Models of intelligent CAD in engineering divisions with training elements

G B Burdo* and A N Bolotov
Tver State Technical University, A. Nikitin Emb. 22, Tver, 170026, Russian Federation
*gbtms@yandex.ru

Abstract. The paper considers one of the issues of automated process control system for machining processes. The proposed approach is based on the implementation of such elements as the information accumulation, analysis, generalization, and knowledge elicitation. Such method allows creating new technological patterns, so it means that there are some elements of artificial intelligence in an automated system. The signs that form new knowledge are identified signs that correspond to a certain level of technological process decomposition. In order to increase the reliability of obtaining quality solutions, it is planned to involve experts for the most critical situations. Currently, the proposed method is undergoing experimental testing.

1. Introduction
Most modern machine-building enterprises have a diversity of their products and frequent changes in the product types while reducing the time for preproduction engineering.

Nowadays, there is an active implementation of artificial intelligence elements into preproduction engineering CAD, which can significantly reduce its duration. However, this direction of preproduction engineering CAD development is clearly not enough.

2. Problem statement
Based on the analysis [1-9], the principles of creating CAD for engineering divisions with training elements become more specific. They are:

1. Information and temporary integration with an automated process control system;
2. Integration with product life cycle support systems;
3. Implementation of procedures for information accumulation and synthesis (design experience) in engineering division CAD.

The last principle involves the implementation of accumulation procedures [9] and generalization of experience in applying the criteria (1), as well as generalization and accumulation of design experience (2).

The most interesting procedures are generalizing and accumulating of design experience. They consist in the fact that each technological solution (TSi) is remembered with the corresponding set of part features (SFi), including many structures \{S_{ik}\} and parameters \{P_{jk}\} of a part, and many organizational and production features OF_{k} that determine organizational and production conditions for the implementation of production processes (PP), objective function (OF), equipment, tools, instrumentation:
\[ TS_i \leftrightarrow \left\{ \{S_i\}, \{P_i\}, OPF_i \right\}_k, MK_k = \left\{ \{S_i\}, \{P_i\}, OPF_i \right\}_k \]  

(1)

The sets \( \{ MK_k \} \) are accumulated for each type of \( TS_i \) solution. Their generalization gives a technological image \( Im \). There is a determined interval of technological solutions \( \Delta TS_i \) corresponding to the same image. \( TS_i' \) verified in engineering divisions should:

\[ TS_i' \leftrightarrow \left\{ \left\{ S_i' \in \bigcup S_i \right\}, \left\{ P_i' \right\} \in \left\{ AP_i \right\}, \left\{ OPF_i' \right\} \in \left\{ \Delta OPF \right\} \right\} \]  

(2)

In this case, the decision is considered reliable. Summarizing the experience: \( TP_j' \times TP_i \times \{ SF_k \} \rightarrow Im_j \) gives a technological image, which is characterized by certain interval of allowed values \( \{ \Delta MP \} \) and \( \{ \Delta OPF \} \). The image \( Im_j \):

\[ Im_j = \{ \{ S = \bigcup S_i \}, \{ \Delta P_j \}, \{ \Delta OPF_j \}, \{ \Delta \} \wedge \{ PN \} \} \]  

(3)

where \( \{ PN \} \) is the set of part numbers and names for which technological processes were designed.

The experience should be accumulated and generalized in stages, starting with the minimum composition of elements in \( SF_K \) sets, expanding them gradually to full volumes, building a hierarchy of images. Full \( SF_K \) allows direct selecting of \( TS_i \) of any level. A special case of accumulation and generalization is their interlevel procedure:

\[ TS_i' \leftrightarrow \left\{ TS_i'^{-1}, MK'_k \right\} ; TS_i' \times TS_i'^{\prime} \times SF_{K} \times TS_i'^{-1} \rightarrow Im_j' ; \quad Im_j' = \{ TS_i'^{-1}, SF_{K} \} \]  

(4)

where \( j \) is the level number, \( SF_{K} \) is a subset of \( SF_{K} \) set necessary for \( TS_i' \) synthesis based on the previous level solution \( TS_i'^{-1} \).

3. Training procedures at process design decomposition levels

The procedures for the accumulating and generalizing solutions correspond to design process decomposition levels; each one corresponds to the \( Im \) image. The first level accumulates and generalizes information on the preforming methods, processing routes \( PR \) and stages \( S \) of part manufacturing [10].

For preforming methods, the features \( SF_i^1 \) that uniquely determine its choice are:

\[ B_i \leftrightarrow \left\{ \left\{ PT_i, S_i, CD_j, N, PM, m, \{ OPF_j \}, OF, PN \right\}_n \right\} = SF_i^1_n, \]  

(5)

where \( B_i \) is the \( i \)-th method of obtaining blanks; \( PT_i \) is the type of a part; \( S_i \) is a graph of surface bonds defining a blank contour; \( CD_j \) defines its dimensional parameters; \( N \) is an annual release program; \( PM \) is a part material; \( m \) is mass; \( PN \) is a part number; \( ObF \) is an objective function. The image formation procedure is the following:

\[ \{ B_i \} \times \{ SF_i^1 \} \rightarrow \{ Im_i^1 \} \]  

(6)

\[ Im_i^1 = \{ \{ PT_i \}, \{ S_i \}, \{ \Delta CD_j \}, \{ \Delta N \}, \{ PM \}, m, \{ OPF_j \}, \{ PN \}, \{ OF \} \}_i \]  

(7)

The surface treatment route is determined by the parameters \( SF_i^2 \).

\[ PR_i \leftrightarrow \left\{ \left\{ ST_m, B_i, BSP, \{ SS_j \}_m, L_m, \{ SA_j \}_m, RP_m, PM, N, PhM_m, \{ OPF_j \}, \{ PN \} \right\}_n \right\} = SF_i^2_m, \]  

(8)
where $S_{T_m}$ is a surface type; $BSP_i$ defines system parameters of a blank including dimensional links between its surfaces and dimensional accuracy; $\{SS_j\}_m$ is a set of surface sizes; $L_m$ are the links of surfaces with others; $\{SA_j\}_m, RP_m$ are sets that determine the parameters of size accuracy and relative position; $PhM$ are physical and mechanical properties of the surface.

\[
\{PR_i\}_T \times \{PR_i\}_T \times \{SF^2_{Pr}\}_T \rightarrow \{1m^2_i\}_T
\]  

(9)

\[
\{1m^2_i\}_T = \left\{ \left[ \{ST_m, [B_i]_T, [BSP_i]_T, L_m, [\DeltaSA_j]_m, PhM_m, [\DeltaRP_j]_m, \DeltaN_i, \{PM\}_m, \{OF\}_j \} \right] \right\}
\]  

(10)

The accuracy and surface undulation are a subject of practical verification [11]. The processing steps $S_k$ are determined by the following features $SF^3_{ik}$:

\[
S_k \leftrightarrow \left\{ \{PT_i, [B_i]_T, [BSP_i]_T, [SS_j]_m, L_m, [OPI]_j, [OF], PM, PhM_m, \{SA_j\}_m, RP_m \} \right\}
\]  

(11)

A procedure for generalization-image creation is the following:

\[
\{ S_k \}_T \times \{ S_k \}_T \times \{ SF^3_{ik} \}_T \rightarrow \{1m^3_{ik}\}_T
\]  

(12)

and the image $1m^3_{ik}$ is:

\[
1m^3_{ik} = \left\{ \left[ \{PT_i, [B_i]_T, [BSP_i]_T, \{TS_j\}_m, PM, PhM_m, \DeltaN_i, \{SA_j\}_m, \{ARP_j\}_m, \{PN\}_i \} \right] \right\}
\]  

(13)

where $LD_i$ determines dimensional links of the technological databases of a part.

The part processing rout ($R$) is determined by the features $SF^2_{Li}$:

\[
M_i \leftrightarrow \left\{ \left[ \{PT_i, [B_i]_T, [BSP_i]_T, PM, PhM_m\} \right] \right\} = SF^2_{Li}
\]  

(14)

where $\{DD\}_i$ is a set of defining dimensions of the part (length, width, height, reduced diameter, etc.); it is a graph of the overall dimensions of a part.

\[
\{R_i\}_T \times \{R_i\}_T \times \{SF^2_{Li}\}_T \rightarrow \{1m^2_i\}_T
\]  

(15)

\[
1m^2_i = \left\{ \left[ \{PT_i, [B_i]_T, [BSP_i]_T, PM, \{TS_j\}_m\} \right] \right\}
\]  

(16)

Process technology is determined by features $SF^3_{Li}$:

\[
OF_i \leftrightarrow \left\{ \left[ PT_i, [B_i]_T, [OPI]_j, [TS_j]_m \right] \right\} = SF^3_{Li}
\]  

(17)

where $LD_i$ are the dimensional links of part surfaces.

The procedure for obtaining an image is the following:

\[
\left[ \Pr T_i \right]_T \times \left[ \Pr T_i \right]_T \times SF^3_{Li} \rightarrow 1m^3_i.
\]  

(18)

\[
1m^3_i = \left\{ \left[ PT_i, [B_i]_T, [BSP_i]_T, [ARP_j]_m, PM, PhM_m, \{SA_j\}_m, \{DD\}_i, [OBF], [PN] \right] \right\}
\]  

(19)

The parameters of cutting conditions are determined by the features $SF^3_{Li}$.
Control programs (CP) are defined by the features \( SF_2^4 \).

\[
CP_i \leftrightarrow \left\{ PT_i, L_i^p, L_i^p', \{ OF_i \}, \{ TS_i \}, \{ RP_m^i \}, \{ PM^i \}, \{ PhM^i \}, \{ SS_i \} \right\} = SF_2^4,
\]

where \( L_i^p \) are dimensional links of the part corresponding to its post-treatment state; \( L_i^p' \) are the same links, but before being processed; \( S_i \) is a temporary structure of transitions in the operation features.

For a quick search of programs to adjust them it is enough to use \( PT_i, L_i^p, L_i^p' \).

The experience (control program adjustment) is generalized according to the results of their development in an engineering division:

\[
\{ CP_i \}^n \times \{ CP_i \} \times \{ M_2^i \} \rightarrow \{ Im_2^i \}; \quad Im_2^i = \left\{ \{ PT_i, L_i^p, L_i^p', \{ PN \} \} \right\}
\]

After adding the remaining unaccounted features, we can obtain the corresponding subsets of the image \( Im_2^i \).

This level should involve generalization of information on the actual operation time in two directions.

The first direction includes determination, comparison and adjustment of time to complete a specific operation:

\[
T_{UCI}^c \times \{ T_{UCI}^{ac} \} \rightarrow T_{UCI}^{adj}
\]

where \( T_{UCI} \) is a unit costing time of the \( i \)-th operation of a particular part; indexes \( c, ac, adj \) represent calculated, actual, adjusted values. The second direction includes time cost analysis and their adjustment to perform many elements of various operations characterized by the following parameters:

\[
\{ z_j \}; \quad \{ T_{UCI}^c \} \times \{ T_{UCI}^{ac} \} \times \{ Z_j \} \rightarrow t_j^{adj},
\]

where \( t_j^{adj} \) is a set of adjusted components of unit costing time corresponding to the set of operation elements \( Z_j \). Images are a base for type design at all levels, up to full analogues [12].

Figure 1 shows the model for accumulation and generalization of information in CAD for engineering divisions. There is a technological solution (a production process model information model of the \( i \)-th level) and the attributes (parameters) listed above. Solutions are grouped according to structurally and technologically similar details; attribute intervals are determined and evaluated.
The solution and intervals of features (parameters) are entered into a knowledge base. Further, a technological solution of any level is selected by comparing the values of part features with the intervals of feature values in a knowledge base. CAD for engineering divisions accumulates and determines parameter intervals; experts are involved in assessment and generalization.

4. Conclusion
The presented model of accumulation and generalization of information allows building CAD in engineering divisions with the elements of artificial intelligence, which will reduce the production design time. The generalization and accumulation of knowledge involves the work of experts and takes into account the results of the development results of production processes in engineering divisions. The proposed engineering division CAD with training elements can be implemented in the software environment of well-known domestic engineering division CAD. This CAD for engineering divisions allows a company to achieve market success and gain an advantage over competing manufacturers while reducing the production design time, reducing labour intensity at the preproduction stage.

Acknowledgments
This work has been supported by the Russian Foundation for Basic Research (project no. 19-37-50084).

References
[1] Burdo G B and Palyukh B V 2009 Improving the efficiency of managing technological units under conditions of a single-piece and batch production Vestnik of Don State Tech. Univ. 94 659–66
[2] Burdo G B, Palyukh B V, Ispiryan N V, Isaev A A and Burdo V G 2013 Automation of multiproduct manufacture work preparation. Mechanics and Physics of Processes on the Surface and in Contact of Solids and Parts of Technological and Energy Equipment: Interacad. Proc. 6 106–10
[3] Evgenev G B 2001 Systemology of Engineering Knowledge (Moscow: Bauman MSTU)
[4] Pozdeev B M 2004 Knowledge management and intelligent decision support at design and production stages in machine-building industry Proc. 9th Nat. Conf. on Artificial Intelligence with Intern. Participation KII-2004 3 1039–50
[5] Yablochnikov E I 2009 Organization of a single information space for manufacturing design using PDM SmarTeam. IT in Design and Production 3 22–9
[6] Korsakov V S, Kapustin N M and Tempelkhof K Kh 1986 *Automation of Technological Process Design in Mechanical Engineering* (Moscow: Mashinostroenie)

[7] Kondakov A I 2007 *Technological Process CAD* (Moscow: Academiya) p 272

[8] Tsvetkov V D 1979 *System and Structural Modelling and Automation of Technological Process Design*. (Minsk: Nauka i Tekhnika)

[9] Burdo G B and Stoyanova O V 2014 Automated process control system for creating high-technology engineering products *Software & Systems* 2(106) 164–70

[10] Fatima A, Nazir N, Gufran Khan M 2017 Data cleaning in data warehouse: A survey of data preprocessing techniques and tools *I.J. Information Technology and Computer Science* 3 50–61 DOI: 10.5815/ijitcs.2017.03.06

[11] Aliyeva A G and Shahverdiyevab R O 2018 Perspective directions of development of innovative structures on the basis of modern technologies *I.J. Engineering and Manufacturing* 4 1–12 DOI: 10.5815/ijem.2018.04.01

[12] Nguyen Van Dinh and Nguyen Xuan Thao 2018 Some measures of picture fuzzy sets and their application in multi-attribute decision making *I.J. Mathematical Sciences and Computing* 3 23–41 DOI: 10.5815/ijmsc.2018.03.03