themselves, the stresses are not high and are evenly distributed over the entire surface of the bones. The observed stress concentrations are very dangerous to the patient because they can lead to severe damage to the disc and consequently to discopathy and further aggravation of spondylolisthesis and increased pressure on the spinal cord. In extreme cases, a patient may suffer loss of sensation (numbness) in the lower limbs and loss of walking ability.

Further analysis concerned the model of the lumbar region of the spine with the transpedicular stabilizer. An analysis of the obtained stress distribution maps showed that, in the examined element, the use of the stabiliser as a support structure substantially reduced the stresses acting on the vertebrae and the intervertebral discs (Figs. 10, 11). In the patient investigated in this study, insertion of the stabiliser to the lumbar spine transferred nearly all of the load to the stabiliser rods (Fig. 10a). In this way, the deformed parts of the spine were decompressed and could be subjected to corrective and rehabilitation care (Fig. 10b). The results show that the highest values of Huber–von Mises reduced stresses were observed in stabiliser rods (a maximum value of 946 MPa). This considerable increase in stresses in the system with the stabiliser compared to the physiological model was mainly due to the change in spinal biomechanics and was also caused by the fact that the cross sections of spinal vertebrae and intervertebral discs were much larger than those of the stabiliser rods (d = 6.5 mm, l = 70 mm) and screws (D = 8mm).

a) b)

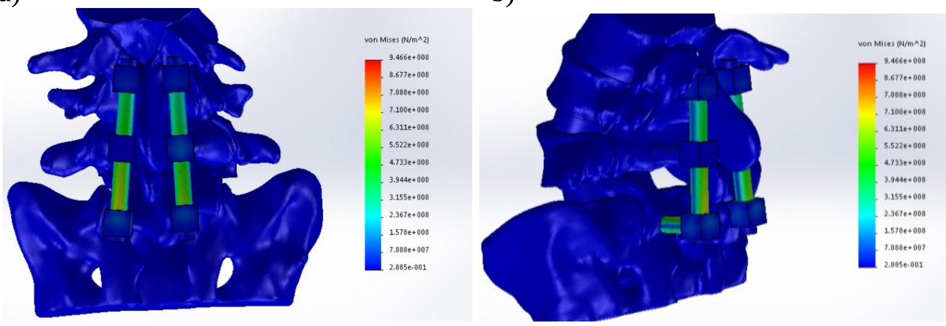

Fig. 10. Stresses acting on the vertebrae and the inter-vertebral discs

It is also important to note that high stress values were observed in stabiliser screws. This applied to screws fixed in the L4 vertebra and the sacral bone (Fig. 11). In contrast, the stresses in screws located in the L5 vertebra were negligible.

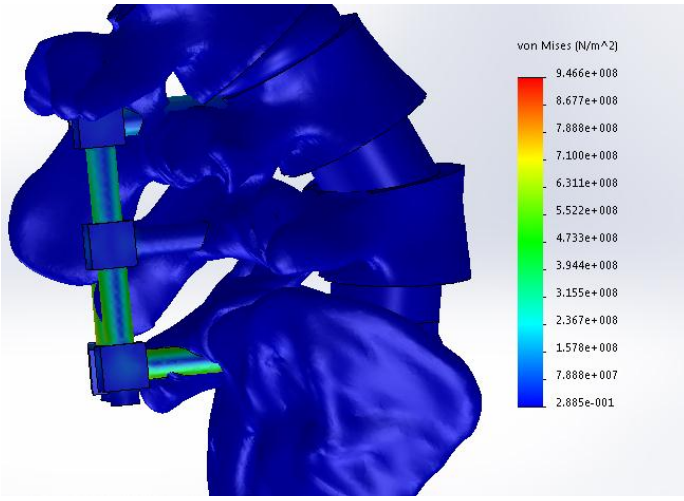

Fig. 11. Analysis of the obtained stress distribution maps

Based on the results of the simulation, it can be said that a transpedicular stabiliser can be used to decompress an injured part of the spine and to help improve the patient's quality of life.

6. CONCLUSIONS

In this study an attempt was made to analyse the complex mechanical system of a spine segment stabilised to promote healing in second-grade L5-S1 spondylolisthesis in a 21-year-old man. The effects of transpedicular stabilisation on the biomechanics of the human lumbar spine were evaluated using two different models of the spine: a physiological model and a model with a transpedicular stabiliser. The models were developed on the basis of CT images which were processed using MIMICS software. The models were then imported into the CAD environment: they consisted of vertebrae and intervertebral discs with and without a transpedicular stabiliser. They were used to perform a static analysis for a normal upper-body load.

The results of the static load simulations of the physiological model showed that, in this case of spondylolisthesis, the areas that were exposed to the largest loads were the posterior and anterior part of the intervertebral disc located between the L5 vertebra and the sacral bone. The purpose of stabilisation with transpedicular screws was to stabilise and decompress these structures. The analysis performed on the transpedicular stabilisation model showed that insertion of transpedicular screws stabilised the system and made it rigid. The L5-S1 disc was decompressed, and the stresses were taken over by screw connectors and the screws fixed in the L4 vertebra and the sacral bone.

The Finite Element Method, which is widely applied in modern engineering, was used to better understand the lumbar spine condition of spondylolisthesis and to evaluate treatment of this condition by transpedicular stabilisation. The application of this method allowed a better insight into the anatomy, physiology and kinematics of a spine with second grade L5-S1 spondylolisthesis as well as the assessment of the effectiveness of its treatment with transpedicular screws.

Despite some simplifications in mapping the reality, FEM can be used extensively for medical purposes. It allows to build patient-customized implants and prostheses, as well as providing detailed information on the biomechanics of systems in particular disease entities. It significantly accelerates the design process and ultimately reduces the price of the products offered, making them more accessible to the general public.

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WPC composites, homogenization methods, Digimat software

Wiesław FRĄCZ, Grzegorz JANOWSKI**

INFLUENCE OF HOMOGENIZATION METHODS IN PREDICTION OF STRENGTH PROPERTIES FOR WPC COMPOSITES

Abstract

In order to reduce costs of experimental research, new methods of forecasting material properties are being developed. The current intensive increase in computing power motivates to develop the computer simulations for material properties prediction. This is due to the possibility of using analytical and numerical methods of homogenization. In this work calculations for predicting the properties of WPC composites using analytical homogenization methods, i.e. Mori-Tanaka (first and second order) models, Nemat-Nasser and Hori models and numerical homogenization methods were performed.

1. INTRODUCTION

The common feature of all composite materials is that their micro-scale properties strongly influence on the macro-scale properties of the entire material. The ability to describe microstructural phenomena leads to a better understanding of the macroscopic behavior of the material, but most often the exact microstructural properties are unknown, so it is generally necessary to assume certain assumptions. These properties can be determined by homogenization procedures that are appropriate to averaging the material properties of the analysed area. This sample of material is often referred as a Representative Volume Element (RVE) (Amirmaleki et al., 2016; Soni, Singh, Mitra & Falzon, 2014; Trzepieciński, Ryzińska, Biglar & Gromada, 2017; Frącz & Janowski, 2016).

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Several years ago, calculations about material homogenization could be performed by making appropriate experiments and trials based on existing material sample, or by using analytical methods, which have relatively strong constraints and often fail to provide adequate results. Recently the possibilities of simulating the numerical microstructural behaviors in 3D have been developed in order to obtain more accurate results and consequently, more accurate determination of material properties (Pierard, LLorca, Segurado & Doghri, 2007). These numerical simulations can significantly reduce the number of time consuming and costly experiments with carefully produced samples of material. This should improve the development and design of new materials for modern engineering applications.

Research on the properties of composites based on averaging has been ongoing for many years. Estimates of structural properties have been made based on number of assumptions about internal phenomena in the microstructure of the material. Works of Maxwell (Maxwell, 1867, 1873) and Rayleigh (Rayleigh, 1892) were to describe the general macroscopic properties of materials consisting of a spherical particle reinforced in matrix. As far as Voigt (Voigt, 1889) is concerned, it is one of the precursors of early prediction of the effective mechanical properties of heterogeneous materials. Voigt assumed that the field of deformation in the bulk sample of heterogeneous material was homogeneous, leading to a fairly effective definition of the generalized properties of the material. Over the next decades some important assumptions developing the possibilities of homogenization methods have been developed. The main assumption of the Eshelby (Eshelby, 1957) model is based on the concept of self-deformation, which is used to determine the solution of the single-inclusion problem placed in the infinite matrix of the material under uniform external load. The result of this type of assumption is not largely error-free, however, the difficulty of solving this problem is relatively small and the model itself is easy to use. It was the basis for the development of many approximation methods of homogenization, based on the calculation of the interaction between the inclusion of specific geometry and the matrix.

An example of the most popular model of homogenization is Mori-Tanaka model (Mori & Tanaka, 1973). The general assumption of the model is based on the approximate solution of Eshelby. It has been assumed that the strain concentration tensor relating the volume average of strain over all inclusions to the mean matrix strain is directly the strain concentration tensor of the single inclusion problem. This formulation is presented by:

$$B^{\varepsilon} = H^{\varepsilon}(I, C_0, C_1) \tag{1}$$

where: B^{ε} – strain concentration tensor,

H^{ε} – single inclusion strain concentration tensor,

C_0 – matrix stiffness,

C_1 – inclusion stiffness.

The area is infinite and considered to the average matrix strains in the current RVE as the far field strain. This led Benveniste (Benveniste, 1987) to the advanced interpretation of the Mori-Tanaka model – any inclusion in RVE is interpreted as an individual inclusion in the polymer matrix.

The efficiency of this model is very high in predicting the properties of biphasic material to about 25% of inclusions content (*e-Xstream engineering*, 2016).

It was noted that Mori-Tanaka model has additional formulation. For in-elastic composites, e.g., elasto-plastic type the tangent operator for each phase is calculated with the volume average of the strain field in the phase. This received value is described as the first statistical moment of the per-phase strain field. In second-order homogenization not only first but second moment of each phases strain field were used. The second moment is connected to the variance. The latter improves the statistical information in relation to only a simple mean value. Hence it is often expected better predictions value using second-order instead of first-order homogenization.

The second order theory brings some correction when three conditions are received:

– fiber is reinforcement,
– it was established high stiffness contrast between matrix and fibers,
– the elasto-plastic matrix is characterized by small strengthening.

Otherwise, no important differences are received between the predictions of first- and second-order homogenization method (Lagoudas, Gavazzi & Nigam, 1991, Mercier, & Molinari, 2009).

The Double inclusion model was formulated by Nemat-Nasser and Hori (Nemat-Nasser & Hori, 1993) The main premise is that each inclusion (I) (of C_1 stiffness) is surrounded in its close environment (I_o) with matrix (of C_0 stiffness), while outside those place there is a reference medium (of C_r stiffness). Simply put, RVE of composite is swapped with a composite model made of imaginary reference matrix (of C_r stiffness) in which are placed inclusions (of C_1 stiffness) surrounded with a material of matrix (of C_0 stiffness).

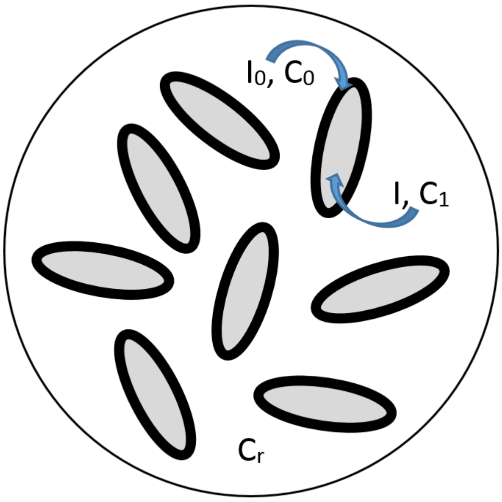

Fig. 1. The idea of Double Inclusion model

Interpolative Double Inclusion model (Lielens, 1999) is determined by the following strain concentration tensor connected with the mean strain over the inclusions to its equivalent over the matrix:

$$B^{\varepsilon} = [(1-\xi(v_1))(B_l^{\varepsilon})^{-1} + \xi(v_1)(B_u^{\varepsilon})^{-1}]^{-1} \tag{2}$$

where: B_l^{ε} – strain concentration tensor for Mori-Tanaka model ($B_l^{\varepsilon} = H^{\varepsilon}(I, C_0, C_1)$)

B_u^{ε} – strain concentration tensor for inverse Mori-Tanaka model ($B_u^{\varepsilon} = H^{\varepsilon}(I, C_1 C_0)$)

$\xi(v_1)$ – interpolation function.

Interpolation function was simplified to quadratic formulation:

$$\xi(v_1) = \frac{1}{2} v_1 (1 + v_1) \tag{3}$$

where: v_1 – volume fraction for inclusion.

For two-phase composites with linear elastic strength characteristic this model usually gives good predictions of the properties, over all ranges of pa-rticles volume content, aspect ratios and stiffness contrasts.

The limitations encountered with the use of analytical homogenization methods require additional calculation methods. Therefore, in recent years numerical methods of direct calculation of effective material data have become increasingly numerous and significant (Bendsøe & Kikuchi, 1988). Most of these methods are only developed with respect to the linear strain range – the range of small deformations. Due to the growing calculating power of computers, several methods have been developed to predict the nonlinear behavior of composite material. Numerical calculations can be performed in 2D space, where discretization is most often used to divide the area into triangles. This solution allows to calculate the values that appear in the cross section of material. However, there are some constraints resulting from the specificity of the solution to the problem (e.g. flow direction only penetrating the modeled surface, etc.) (Abdulle, 2013; Bouchart, Brieu, Kondo & Abdelaziz, 2007). Due to the advancement of computer technology in most recent years, more simulation packages are equipped with the ability to solve 3D problems. Discretization usually consists in dividing the area into tetrahedrons finite elements (FE). Such modeling is devoid of the fundamental limitations of 2D technology but is much more demanding in terms of memory and computing power. One of the main types of FE used in microstructural calculations are Voxel finite elements (Doghri & Tinel, 2006). These type of finite elements are regular, incompatible set of brick elements. Each element is assigned to the phase material where its center is located. It is targeted for advanced RVE where discretization is difficult to reproduce the shape of matrix and analyzed inclusions.

In this work calculations for predicting the properties of WPC composites using mainly analytical homogenization methods, i.e. Mori-Tanaka (first and second order) model, Nemat-Nasser and Hori model and the numerical homogenization were performed using Digimat software.

2. EXPERIMENT

The research material was wood-polymer composite (WPC). It consisted of a Moplen HP648T polypropylene as polymer matrix and Lignocel C120 wood fibers (WF), with L/d = 10. The percentage of wood fiber in composite was 10% vol. The composite was extruded using a Zamak EPH-25 single screw extruder (Fig. 2) and then granulated. The resulting granulate was injected into a mold cavity by means of Dr Boy 55E injection molding machine. The specimens for uniaxial tension test, acc. to EN ISO 527-1 were manufactured in this way. The uniaxial tensile test was performed using Zwick Roell Z030 testing machine. Ten specimens were tested at speed of 50 mm/min according to PN-EN ISO 527 standard. The obtained stress-strain characteristic was used as a verification criterion for further numerical analysis.

3. CALCULATIONS

Fig. 2. Manufacturing of WPC composites: 1 – Zamak EPH-25 extruder, 2 – cooling bath, 3 – granulator

The composite properties prediction studies were carried out using DIGIMAT 2017 commercial code. The DIGIMAT MF module of this software was used for calculations using analytical homogenization models. This software allows to make calculations using different models including Mori-Tanaka (first and second order) and Double Inclusion model (Nemat-Nasser and Hori model). For the analysis, data for matrix and fibers have to be introduced. For the proper description of the matrix, experimental data from uniaxial tensile test (Tab. 1, Fig. 3) were introduced and the elasto-plastic model with isotropic symmetry was chosen.

Tab. 1. Chosen properties of the polymer matrix

Property	Value/unit
Density	900 kg/m^3
Young's modulus	1600 MPa
Poisson's ratio	0.39
Yield stress	17
K	19.277
n	0.294

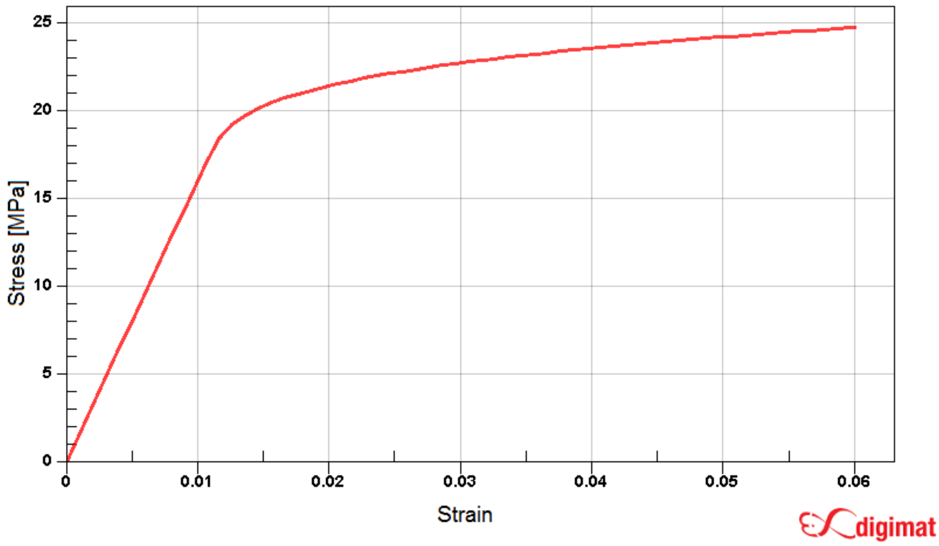

Fig. 3. Stress-strain characteristics for Moplen HP648T polypropylene matrix (elasto-plastic range)

In addition, the data of wood fibers properties – (Tab. 2, Fig. 4) were introduced. They were determined on the basis of literature (Frącz & Janowski, 2016). An elastic mechanical model with transversally isotropic symmetry was selected. In addition, an important step in the preparation of the analysis was to define the geometric parameters of the fibers: the fiber orientation tensor and the l/d ratio. The percentage of wood fiber in polymer matrix was defined as 10%.

Tab. 2. The selected properties of analysed wood fibers

Property	**Value/unit**
density	2000 kg/m^3
Young's modulus E1	10000 MPa
Young's modulus E2	10000 MPa
Poisson's ratio v12	0.3
Poisson's ratio v21	0.3
Shear modulus	3846 MPa

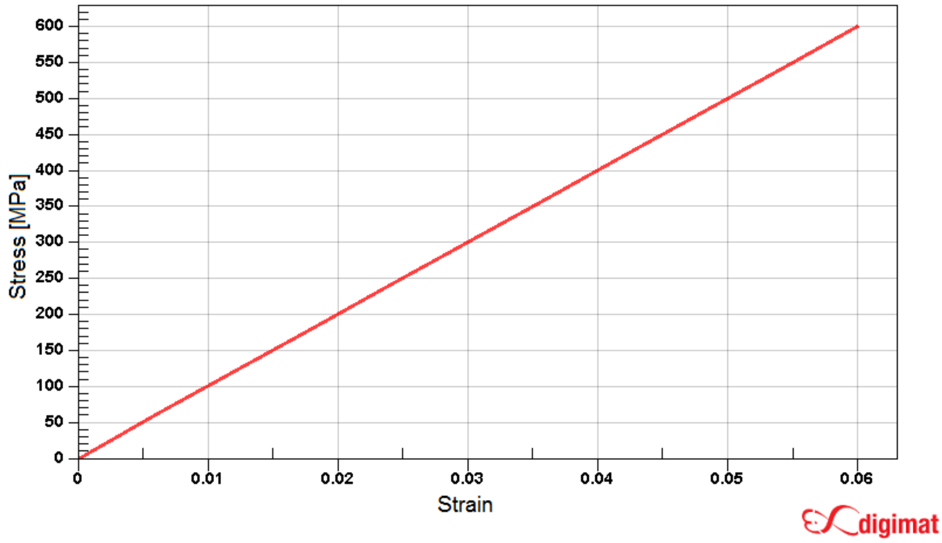

Fig. 4. Stress-strain characteristic for wood fiber (elastic range)

In order to carry out the numerical homogenization using the DIGIMAT FE software, the data about fiber orientation, distribution and geometry in RVE (Tab. 3) were introduced. To describe the adequate shape of the fibers, a curved cylinder geometry was selected which describes well the actual shape of the wood fiber in real conditions. The RVE dimensions were large enough to determine the actual distribution of fibers in the polymer matrix, but also small enough to make good calculations. The RVE with placed fibers in the polymer matrix according to the preset orientation tensor was discretized using 250 thousands finite elements of Voxel type (Tab. 3). The visualization of RVE before and after discretization was shown in Fig. 5.

Tab. 3. The input data for micromechanical analysis using Digimat FE software

Fiber diameter	0.01 mm
Fiber length	0.1 mm
The ratio of length to fiber diameter (L/D)	10
Fiber volume content	0.106445
RVE dimensions	0.2x0.1x0.1 mm
The amount of FE type Voxel in RVE	250 000
The orientation tensor values: a[1,1] a[2,2] a[3,3]	 0.73 0.18 0.09

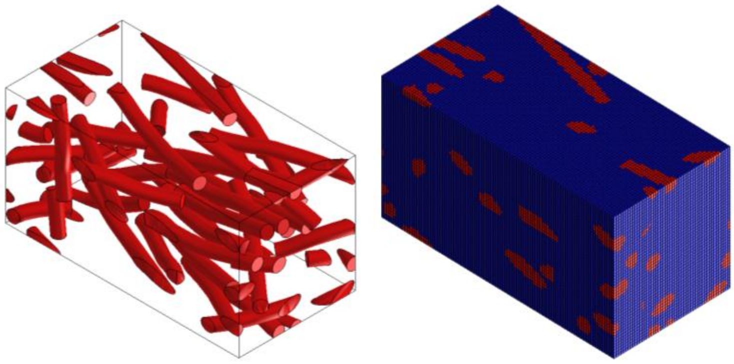

Fig. 5. The visualization of fibers (with curved cylinder geometry) distribution in RVE for defined orientation tensor value: before (left) and after (right) discretization

3. RESULTS ANALYSIS

One of the most important results is the stiffness matrix. It can be noted that the obtained stiffness matrix using the Mori-Tanaka homogenization model has the same value for the first and second order models (Fig. 6). Furthermore, in the case of stiffness matrix using a numerical model, the matrix was filled in all cells, indicating a slight numerical error.

a)

	11	22	33	12	23	13
11	3755.2	2317.2	2290.5	0	0	0
22	2317.2	3584.1	2270	0	0	0
33	2290.5	2270	3558.8	0	0	0
12	0	0	0	644.4	0	0
23	0	0	0	0	647.49	0
13	0	0	0	0	0	628.5

b)

	11	22	33	12	23	13
11	3755.2	2317.2	2290.5	0	0	0
22	2317.2	3584.1	2270	0	0	0
33	2290.5	2270	3558.8	0	0	0
12	0	0	0	644.4	0	0
23	0	0	0	0	647.49	0
13	0	0	0	0	0	628.5

c)

	11	22	33	12	23	13
11	3771.1	2328.1	2301.2	0	0	0
22	2328.1	3597.2	2281.2	0	0	0
33	2301.2	2281.2	3571.5	0	0	0
12	0	0	0	645.62	0	0
23	0	0	0	0	648.24	0
13	0	0	0	0	0	629.27

d)

	11	22	33	12	23	13
11	3851.07	2378.55	2320.42	18.6963	3.56373	4.72553
22	2378.41	3648.28	2288.18	27.4198	9.20855	15.4909
33	2318.58	2287.02	3672.57	18.3458	2.55344	-1.79352
12	1.7039	1.67646	2.73226	661.937	12.3035	-2.06523
23	-1.04414	-0.60794	-0.590882	10.7581	665.909	2.7773
13	6.43266	9.87309	6.18807	-1.23184	2.7086	619.035

Fig. 6. Stiffness matrices for WPC composite with 10% WF: a) Mori-Tanaka homogenization model (1st order), b) Mori-Tanaka homogenization model (2nd order), c) Nemat-Nasser Hori homogenization model, d) numerical homogenization

In addition, composite strength data were obtained after homogenization in the elastic range (Tab. 4). It was noted that the Mori-Tanaka models of first and second order give the same results. Very good compatibility was obtained in results of all analytical homogenization methods. The results of calculations using numerical homogenization method are quite different from them.

Tab. 4. Received data (in elastic range) for variable type of homogenization

	Mori-Tanaka (1st order)	Mori-Tanaka (2nd order)	Nemat-Nasser and Hori	Numerical homogenization
Density	1001 kg/m^3	1001 kg/m^3	1001 kg/m^3	1006 kg/m^3
Young's modulus E1	1937.7 MPa	1937.7 MPa	1944.1 MPa	1994.0 MPa
Young's modulus E2	1814.8 MPa	1814.8 MPa	1818.2 MPa	1857.9 MPa
Young's modulus E3	1821.1 MPa	1821.1 MPa	1824.4 MPa	1940.1 MPa
Poisson's ratio v12	0.4008	0.4008	0.40105	0.41989
Poisson's ratio v21	0.37358	0.37358	0.37507	0.39134
Poisson's ratio v13	0.38797	0.38797	0.38817	0.37021
Poisson's ratio v31	0.36462	0.36462	0.36426	0.35976
Poisson's ratio v23	0.39624	0.39624	0.39841	0.37574
Poisson's ratio v32	0.39761	0.39761	0.39841	0.39237
Shear modulus G12	644.4 MPa	644.4 MPa	645.6 MPa	661.7 MPa
Shear modulus G23	628.5 MPa	628.5 MPa	629.3 MPa	665.7 MPa
Shear modulus G13	647.5 MPa	647.5 MPa	648.2 MPa	618.9 MPa

One of the most important results of strength data is the stress-strain characteristic from uniaxial tensile test. The characteristics obtained from the experiment stress-strain were compared with the results of the homogenization calculations. It was noted that the worst compatibility with the experiment gives the characteristic calculated using numerical homogenization (Fig. 7, Tab. 5). Analytical methods of homogenization give much more compatibility of results. For the analyzed value of 0.1 strain, the greatest compatibility of the stress-strain results was found for the numerical homogenization model (12.5% of the relative error). Such a high relative error value (relative to the experiment) is due to an assumed elastic-plastic model for the polymer matrix which does not fully reflect the viscoelastic nature of the polymer. It should be noted, however, that the scope of the analysis concerns very small values of the strain. A more significant and interesting result is the relative error of stress values for the strain of 0.3 and 0.5. For the value of 0.3, the lowest relative error value for the Nemat-Nasser and Hori model was obtained (relative error was 1.08%). Moreover, for strain 0.05, the highest compatibility of the stress values with the experiment was obtained for the Mori-Tanaka (second order) homogenization model (relative error value was only 0.27%). It should be noted that the Mori-Tanaka homogenization models of first and second order definitely gives different results in calculating the stress-strain characteristics above 0.01 strain. This is due to the fact that these calculations were in elastic-plastic range.

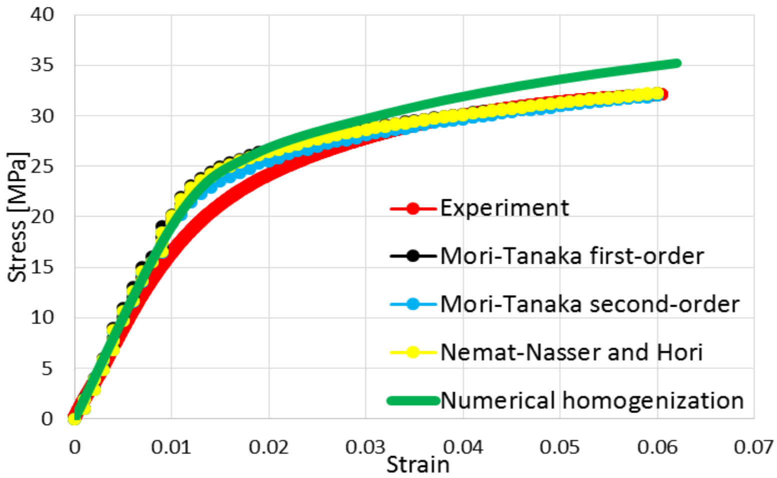

Fig. 7. Stress-strain characteristic for WPC composite with 10% WF for different homogenization models

Tab. 5. Relative errors calculated for individual homogenization methods at fixed strain value

Strain	Homogenization methods (relative to the experiment)			
	Mori-Tanaka (1st order)	Mori-Tanaka (2nd order)	Nemat-Nasser and Hori	Numerical homogenization
0.01	17.73%	21.23%	17.22%	12.50%
0.03	2.88%	3.15%	1.08%	6.84%
0.05	0.28%	0.27%	1.28%	6.98%

4. CONCLUSIONS

1. WPC composite properties were predicted using analytical and numerical homogenization methods. For this purpose, it was important to introduce the strength and geometry data of the fiber and matrix.
2. In the case of numerical homogenization, an additional significant step was the design of RVE that reflected the heterogeneous structure of the composite.
3. It was noted that the stiffness matrix calculated using the numerical model of homogenization was filled in all cells, indicating that occurred small numerical errors.
4. It can be noted that the results of calculations based on the first and second order Mori-Tanaka models are very similar up approx. 0.01 strain. Only in the case of the obtained stress-strain characteristics the results are different. This is most probably due to the fact that at this stage the analysis was considered in the area of larger deformations (elasto-plastic range).

5. For all types of analytical homogenization, there is a relatively good agreement between the results of the calculations and the experimental results. It is most likely caused that the analyzed composite contained only 10% vol. of inclusions. With such a fiber content in the polymer matrix, analytical models such as the Mori-Tanaka model gives a high degree of compatibility between the results of the calculation and the experiment.

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CREATING MARKETING KNOWLEDGE ABOUT THE CONSUMER IN THE CONTEXT OF THE DEVELOPMENT OF INTERNET TOOLS

Abstract

The aim of the article is to present marketing knowledge about the consumer as an enterprise resource and the role of marketing research in expanding it in the context of progressive virtualization of social life and the development of Internet tools. The current article was written on the basis of an in-depth literature study and an analysis of the selected results of quantitative research conducted in 2013 on a sample of 152 enterprises.

1. INTRODUCTION

Managing a contemporary enterprise requires skillful application of the development of information and communication technologies in the processes of producing knowledge, which is currently becoming the key resource of the company. It is related to shaping organizational culture in which knowledge is a significant value, as well as to motivating people to become knowledge workers through exploiting the potential of new Internet tools. As a consequence, it should translate into synergy between talent and Internet technology, whose application in knowledge management is constantly developing, which is manifested in the instrumental, functional as well as procedural dimension.

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Taking into consideration situating the consumer in the center of business models, it needs to be pointed out that there is a need to continually collect data and produce knowledge about their behavior and changing preferences, motivations, moods, respected values, lifestyles and criteria of choosing the increasingly individualized products purchased online and in traditional stores. It means that in the structure of knowledge resources, a significant role is played by marketing knowledge.

The aim of the article is to present marketing knowledge about the consumer as an enterprise resource and the role of marketing research in expanding it in the context of progressive virtualization of social life and the development of Internet tools. The basis of preparing this article was a literature study and empirical research conducted as part of a project entitled "The Internet in marketing and the application of new technologies in managing cooperation between a company and its clients." The methodology of the research and selected results are presented in the current article. Achieving the formulated objectives also required considering the development of the software which produces knowledge as an enterprise resource, as well as presenting the significance of marketing research, including online research, in the processes of producing knowledge about the consumer.

2. THE DEVELOPMENT OF SOFTWARE WHICH PRODUCES KNOWLEDGE AS AN ENTERPRISE RESOURCE

The category of knowledge is currently becoming the key resource of companies, a resource which requires effective management in order to gain long-term competitive advantage. As a consequence, the objective of the strategy in this respect is creating favorable conditions for producing and developing knowledge, as well as disseminating it, employing it in solving decision problems and protecting it. Knowledge resources constitute the basis of improving and modernizing the processes taking place in an enterprise, as well as the goods and services offered by the company. It needs to be stressed that producing knowledge is the basic area of activities for some enterprises. It is due to e.g. the tendency to outsource marketing research and growing expectations of research agencies, which are not only to supply marketing research users with data and information, but also with accurately profiled knowledge. One of the tools of knowledge management is a two-dimensional competence matrix, which is created on the basis of the competitiveness of knowledge resources and the extent of using knowledge. Figure 1 also presents recommendations for particular types of competence ensuing from the matrix.

		The extent of using knowledge	
		small	large
The competitiveness of knowledge resources	high	unused competences ↓ identified and used	unique competences ↓ protection, broader use
	low	irrelevant competences ↓ outsourcing	basic competences ↓ preservation, development

Fig. 1. Competence matrix as a knowledge management tool (Probst, Raub & Romhardt, 2002, p. 66)

The importance of IT solutions in knowledge management is pictured by the pyramid of IT support for business decisions, which encompasses the technology of databases, data mining and Business Intelligence, which serves the purpose of conducting business analyses and indicating direct decision-making solutions (Trajer, Paszek & Iwan, 2012).

From the point of view of the applicative nature of knowledge and the need for transforming tacit knowledge into explicit knowledge, a significant role is played by the visualization of knowledge, which can take various forms, from structured text and charts, pictures, heuristic sketches, conceptual diagrams, visual metaphors, knowledge maps, to interactive visualizations and animations (Eppler & Burkhard, 2007).

The development of marketing knowledge about the consumer is influenced by the virtualization of customers' behavior, which means that the buyer's whole decision process, consisting in recognizing a given need, looking for information, comparing variants of offers, the purchase and the evaluation of the choice one has made can take place online. It is accompanied by the development of software which measures consumer behavior on the Internet.

One challenge related to measuring consumer behavior online is that presently there are many various types of devices which can be connected to the Internet. There is a need for measuring the behavior of users of various devices and platforms in a situation when there are difficulties with unambiguous identifiers which allow for registering the continuity of such behavior. A certain solution of this problem is independent measurement on different platforms with a calibration panel (a measuring application on every device of a given user), which allows for data integration through data fusion and mathematical algorithms (Pliszka, 2017).

Due to the quickly growing amount of digital information and the dynamic development of the technology which analyzes databases, attention needs to be drawn to big data. This category is described with 5Vs (volume, velocity, variety, value and veracity), or big amounts of data, their changeability, diversity, value related to the need of verifying data and credibility. It is worth adding that while initially the object of analyses in enterprises was what was taking place in the area of the supply chain and finances, and, subsequently, the analysis of sales and customers gained significance, currently, in order to create competitive advantage, enterprises strive to conduct demand forecasts and to personalize offers (Bulska, 2015).

Taking into account the development of Web 2.0, which makes consumers participate more and more actively in creating contents and contribute to creating the Internet culture, it needs to be pointed out that sentiment analysis is employed in producing knowledge about the consumer. Such analysis concerns "soft," disorganized streams of information. Its objective is to identify the consumer's attitude to the product, idea, a specific value or another analyzed issue. In this analysis, natural language processing and analytical techniques are employed. It allows for identifying certain regularities in written statements and monitoring their tone. More advanced analyses can also determine the level of unambiguousness and the strength of the statement (Paharia, 2014).

Due to exponentially and continuously increasing data, a need is felt to devise algorithms which would select significant information from a set of data and construct models of behavior of customers who are of key significance from the point of view of the conducted marketing activities. The value of such solutions, which also refer to the achievements from the area of artificial intelligence, is reflected in creating the foundations for predicting future customer behaviors, reinforcing the positive ones and preventing the negative ones (Rowecka & Wojtasik, 2016).

The development of software leads to the growing significance of the idea of excellence based on data. It is related to employing artificial intelligence. Its use requires determining the scope of decisions which remain within the competence of talented employees, and those which are left to autonomous algorithms. The anthropomorphism-based models of employing artificial intelligence in making decisions are presented in Table 1. It means that artificial intelligence can play the role of an autonomous strategic advisor, an independent outsourcer, an employee or a manager making decisions.

At the same time, it should be observed that 5% of jobs could become entirely automatized, while in the case of over a half of all jobs computerization and robotization could contribute to a situation in which almost one third of human responsibilities could be taken over by machines (Chui, Manyika & Miremadi, 2015). It concerns not only production and customer service, but also management and marketing.

Tab. 1. Anthropomorphism-based models of employing artificial intelligence in business

The type of a model of artificial intelligence	Description
Autonomous strategic advisor	Autonomous algorithms evaluate and make recommendations basing on the data; however, the decision about what needs to be autonomized and how to implement these decisions is left to the employees who supervise the algorithms. In this model, data analysts perform the function of an intermediary between the senior management supervising autonomous software and those areas of the company in which algorithms have been implemented.
Autonomous outsourcer	In this case, algorithmization takes the form of outsourcing business processes with all its advantages and disadvantages. Data analysts are project managers in this model.
Autonomous employee	For this solution, it is characteristic that software is treated as a "co-worker" who supplies the correct answer. The model of machine learning does not constitute a static fragment of the code, but there are new data introduced into it. The role of data analysts is to eliminate tensions created between the man and the machine.
Manager making decisions	In this model, human leadership gives way to the power of algorithms, and the role of employees is to expand the boundaries of the effective autonomy of algorithms. In companies which implement this model of artificial intelligence, machines perform transactions and make investments which people do not comprehend in the cognitive sense. They also make justifications and produce narratives which explain the decisions they make to people.

Source: Based on: (Schrage, 2017, p. 100–105).

3. THE SIGNIFICANCE OF MARKETING RESEARCH IN PRODUCING KNOWLEDGE ABOUT THE CONSUMER

Rapid technological changes in producing, storing and using information and knowledge, as well as in sharing them, make them more accessible for employees of enterprises and consumers alike. Meeting the challenges of the modern market requires employees to have interdisciplinary knowledge and cooperate with customers in order to satisfy their increasingly sophisticated needs through using information in an innovative way and producing new knowledge from already existing knowledge. Moreover, it should be observed that there is a shift in the significance of the sources of knowledge, which is produced more and more often as a result of network forms of cooperation with consumers and partners (Morawski, 2006).

The development of the Internet leads to expanding market space, accompanied by consumers transferring various types of activities from the physical sphere to cyberspace and the increasing role of the consumer through their active participation in creating values within networks. Among the reasons for customers' interest in co-creating values, individualization of consumers' behavior needs to be indicated, as well as their search for new forms of social integration and their desire to be innovative in different areas of life. Moreover, the development of the ways in which the Internet can be applied leads to the transition from "push" business models and solutions, consisting in adapting the offer with regard to the identified needs of customers, to the "pull" model, whose essence lies in customers' high activity in initiating new solutions which develop the market offer.

It all implies new challenges for marketing research. Creating a detailed image of every customer which would help predict their future behavior requires obtaining data from various sources, including data about the customers which can be recorded as their behaviors are being monitored, as well as collected with their active, conscious participation.

Conducting classic marketing research contributes to a better understanding of consumer behaviors and the factors which shape them, but it is based on declarations solely. On the other hand, automatized measurements which provide hard data are at risk of certain underestimation, resulting from e.g. browser cache, firewalls which often ascribe a single IP address to many different users, as well as overestimation related to the functioning of the so-called web crawlers or frames dividing a website into parts which are counted as separate page views. It means that building in-depth knowledge about customers requires employing automatized measurements, marketing intelligence, as well as qualitative and quantitative marketing research, including online research.

Taking into account the functions of the Internet, including the informative, communicative and social function, as well as its interactivity as a medium, one should refer to the sociological view of production, development, dissemination and application of knowledge. According to this approach, relationships between individuals and groups are a plane of creating knowledge. It means that producing knowledge requires shaping new relationships and managing the ones which already exist (Mikuła, Pietruszka-Ortyl & Potocki, 2002). The process of creating knowledge takes place in two interrelated loops, the first of which stands for individuals learning on the basis of the obtained information, and the second – social learning based on mutual transfer of information thanks to relationships between people (Golińska-Pieszyńska, 2009). It also concerns the relationships between researchers and consumers who participate in marketing research as respondents.

In the processes of producing knowledge in the virtual environment, an important role is played by marketing research, whose application in reference to the loop of individual and social learning is presented in Figure 2.

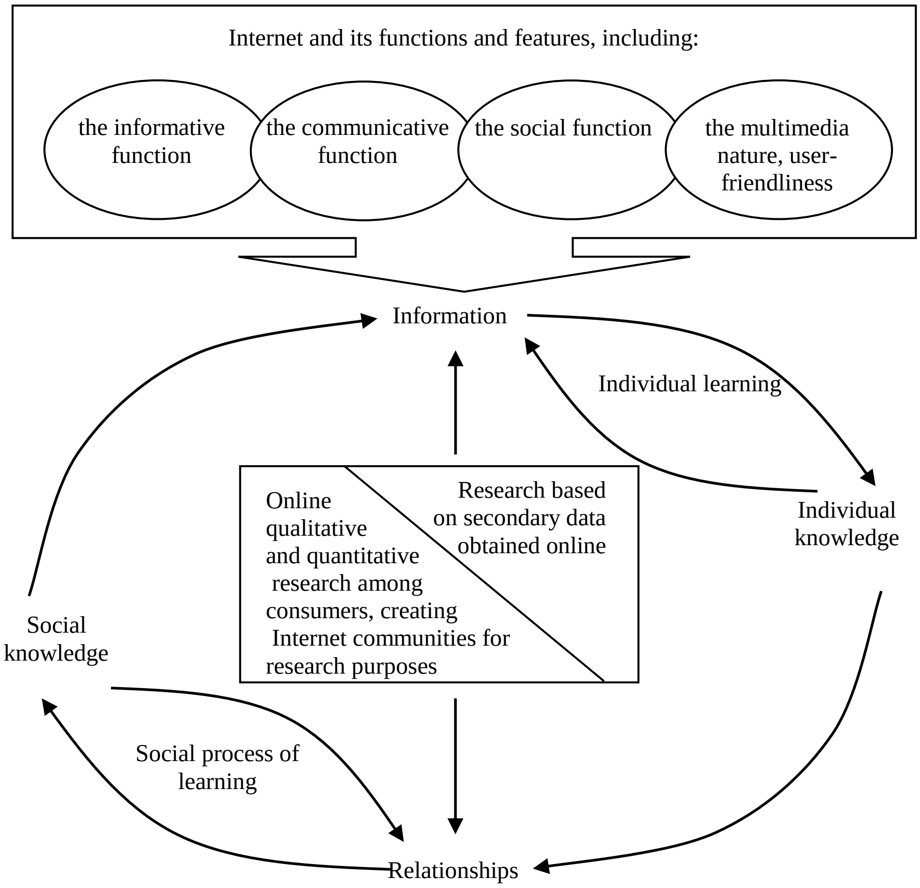

Fig. 2. Online marketing research in producing knowledge - the sociological dimension (authors' own study using: (Sawhney & Prandelli, 2000, p. 27)).

The complexity of modern market processes and consumer behavior leads to the need for employing the idea of triangulation (Flick, 2011), including triangulation of data and their sources as well as methods in order to produce marketing knowledge about the consumer using Internet tools.

At the same time, it should be stressed that a change in the area of marketing research, caused by the increasing extent of the virtualization of social life, is that not only the existing Internet communities are used in marketing research, but also new ones are created for research purposes. Adopting a perspective in which respondents are members of Internet communities results in the research process also encompassing the interactions which occur between them. It is related to replacing the "top-bottom" model of communication, or between a researcher and a single respondent, with the "bottom-bottom-top" model, concerning mainly the interactions between the participants of the study. In this case, the role of the researcher does not lie in guiding the discussion, but in inspiring its participants and listening to their statements (Mróz & Feldy, 2010; Cooke & Buckley, 2008; Smith, 2009).

At this point, a question arises concerning the usefulness of opinions expressed by consumers in producing marketing knowledge for policy makers in different types of enterprises. A quantitative study was conducted in search for the answer to this question. The most important information about this study and its organization is presented below.

4. THE METHODOLOGY OF THE EMPIRICAL STUDY

The empirical study was of quantitative character and was conducted as part of a project entitled "The Internet in marketing and the application of new technologies in managing cooperation between a company and its clients" (project manager: Prof. Krystyna Mazurek-Łopacińska, Ph.D.; the main researcher: Magdalena Sobocińska, Ph.D.). It was conducted in 2013 on a nationwide sample of 152 enterprises, including 51 companies with up to 49 employees, 51 companies with between 50 and 200 employees and 50 companies with over 200 employees. The study concerned managers responsible for employing the Internet in marketing activities or for establishing and maintaining relationships between the company and the customers using new technologies. With the professional character of the research in view, interviews using a standardized questionnaire, after a pilot experiment, were conducted in the CATI studio of ARC Rynek i Opinia Research Institute in Warsaw. Telephone numbers to the respondents were rendomly selected from a database of enterprises.

5. USEFULNESS OF CUSTOMERS' OPINIONS FOR ENTERPRISES IN THE LIGHT OF THE RESULTS OF THE QUANTITATIVE STUDY

In the era of the development of the Internet, customers are given more and more possibilities to express their opinions, which can provide an impulse to consider introducing changes to an enterprise's offer. It should be stressed that customers' opinions and remarks are perceived in the studied enterprises mainly as a source of information about the recipients' impressions and their reactions to the conducted marketing activities. Such a significance from the point of view of the enterprise is given to customers' opinions and suggestions by 37.5% of the studied managers (see Table 2).

Tab. 2. Usefulness of customers' opinions for enterprises

The size of the enterprise / The manner of perceiving opinions	Companies employing up to 49 persons	Companies employing from 50 to 200 persons	Companies employing over 200 persons	Total
Customers' opinions only provide tips for improving the features of the offer	25.5%	25.5%	38.0%	29.6%
Customers' opinions contain interesting ideas and suggest-ions concerning the fundamen-tal features of the offer	17.6%	19.6%	6.0%	14.5%
Customers' opinions express their dissatisfaction and are a basis for complaint	2.0%	2.0%	6.0%	3.3%
The opinions are a source of information about customers' impressions and reactions to marketing activities	31.4%	39.2%	42.0%	37.5%
Customers' opinions are not significant for creating the offer	23.5%	13.7%	8.0%	15.1%
Total	100 %	100 %	100 %	100 %

Source: Authors' own study on the basis of a questionnaire study (CATI)

Taking into account the increasing possibilities of exploiting customer potential in the processes of creating innovation, it should be observed that almost every second studied manager (44.1%) perceives the remarks and suggestions voiced by the customers in the context of useful ideas and hints concerning changes in the offer of the enterprise. 14.5% of the managers assess them as interesting and valuable suggestions concerning changes of the fundamental features of the offer, and 29.6% of the respondents state that these suggestions could improve features of the offer. It should be seen as a positive fact that a small percentage (3.3%) of policy makers in different types of enterprises who participated in the research believe that customers' opinions and remarks are mainly an expression of their dissatisfaction and as a consequence they are a basis for complaint. The failure to see the opportunities provided by the demand models of innovation is also attested by the fact that 15.1% of the studied managers believe that customers' opinions and remarks have not so far been significant for creating the offer of the enterprise. It should be stressed, however, that managers' opinions are diversified in the cross-section of the size of enterprises they represent. Policy makers from bigger companies indicate that customers' opinions do not play a significant role in creating the offer less often than the representatives of smaller market subjects.

Taking into account the aim of the present article, it should be noted that the Internet serves more to develop the subsystem of marketing research than to conduct quantitative and qualitative marketing research online. It is attested by the fact that while 86.2% of the studied enterprises look for reports or press publications online, only 5.9% of the studied policy makers state that they conduct research using the Internet on relatively large samples, and 9.9% carry out qualitative studies online.

Moreover, the results of another study indicate that the potential of the Internet is not fully exploited in the marketing activities carried out by Polish enterprises and in producing knowledge about the consumer. It leads to the conclusion that although enterprises attach more and more importance to modern informative-communicative technologies, they fail to sufficiently employ different types of software which supports marketing (Kapera, 2014).

The image presenting the significance ascribed to the consumer in meeting the goals of enterprises which emerges on the basis of the conducted empirical research and literature studies leads to the conclusion that enterprises operating on the Polish market more often carry out standard marketing activities in which the purchaser plays the role of their addressee then employ the Internet to engage the recipient in creating values within networks. Moreover, the results of the authors' quantitative research indicate that only every second studied market subject has a strategy of the company's presence in the Internet, which is an expression of adopting an integrated, holistic and planned approach to the virtualization of marketing and the production of knowledge about the customer.

6. SUMMARY

Enterprises which can produce, obtain and transfer knowledge, as well as adapt their strategies and operational tactics to new information, are described as learning organizations. The basis of these activities is:

- a systemic approach to problem solving, which requires diagnosing problems to be based on scientific methods, and not on guesswork, and on the data processed using tools for statistical data instead of speculations,
- experimenting, understood in the context of searching for new knowledge and verifying it with the use of scientific methods,
- drawing conclusions from one's own experiences,
- taking into account good solutions originating from the outside by employing the technique of benchmarking and looking for inspiration in other lines of business, as well as by observing customers and obtaining information from them,
- transferring knowledge (Garvin, 1993).

Formulating the conclusion, we need to stress that in spite of the new possibilities for knowledge management created by the development of Internet tools, the significance of people and cultural conditioning cannot be overlooked. Moreover, it is significant to appreciate both quantitative and qualitative aspects, as well as to take into account the fact that knowledge management is a dynamically changing system of organization (Dalkir, 2005).

The evolution of management models is expressed in a transition from administering databases, managing data and information to managing knowledge, including the knowledge about the consumer as a unique resource of the enterprise. The greater the extent to which knowledge resources about consumers fulfill the criteria conditioning the permanence of competitive advantage is, the greater their value, since as a consequence they make it possible to create new ideas and new sources of values. Moreover, they should be difficult to acquire and imitate, as well as complementary and permanent (Amit & Schoemaker, 1997). In creating knowledge resources about the consumer, an important role is played by qualitative and quantitative marketing research, including online research, which makes it possible to launch social processes of learning from consumers. Striving to obtain in-depth marketing knowledge, one needs to employ triangulation of methods and integrate the methods of automated measurement with studies based on the opinions expressed by the consumers.

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