International Journal of Mechanical Engineering and Technology (IJMET)
Volume 8, Issue 9, September 2017, pp. 378–390, Article ID: IJMET_08_09_041
Available online at http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=9
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

SYSTEM MODEL TOOLING FOR INJECTION MOLDING

Svitlana Sotnik
Department of Computer-Integrated Technologies, Automation and Mechatronics,
Kharkiv National University of RadioElectronics, Kharkiv, Ukraine

Rami Matarneh
Department of Computer Science,
Prince Sattam Bin Abdulaziz University, Al-Kharj, Saudi Arabia

Vyacheslav Lyashenko
Department of Informatics,
Kharkiv National University of RadioElectronics, Kharkiv, Ukraine

ABSTRACT

Optimization of scientific research and the introduction of their results into the real process is the basis for the development of modern production. The solution of such a problem can be achieved by modeling the objects and processes under study. To do this, we consider the process of molding plastic parts under pressure. We formalized the model of technological equipment for injection molding. This allows us to perform static and dynamic modeling of the creation and management of complex structures.

Key words: System Model, Tooling, Injection Molding, Plastic Parts.

Cite this Article: Svitlana Sotnik, Rami Matarneh and Vyacheslav Lyashenko, System Model Tooling For Injection Molding, *International Journal of Mechanical Engineering and Technology* 8(9), 2017, pp. 378–390.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=9

1. INTRODUCTION

Nowadays, one of the essential tasks of modern technological progress is the optimization of ongoing researches and make use of their results in the real world problems, this can be achieved by modeling the studied objects and processes. However, the design of the tooling (TO) and analysis of the stages of its development, as well as other equally important tasks better solved by modeling with the aim of considering the impact of the design features, parameters or stages of the process on the quality of the products. System simulation is a versatile method that can be applied to any systems and tasks [1-3].

The practical significance of this method explores a "not shown" and can be not only a tool of analysis and explanation of the properties of system objects, but also to predict new properties, to be a "prediction tool" behavior and synthesis of systems with predetermined properties.

Plastics are indispensable in many fields of engineering and the modeling tooling for manufacture of plastic components are specific [4-6].

A great variety of geometric forms and dimensions, requirements for dimensional accuracy and accuracy of the mutual arrangement of surfaces, a wide range of polymer materials and the related differences in their technological properties require an individual approach to the design of the equipment, compromise and often unconventional solutions.

The rational system model, and subsequently quality production equipment allows to ensure the required accuracy of dimensions of parts, to the surface without any traces of sprues and ejectors, etc.

In this research, TO implies molding form (MF) for molding plastic parts. Modeling objects, namely, TO describes the position of system approach. The definition of a set of elements, relations between elements, the possible states of each element, essential characteristics of states and the relations between them.

2. MATERIALS AND METHODS

2.1 Literature review on the research topic

The basic principles of the design of tooling for injection molding and its constructive features inherent in the work [7], where there is a full review of all aspects of the process of molding that goes from practical to theoretical, and from elementary to advanced. Describe the key features of computer for the design of plastic parts and most tooling.

The work [8] devoted to new methods and tools to support the design process to get more effective solution when designing tooling (molds). The proposed multidisciplinary structure based on the methodology "Design for six Sigma". Focuses on the platform to support the design of any instrument for the mold without undercuts, which optimizes the design of the equipment.

In [9] analyzed a recent study in the field of mathematical modeling and optimization of the casting process under pressure, the considered optimization methods, which include design of experiments, artificial neural networks and evolutionary algorithms. The article also discusses the optimization study conducted in occurred injecting Molding (IM) process, in respect of certain characteristics associated with this element, as a system of ejection and the configuration of the cooling channel, process conditions, location of intake and balancing the pressure in the forming cavity. Presents current research on the mathematical modeling of the IM process, with an explanation of the process simulations and the benefits of each particular model. Learn how DOE, ANN and EA.

The method of experiments planning (Design of Experiment (DOE)) – a systematic approach to the study of the system or process. DOE includes: analysis of change process; the determination of optimal process parameters; determination of the optimal design process [9-11].

The method of "Artificial Neural Networks" (ANN) is a combination of nonlinear transformations of the input data with the ability to recover the complex non-linear dependencies. Prediction based on the inverse of the error distribution [9, 11, 12].

The method of "Evolutionary algorithms" (EA) is used when finding the optimal solution takes a long time and is quite complex. The efficiency of the evolutionary algorithm depends on the choice of the values of its parameters. Selection of parameters can be carried out before starting the evolutionary algorithm. However, the optimal parameter values may change during the course of the algorithm. Therefore, the required method of adaptive adjustment parameters in the optimization process. The values parameters of the evolutionary algorithm lie in a given interval of values. The task of choosing parameter values discretizing, dividing the range values of the parameter into intervals. Partitioning into intervals may be performed before running the algorithm and does not vary in the course of his work. However, the change in partitioning during the work contributes to the improvement of the algorithm [10, 13].

We can also use image analysis techniques and voice control to robotize the casting process [14-16].

2.2 Modeling tooling

The ultimate goal of design is obtaining the best technical solution among possible alternatives. This is achieved in the process of solving the synthesis problem, which aims at determining the optimal structure and parameters of the object.

In the process of the automated designing and creation of computer aided design the ability of structural-parametric description of the snap-in is essential, as it shows from what units, parts, nodes and how these components interact, what are their weight, dimensional characteristics, which will allow us to generate many alternatives to MF.

Considering parametric modeling to build tooling (shape) by solving the equations that express the geometric relationships with equations that describe the specified dimensions and the relationships between them.

In parametric modeling the build tooling is usually carried out in the following sequence:

1. Construction drawing.
2. Enter interactive mode, geometric relationships, and data on the size of snap.
3. Construction drawing that meets the restrictions and requirements sizes.
4. Steps 2 and 3 are repeated with a change in limits or dimensions until getting the right model.
5. Create a three-dimensional model of a plane figure. The thickness and the angle of rotation can also be dimensional parameters which makes it possible to easily change the created three-dimensional shape if necessary. Form in parametric modeling is changed not directly, but through using geometric relations and dimensions, therefore the designer can develop many alternative projects, not caring about the details, but focusing on functional aspects.

Considering the structural modeling TO is assumed to be the correct organization structure of all the subsystems, which determines the optimal functioning of the entire snap, in general.

The structure of each subsystem may vary depending on internal and external factors of the casting process.

The essence of the relationship well-built the structure of the system with the results of its work.

Let the System Ω – is a finite set of elements (E) and a regulating device (R), which establishes relationships between items (e_i) and transformation management, managing relationships, creating an indivisible unit of function. Topologically, the system shown in Fig. 1 [17].

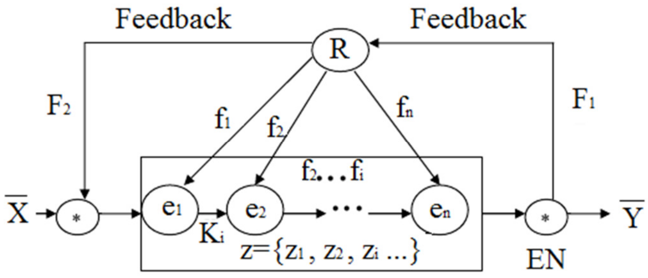


Figure 1 Topological diagram of the system

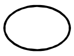
where e_i – the elements of the system, $e_i \in E$,

R – control (regulate) device,

K_i – link to transform the inputs to outputs, $k_i \in K$,

$\overline{X}$ – input (a lot of impact ($x_i \in \overline{X}$)),

$\overline{Y}$ – output (multiple outputs ($y_i \in \overline{Y}$)),

 – a transducer (resolver) that distinguishes input and output from the effects of management (regulation),

f_i – regard for the impact on the system in terms of regulation, $f_i \in f$,

F_i – feedback, transferring the impact on regulation F,

EN – the external environment,

Z – internal resources (internal state) system.

The structure of a simple system can be represented in the form of a vector:

$$F \rightarrow (S_1, S_2, ..., S_k, ...) \Rightarrow \sum_{\Phi}^{J=1} , \qquad (1)$$

where $S_1, S_2, ..., S_k$ – the element of j^{th} subsystem, which can also be system,

J – the hierarchy degree of the system,

Φ – the purpose of the j^{th} subsystem,

F – management subsystems.

A complex system is a system that has a large number of elements ($\|\Omega\| \rightarrow \max$, that is power element set E tends to a maximum), which has a complex goal structure of internal states ($\|\Omega\| \rightarrow \max$), that is a set of resources Z has a maximum power), complex conversion function and the structural system is specified as a multilevel hierarchical system.

Formalization of the calculation of structural parameters of the system Ω can be presented taking into consideration a number of key structural indicators [17, 18] as follows:

1) Complexity – is a metric value, which corresponds to: the number of elements and relations between them C_Ω (structural complexity) and complexity in system functions C_F (the functional complexity), $c = C_\Omega + C_F$ where

$$\left.\begin{aligned} C_\Omega &= (1+\xi\mu)\sum_{i=1}^{m} c_i k_i \\ \mu &= \frac{M}{N(N-1)k(k-1)r\cdot l(r\cdot l-1)} \end{aligned}\right\}, \quad (2)$$

where N – the number of levels in the system Ω,

k – the number of elements in the system level Ω,

r – the number of inputs of the system (average expression),

l – the number of outputs of the system (average expression),

M – the amount of actually implemented in the system Ω,

ξ – the relative coefficient for a functioning system in a real environment,

c_i – the manufacturing element complexity of the i^{th} type,

k_i – the number of elements of the i^{th} type in the system,

m – the number of all elements in the system.

$$\xi = \frac{\text{complexity\_implementation\_links}}{\text{complexity\_implementation\_elements}}. \quad (3)$$

If the system is defined as a project, that is, in statics,

$$c = \mu. \quad (4)$$

Functional complexity C_F can be defined as

$$C_F = (M \times L)k_o, \quad (5)$$

where M – is the number of parallel jobs;

L – the most difficult job (the length of the longest chain of the process),

k_o – the relative ratio associated with the implementation of the system in the implementation environment.

2) The reliability W – is a metric value that is associated with the ability of the system to maintain the desired properties of the behavior under internal and external influences on the system, that is:

$$W^D = \phi(\bar{T}, P(t_i, t_{i+1}), T^H, \Delta(t_i, t_{i+1})), \quad (6)$$

where $\bar{T}$ – the average time an infallible (error free, trouble free) operation of the system,

P – the probability of the number of failures in the time interval (t_i, t_{i+1}),

T^H – during normal operation of the system, that is the time from the beginning of system operation until the result of the accumulation of errors and failures, the system starts to work poorly,

$\Delta(t_i, t_{i+1})$ – the number of failures (errors) in this time interval (t_i, t_{i+1}).

The formula applies to the already existing system. If the system is designed, the reliability is computed by the formula:

$$W^{CM} = \tilde{\varphi}(C = \tilde{\tilde{\varphi}}(k_v, N, \#S\#)), \qquad (7)$$

where $\#S\#$ – the number of subsystems in the system.

The equations (4), (5), (6) and (7) are applicable if the system is given as a scheme (draft).

3) The bandwidth of Π determines the max/min system operation time $\Pi = \Pi_1 + \Pi_2$.

$$\Pi_1 = \frac{\#\overline{\overline{S}}_I\#}{\#S\#}, \qquad (8)$$

$$\Pi_2 = \frac{M}{(H \times L)K}, \qquad (9)$$

where $\#\overline{\overline{S}}_I\#$ – number of identical subsystems with elements that own the media outlets,

L – the length of the computational chain,

H – the degree of "parallelism" (the number of concurrent jobs),

$\#S\#$ – the number of subsystems in the system.

4) U – versatility. How many activities can be embodied in the system. The relationship between inputs and output is called the way of the action item:

$$U_1 = \frac{K_v}{N} \qquad (10)$$

$$U_2 = \frac{\#\tilde{S}^*\#}{\#S\#} \qquad (11)$$

where K_v – the number of elements with the maximum number of different types of inputs,

N – the number of all elements in the system,

$\#\tilde{S}^*\#$ – the number of subsystems of different functions,

$\#S\#$ – the number of subsystems in the system.

5) The information content of the system I_ε.

$$I_\varepsilon = \frac{\overline{K_I}}{N}, \qquad (12)$$

where $\overline{K_I}$ – the number of elements with the maximum number of same type of outputs; – the total number of elements.

6) Hierarchy Y^{ε}

$$Y^{\varepsilon} = \frac{\#Y^f\#}{\#Y\#}, \quad (13)$$

where $\#Y^f\#$ – the number of equations (paths) according to the types of hierarchies: management, information, functions, activities and time;

$\#Y\#$ – the total number of equations (paths) in the system.

The smallest hierarchy Y^f must be managed and the most function.

Thus, before building the system we need to determine the main indicators (1–13).

3. RESULTS

On the basis of the decomposition of elements [19] forms according to their structural characteristics, it is possible to develop a system model TO, which will be a formal presentation that allows us to use methods of computer processing system models in order to be able to analyze and perform formal operations on them.

The proposed system model presented as a graph as shown in Fig. 2. analyzing such representation of the structure of technological equipment is difficult, so it is desirable present system model TO in a form that convenient for computer processing. Therefore, we represent the MF model in term of the extended regular system models (ERSM):

$$R_{MF} = \lfloor R_{MF_1} \wedge R_{MF_2} \wedge \ldots \wedge R_{MF_n} \rfloor, \quad (14)$$

where $R_{MF_n} = \lfloor R_{SS_1} \wedge R_{SS_2} \wedge \ldots \wedge R_{SS_n} \rfloor$,

where $R_{SS_n} = \lfloor R_{T_1} \wedge R_{T_2} \wedge \ldots \wedge R_{T_n} \rfloor$,

\

where $R_{T_n} = \lfloor R_{v_1} \wedge R_{V_2} \wedge \ldots \wedge R_{v_n} \rfloor$,

where $R_{V_n} = \lfloor R_{CE_1} \wedge R_{CE_2} \wedge \ldots \wedge R_{CE_n} \rfloor$,

where R_{CE_n} – system model of n^{th} structural element of n-view of n-type of n^{th} subsystem of the n^{th} injection mold.

By substituting the expression R_{V_n} to R_{T_n}, and, accordingly, R_{T_n} into R_{SS_n} and so on it is possible to obtain a system model in the basis of parts, kinds, types, subsystems and alternatives to MF.

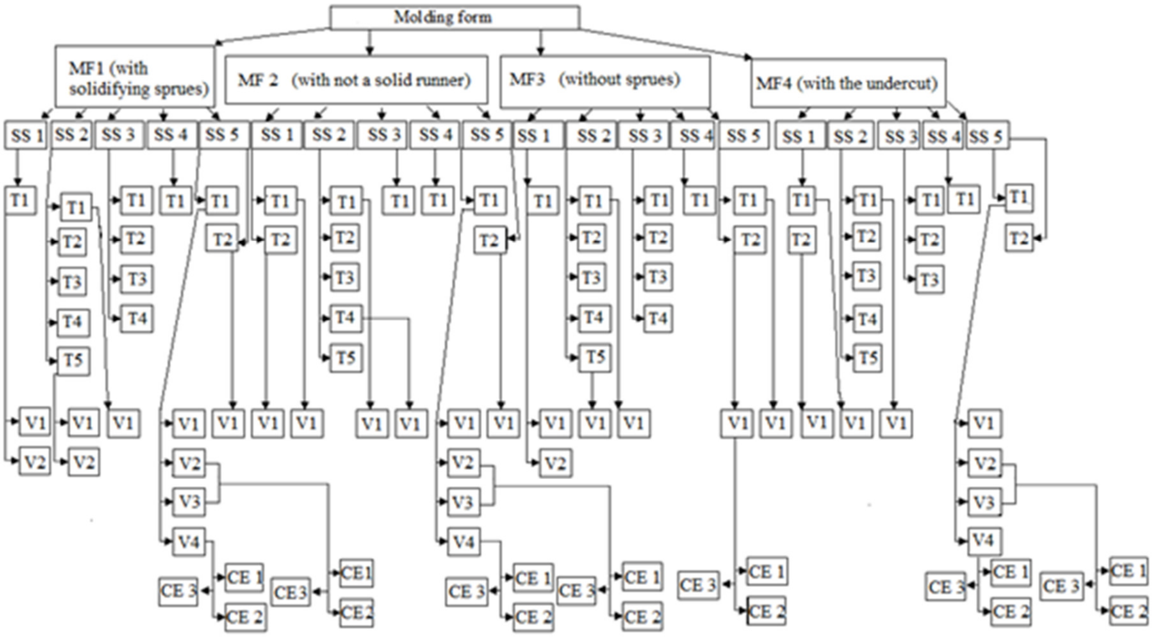


Figure 2 The structure of tooling

MF1, MF2, MF3, MF4 – alternative to injection molds,

SS 1 – The subsystem formalizing the details,

SS 2 – The subsystem centering,

SS 3 – The subsystem of removal of the casting from the mold,

SS 4 – The subsystem cooling and temperature control,

SS 5 – The subsystem gating and suction channels.

T 1…N – The type of the of n^{th} subsystem,

V 1…N – Element view n-type of n^{th} subsystem,

CE 1…N – The feature of n-form of n-type of n^{th} subsystem.

Each constructive element (CE) has a lifetime distributed across the phases of the life cycle (LC): design of CE, production of CE, operation of CE, modernization of CE and CE disposal.

By considering every constructive element, the model of MF can have presented as shown in Fig. 3.

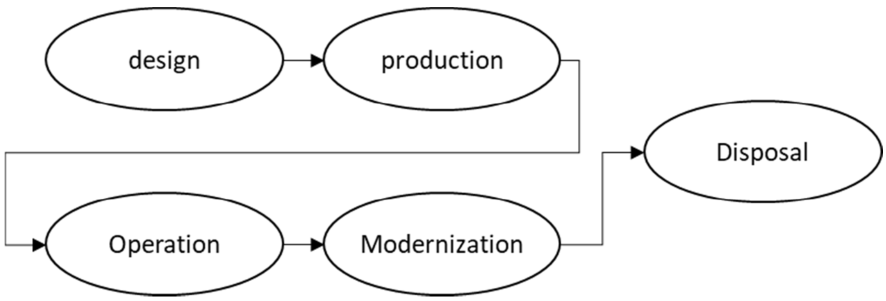


Figure 3 Phases of the life cycle of each part included in MF

Presenting phases of the life cycle of CE model in term of ERSM will take the following form:

$$R_{CE_n} = R_{Ds} \cdot R_{Pr} \cdot R_{Op} \cdot R_{Mz} \cdot R_{Dp}, \quad (15)$$

During the life cycle, at each phase, the CE is a complex hierarchical system whose model can be displayed in the following form (see Fig. 4).

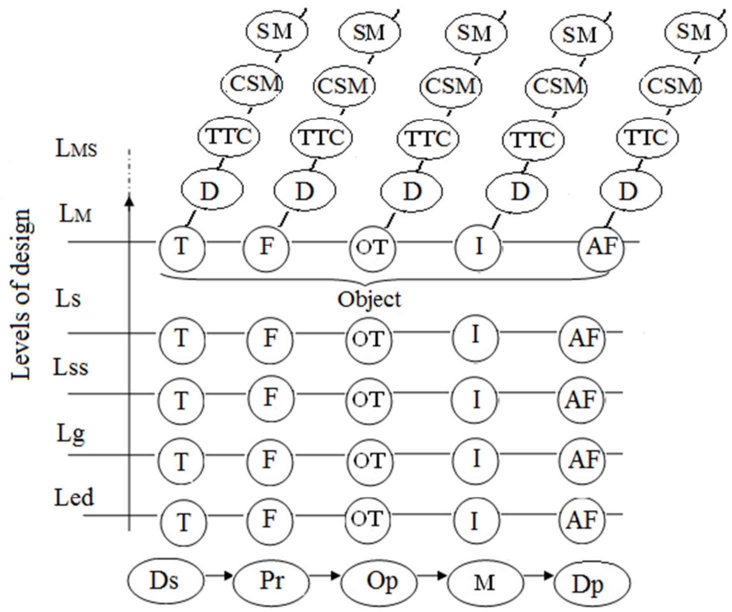


Figure 4 Morphological cube project activity

In Fig. 4 the following should be noted:

L_{ed} – element-level design (base design), L_g – group level, L_{ss} – subsystem level, L_s – system level, L_M – metasystem level, L_{MS} – level of the n^{th} metasystem. At each level of the design of the object there are different aspects of the design: T – target, F – functional, OT – organizational-technical, I – infological, AF – functioning algorithm. D – decomposition of the top level design stratified properties of the project operation and performance characteristics, TTC – development of tactical and technical characteristics decomposition elements of the strata of the project action, CSM – construction of the system model of strata design, SM – system modeling for the correspondence of the developed tactical and technical characteristics of the decomposed stratum elements, tactical and technical requirements of the general goal for the structural element of the MF.

On the target stratum, the system target model is constructed from MF decomposition. In general, the target system model has a hierarchical tree structure, which is based on the main purpose of the system, in this case a complete formal representation of MF.

Functional stratum is the construction of a system functional model of this level that reflects the structure of functional tasks, their parameters, relationships among themselves. In addition to the known set of characteristics (performance, accuracy, reliability), there may be specific ones belonging to this technological equipment.

The organizational and technical stratum determines the means by which the solution of the i^{th} level tasks is realized. All the means at which the tasks of this level will be solved, combined by ties, will constitute a model of the organizational and technical structure of the tooling. It is necessary to determine the attainability of goals and objectives. This requires TTC estimation of the performance characteristics of the organizational structure and their functional necessity. The development of tactical and technical characteristics of decomposed elements implies the basic properties of MF (strength, accuracy, etc.).

At the infological stratum formed a system information model, which determines the structure and characteristics of information flows. The basis for its construction is the functional model and organizational structure of this level.

Considering the input and output parameters of the solution of each task on an element of the organizational structure, the developer examines information flows on the organizational structure with their volumetric and temporal characteristics, defining the organizational structure by the system communication channels.

Let's express ERSM for CE as the strata of the project activity:

$$R_{CE_i Y_{str}} = \left[R_{sys_i}, e, \varnothing, a, a1\right] \qquad (16)$$

where R_{sys_i} – the decomposed element of the target stratum of the i^{th} level of design,

a – basic operation ERSM multiplication operators,

$a1$ – basic operation ERSM conjunction operators.

So the system model of the i^{th} level of the design:

$$R_{MSi} = R_{TM_i} \cdot R_{FMeS_i} \cdot R_{OTMs_i} \cdot R_{IMS_i} \cdot R_{AFMS_i}, \qquad (17)$$

And the system model by the design levels:

$$R_{CE_{Ld}} = R_{MS_i} \cdot R_M \cdot R_s \cdot R_{ss} \cdot R_g \cdot R_{ed}, \qquad (18)$$

Substituting (18) into (15), we obtain a system model of the CE of TO taking into account all the phases of the product life cycle.

$$\begin{aligned} R_{CE_n} = {} & R_{MS_i(Ds)} \cdot R_{M(Ds)} \cdot R_{s(Ds)} \cdot R_{ss(Ds)} \times \\ & \times R_{g(Ds)} \cdot R_{ed(Ds)} \cdot R_{MS_i(Pr)} \cdot R_{M(Pr)} \times \\ & \times R_{s(Ds)} \cdot R_{ss(Ds)} \cdot R_{g(Ds)} \cdot R_{ed(Ds)} \times \\ & \times R_{MS_i(Op)} \cdot R_{M(Op)} \cdot R_{s(Op)} \cdot R_{ss(Op)} \times \\ & \times R_{g(Op)} \cdot R_{de(Op)} \cdot R_{MS_i(M)} \cdot R_{M(M)} \times \\ & \times R_{s(M)} \cdot R_{ss(M)} \cdot R_{g(M)} \cdot R_{ed(M)} \times \\ & \times R_{MS_i(Dp)} \cdot R_{M(Dp)} \cdot R_{s(Dp)} \cdot R_{ss(Dp)} \times \\ & \times R_{g(Dp)} \cdot R_{ed(dp)} \end{aligned} \qquad (19)$$

Substituting (17) in (19), we obtain a system model of the CE of TO in the basis of the projection strata for the projection phase and similarly to the system models of the CE of TO in the basis of the projection strata for all phases of the life cycle

Having constructed system models of CE LF for project activities, design strata, design levels and phases of the life cycle of CE, then expressing them in the form of a program, a formal representation of the CE in the language of regular schemes of system models is obtained, which will make it possible to use computer processing methods of system models in order to they could be analyzed and carried out formal actions on them.

Constructing a systemic model of the CE of TO for project activities, strata design, level design phases of the CE life cycle and expressing them in the form of a program, a formal representation in the language of regular schemes of system models is obtained, which will make it possible to use computer methods for processing system models in order to be able to analyze them and perform formal actions on them.

4. DISCUSSIONS

With the obtained systemic patterns of the CE of TO, is possible to perform static and dynamic simulation to create and manage complex structures of TO designs.

Developed a system model TO is a formal representation of a snap-in that allows the use of methods of computer processing system models in order to be able to analyze and perform formal operations on them.

The choice of TO design is influenced by factors that must be taken into account when fulfilling the requirements. The developed model differs from the existing ones in that the choice of the TO design as a whole consists in determining the necessary equipment, optimal nesting, structure and arrangement of the most advantageous variants of systems capable of satisfying the technical and production-economic requirements for this product with unconditional reliability of the form itself.

The technical requirements consist in providing its geometric shape, surface roughness and dimensional accuracy by maintaining the properties of the projected raw material in the finished product with allowable, residual and orientational stresses to achieve the required stability of these parameters.

The most important performance requirements to the manufacture of the product are: its low cost, high performance, trouble-free operation of form and minimum employment.

5. CONCLUSION

A further development of the system model TO with the possibility of a new class of objects. The proposed system model contains a description of constructive elements of the MF in the form of morphological cube with nodes at each hierarchical level given projection operations, grouped by project activity and strata design, level design phases of the CE life cycle.

This gave the opportunity to obtain a complete formal representation in term of the language of regular schemes of system models and to use methods of computer processing of formal system models.

REFERENCES

[1] Marusich, T. D., and Modeling Ortiz. Modelling and simulation of high-speed machining. *International Journal for Numerical Methods in Engineering,* **38(21)**, 1995, pp. 3675–3694.

[2] Karnopp, Dean C., Donald L. Margolis, and Ronald C. Rosenberg. *System dynamics: modeling, simulation, and control of mechatronic systems*, 5th Edition. New York, USA: John Wiley & Sons, Inc, 2012.

[3] Yu, L., Koh, C. G., Lee, L. J., Koelling, K. W., and Madou, M. J. Experimental investigation and numerical simulation of injection molding with micro-features. *Polymer Engineering & Science,* **42(5)**, 2002, pp. 871–888.

[4] Chen, C. P., Chuang, M. T., Hsiao, Y. H., Yang, Y. K., and Tsai, C. H. Simulation and experimental study in determining injection molding process parameters for thin-shell plastic parts via design of experiments analysis. *Expert Systems with Applications*, **36(7)**, 2009, pp. 10752–10759.

[5] Yang, H., Zhan, M., Liu, Y. L., Xian, F. J., Sun, Z. C., Lin, Y., and Zhang, X. G. Some advanced plastic processing technologies and their numerical simulation. *Journal of Materials Processing Technology,* **151(1)**, 2004, pp. 63–69.

[6] Atzeni, E., Iuliano, L., Minetola, P., and Salmi, A. Redesign and cost estimation of rapid manufactured plastic parts. *Rapid Prototyping Journal,* **16(5)**, 2010, pp. 308–317.

[7] Rosato, D. V., and Rosato, M. G. (2012). *Injection molding handbook*. New York, USA: Springer Science & Business Media, 2000.

[8] Ferreira, I., Cabral, J. A., Saraiva, P., and Oliveira, M. C. A multidisciplinary framework to support the design of injection mold tools. *Structural and Multidisciplinary Optimization*, **49(3)**, 2014, pp. 501–521.

[9] Fernandes, C., Pontes, A. J., Viana, J. C., and Gaspar-Cunha, A. Modeling and Optimization of the Injection-Molding Process: A Review. *Advances in Polymer Technology*. 2016, pp. 21683–21704.

[10] Dobslaw, F. A Parameter Tuning Framework for Metaheuristics Based on Design of Experiments and Artificial Neural Networks. *World Academy of Science, Engineering and Technology*, **64**, 2010, pp. 213–216.

[11] Ries, J., Beullens, P., and Salt, D. Instance-specific multi-objective parameter tuning based on fuzzy logic. *European Journal of Operational Research*, **218(2)**, 2012, pp. 305–315.

[12] Calvet, L., Juan, A. A., Serrat, C., and Ries, J. A statistical learning based approach for parameter fine-tuning of metaheuristics. *SORT-Statistics and Operations Research Transactions*, **1(1)**, 2016, pp. 201–224.

[13] Ramos, I. C., Goldbarg, M. C., Goldbarg, E. G., and Neto, A. D. D. Logistic regression for parameter tuning on an evolutionary algorithm. In *Evolutionary Computation,* **2***,* 2005*,* 1061–1068.

[14] Putyatin, Y. P., Lyashenko, V. V., Ahmad, M. A., Lyubchenko, V. A., and Ahmad, N. A. A Theoretical Interpretation for the Study of Images Processing. *International Journal of Advance Research in Computer Science and Management Studies*, **3(9)**, 2015, pp. 17–31.

[15] Maksymova, S., Matarneh, R., and Lyashenko, V. V. Software for Voice Control Robot: Example of Implementation. *Open Access Library Journal*, **4(8)**, 2017, pp. 1–12.

[16] Maksymova, S., Matarneh, R., Lyashenko, V. V., and Belova, N. V. Voice Control for an Industrial Robot as a Combination of Various Robotic Assembly Process Models. *Journal of Computer and Communications*, **5(11)**, 2017, pp. 1–15.

[17] Hopkins, T. K., and Wallerstein, I. M. *World-systems analysis: theory and methodology*. Beverly Hills; London; New Dehli: Sage, 1982.

[18] Blanchard, B.S., and W.J. Fabrycky. *Systems Engineering and Analysis*, 5th ed. Prentice Hall International Series in Industrial and Systems Engineering. Englewood Cliffs, NJ, USA: Prentice Hall, 2011.

[19] B. Benhadou, A. Haddout, M. Benhadou, H. Bakhtari,Study and optimization of the injection molding of composites based on short hemp fibers. International Journal of Mechanical Engineering and Technology, 7(4), 2016, pp. 38–47.

[20] Basma Benhadou, Abdellah Haddout, Mariam Benhadou, Houssam Ourchid, Study of thermorheological behavior of polypropylene composites reinforced with short hemp fibers during industrial injection molding process. International Journal of Mechanical Engineering and Technology, 7(4), 2016, pp. 29–37

[21] Sotnik, S.V. Strukturno-parametrichne modelyuvannya tehnologichnoї osnastki / S.V. Sotnik // Radioelektronika i molodej v HHI veke_ 13_i Mejdunarodnii molodejnii forum – 2009 g. – tez. dokl. – H. – 2009. – s. 111.