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ALGORITHMS OF COMPUTER CONTROL OF MULTIOBJECT BIOLOGICAL SYSTEMS

Summary of Doctor's work

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GENERAL DESCRIPTION OF WORK

Topicality of the subject

There are biologic systems that are intensively researched and the information characterising their operation usually is sufficient for the development of the control system to control them. Examples of such systems are a man in the context of healthcare or other biological systems, which have undergone intense research.

The biological systems whose research has not been so extensive due to different reasons, economic and technical reasons being among them, are on the opposite side and the logical result is the cases of unsuccessful control of the biological systems: paludification of meadows due to unsuccessful melioration, changes of the number of fish due to changes in the food circumstances, unexpected consequences of the control of the forests, pest control, improvement of bee wintering results (application example) etc.

At the same time there is growing demand for useful and efficient control of the biological systems under the conditions of rapid development of computer technology. It especially refers to such industries as agriculture, food processing, biotechnology and pharmacy.

In this paper problematic of multiobject biological systems computer control is analysed under circumstances of insufficient information. The multiobject biological system is the aggregate of many biological objects of one kind, what is explored as one system, instead of every individual separately.

During last years a new agricultural industry has been defined - Precision Agriculture (PA) (Laurs, 2004, Vilde et al., 2004, Domeika and Kurlavicius, 2004), which is based upon the computer control of the agricultural processes extending even to the individual control over the animals and plants depending on their conditions and the defined goals of the control.

The unsuccessful examples of the control systems of the biological systems despite the rapidly growing possibilities of the computer technology prove that insufficient and incomplete methodology of the development of computer control becomes the factor disturbing the development of the computer control of the biological systems.

In the development of the computer control itself the weak link is insufficient methodology base in the meaning of the operation of biological systems and their simulation. This can be especially seen in the case of multiparameter control with insufficient information on the object. Insufficient understanding of the processes taking place in the biological system leads to the development of unsuitable computer system.

The simulation of biological system problems from the system control viewpoint is related to several problems and these are the problems not characteristic of the technical systems. In the case of the biological systems there is no unambiguous information on the principles of the construction, relations of causes - consequences and interaction with the environment because this system has not been constructed by a man for particular targets by the means selected by a man. This factor restricts the possibilities of application of the simulation methods of the technical systems.

Besides that the analysis of stability during transition processes widely applied in the control systems of the technical systems has not been adapted until now for the peculiarities of the control of the biological systems. Control of the biological system means the modification of the parameters of the environment where it is located. And the biological system reacts to any deviation in the environment parameters as the biological control system to compensate the changes taking place. Thus there is a task of balancing two control systems: one control system (usually several mutually linked loops) is the biological control system (BCS) of the biological system itself, and the other control system is the artificial control system (ACS) which has been created by a man for the control of the first one. Consequently also the analysis of the transition processes is required.

The present Paper is devoted to the methodology of the development of the computer control for the biological systems.

The goal and tasks of the Paper

The goal of the Paper is to create the methodology for the development of the computer control for the multiobject biological system under the conditions of incomplete information on the regularity of the operation of the biological system. Methodology has to provide the correspondence of control system to the criteria of efficiency and harmlessness.

The goal of the Paper shall be reached by performing the following tasks:

1. To develop the methodology for the development of a static and dynamic model of the BCS of multiobject biological system and to demonstrate the example of application of the methodology.
2. To develop the methodology of the development of the ACS of the multiobject biological system including the determination of the percentage of the ACS loop, which is optimal based upon the efficiency criteria. To demonstrate the example of the application of the methodology.
3. To develop the methodology for ensuring the harmlessness of the collaboration of BCS and ACS (competition of the two control loops), taking into account the dynamics of the transition processes. To demonstrate the example of the application of the methodology.
4. To develop the proposals for efficient wintering of bees in the conditions of Latvia (the application example).

Research methodology

The topological simulation methods have been applied for the simulation of the multiobject biological system.

The surveys of experts and "brainstorming" experiments have been used for obtaining the necessary information for the development of the model and testing.

The dynamic model of the biological system has been developed with the software package *Powersim Constructor 2.51* (POWERSIM, Internet) linking it to *Microsoft Excel* software for the purpose of the data exchange.

The data necessary for the verification of the biological system have been obtained on the field experiments. The verification has been performed by means of the software package *Powersim Solver 2.0* (POWERSIM, Internet) where genetic algorithms have been used.

The efficiency of the computer control has been evaluated based upon several criteria of efficiency applying the method of "fair compromise".

The harmlessness of the collaboration of the biological system and the computer control has been simulated by the software package *Powersim Constructor 2.51*.

Scientific novelty

The obtained methodology for the first time describes the methodology of the development of the multiparameter computer control compliant to the criteria of efficiency and harmlessness for multiobject biological systems under the conditions of insufficient information including the analysis of the dynamics of the transitional processes.

Several original solutions have been applied in the algorithms describing the methodology:

- methodology and algorithm of the development and verification of the model of BCS in the dynamics,
- methodology and algorithm of the development of ACS and its optimisation accordingly to efficiency criteria,
- methodology and algorithm of analysis of the harmlessness of the collaboration between two control loops - BCS and ACS.
- application of the incidence matrix and the topological model as a type for information depiction in the process of obtaining information from the experts,
- the application of the topological model of the biologic system and homomorph transfer of its to *Powersim Constructor 2.51* dynamic simulation package,
- multiparameters dynamic model of the biological system with the software *Powersim Constructor 2.51* and verification with *Powersim Solver 2.0* software package,
- analysis of the harmlessness of the cooperation between two control loops - biological and artificial.

Main results

Methodology and its algorithms for the development of the computer control for the multiobject biological system under the conditions of incomplete information on the regularity of the operation of the biological system is developed. Methodology provides the correspondence of control system to the criteria of efficiency and harmlessness.

The following tasks have been fulfilled:

1. The methodology for the development of the static and dynamic model of the multiobject biological system has been developed and demonstrated with the application sample.

The structure of the model has been presented in the form of the topology model. Following the implementation of the functional relationships the model of the biologic system is verified by means of tests performed in the nature.

2. The methodology for the development of the model of target-orientated computer control of the multiobject biological system has been developed and presented by the application sample. The methodology includes the determination of the percentage of the ACS loop, which is optimal based upon the efficiency criteria.

   Methodology is demonstrated by developing of ACS model, which reach the set of targets and satisfies efficiency criteria's.

3. The methodology for the provision of the harmlessness of the collaboration of the BCS and ACS (competition of two control loops) has been developed. Methodology is demonstrated by development of the incorporated model of BCS and ACS for harmlessness analysis.

   The harmlessness of the transfer processes under the dynamic conditions is tested in the situations when parameters change with the highest speed and the fluctuations in the transitional process reach their maximum values.

4. The recommendations for rational bee wintering in the conditions of Latvia have been developed. BCS and ACS models are created.

   Under the conditions of Latvia wintering 100 bee hives it is efficient to do it in bee wintering building equipped with the regulating ventilation system (capacity - 1710 m^3/h) and regulating heating system (capacity - 1000 W) with the condition that the heat transfer rate of the wintering building C=50 W/°C. In such a case the expected average profit is expected to be 634 Ls per year compared to the bees wintered outdoors. The calculations have been made for the depreciation period of 5 years.

   The developed models of bee wintering do not have analogue in the world. They can be used not only in practice, but also for training and study processes.

   Simulation software allows easy change of parameters of control system and environment to simulate different wintering building and climatic parameters.

<u>Practical value of the Paper</u>

1.The established methodology of the development of the computer control for the biological systems can be applied in practice because the area of its application per the types of the biological systems is very wide and the methodology pays special attention to the conditions of insufficient information. That is very often the case in practice.
2.The described principles of the establishment of the model of the biological system can be applied in practice for solving the forecasting tasks also without the implementation of the control system.
3.The comparatively low costs of software increase the availability of the methodology.
4.The results obtained in the Paper can be used in the process of training and study in the computer control and natural sciences study programs.
5.The presented sample of application for improving the bee wintering in the conditions of Latvia can be used in practice because it contains all the necessary information for the implementation of the control in practice. The data can be used also for the optimisation of apiary structure throughout the year cycle.

Publications

Results of Paper are presented and published in following international scientific conferences:

1. E. Stalidzans, A. Krauze, A. Berzonis. Modelling of energetical balance of honeybee wintering generation. In proceedings of 1-st European Scientific Apicultural conference, Pulawy, Poland, 2000. Psczelnicze zestyty naukowe 2000, No.2, 55-62.

2. E. Stalidzans, Z. Markovitch. Expert based model building using incidence matrix and topological model. 12-th European simulation Symposium 2000. Hamburg, Germany. 328-332.

3. A. Krauze, E. Stalidzans, A. Berzonis. Comparative Modelling of Bee Wintering under Latvian and Other Climatic Circumstances. In Proceedings of the scientific conference "Problems and Solutions for Rural Development", 2001, Latvia University of Agriculture, Jelgava, 367-373.

4. E. Stalidzans, Z. Markovitch, A. Krauze, A. Berzonis. Simulation of death dynamics of wintering generation of bees under different climatical conditions. 15-th European Simulation Multiconference 2001. June 6-9, 2001, Prague, Czech Republic, 1039-1043.

5. Z. Markovičs, E. Stalidzāns Mērķa funkcijas noteikšanas variants bioloģisku objektu vadībai. Rīgas Tehniskās universitātes raksti. 5. Sērija Datorzinātne. Datorvadības tehnoloģijas. 6. sējums, RTU, Rīga, 2001. 16-23 lpp.

6. Z. Markovičs, E. Stalidzāns, A. Bērzonis. Modelis bišu ziemotavu efektivitātes noteikšanai dažādos klimatiskajos apstākļos. Rīgas Tehniskās universitātes raksti. 5. Sērija Datorzinātne. Datorvadības tehnoloģijas. 11. sējums, RTU, Rīga, 2002. 28-38 lpp.

7. Z. Markovičs, E. Stalidzāns, A. Bērzonis. Racionālas vadības noteikšana bišu ziemotavas temperatūras regulēšanai. Rīgas Tehniskās universitātes raksti. 5. Sērija Datorzinātne. Datorvadības tehnoloģijas. 11. sējums, RTU, Rīga, 2002. 39-44 lpp

8. E. Stalidzans, Z. Markovics, V. Bilinskis, A. Berzonis. Modelling of computer controlled bee wintering building profitability. Information Technologies and Telecommunications for Rural Development. Jelgava, May 6-7, 2004. 78-84 1pp.

Results of Paper are published in following media

9. E. Stalidzans, A. Berzonis. Bišu krituma dinamika ziemojošās saimes. Latvijas Lauksaimnieks, Riga, 1994 No. 7 13-15 un No. 8 29-31.

10. Ē. Kristapsons, E. Stalidzans, A. Berzonis, A. Kaķītis. Racionālas bišu saimju ziemotavas. Latvijas Lauksaimniecības Universitātes Raksti. Jelgava. (1996) 6, 94-101.

11. E. Stalidzans, V. Bilinskis, A. Berzonis. Hypothesis of modelling energetical balance of bee colonies and changes in the number of bees. 1999. Proceedings. Apimondia 99. 36-th Congress, Vancouver, Canada, 278.

12. E. Stalidzans, A. Berzonis. Analytical development model of bee colony.Environmental Simulation - Riga: Riga Technical University, 1999 (Boundary FieldProblems and Computer Simulation; 41-st issue) 14-21

13. E. Stalidzans, V. Bilinskis, A. Berzonis. Determination of development periods of honeybee colony by temperature in hive in Latvia, year 2000. In Proceedings of the 37. International Apicultural Congress., 28 Oct-1 Nov 2001, Durban, South Africa. Paper No. 378 ISBN: 0-620-27768-8

14. V. Bilinskis, E. Stalidzans, Z. Markowitch, A. Berzonis. Modelling of wintering building profitability depending on outside temperature and humidity. In Final Programme and book of abstracts of XXXVIIIth APIMONDIA International Apicultural Congress., August 24.-29., 2003, Ljubljana, Slovenia. Paper No. 97

15. A. Krauze, V. Bilinskis, E. Stalidzans, A. Berzonis. Different states of bee colony in winter and spent power. In Final Programme and book of abstracts of XXXVIIIth APIMONDIA International Apicultural Congress., August 24.-29., 2003, Ljubljana, Slovenia. Paper No. 99.

Results of Paper are discussed in student scientific conferences in Riga Technical University and in the congress of Latvian Beekeeping association in 2001.

The structure and volume of the Paper. The Doctorate Paper has been written in the Latvian language, there are 159 pages, introduction, 3 chapters' conclusion, the list of references and 4 appendices. There are 47 figures and 13 tables in the Paper. There are 77 titles in the reference list.

Contents of the Paper

Section One (Introduction). The peculiarities of the biological systems are analysed drawing the comparison to the technical systems from the viewpoint of developing the computer control.

The approaches to the simulation of the biological systems found in the literature are quite specific and focused on particular directions because the term of simulation in the biology is very wide (Modeli, 1966; Antamonov, 1977, Lisenkov, 1979; Renshaw, 1995). In the literature no methodology or algorithms of the simulation or research of the biological systems from the viewpoint of the control of the biological systems and transitional processes have been found.

The solution of the task has been split in three parts to be executed in sequence:
1) the methodology for the establishment of the BCS model,
2) the methodology for the establishment of the optimised ACS,
3) the methodology for the coordination of the operation of the BCS and ACS.

As an application sample of methodology the improvement of bee wintering in Latvian circumstances is used.

Section Two. (The methodology for the development of model of the biological control system (BCS).) The operation of the set of the parameters B of the biological system existent in the nature under the conditions of set of environmental parameters V can be described in the form of the model

$M_b=F_b(b_1,...b_k,...b_K; v_,,...,v_s,...v_S; t),$ (1)
$b_k \in B, \ v_s \in V, \ B \cap V=0,$

where $b_1,...b_k$ - the variables characterising the biological system (internal control loop) belong to the set of the parameters B of the biological system,

$v_1...v_s$ - the variables characterising the environment, belong to the set of the parameters V characterising the environment,

t - time.

Reproduction and metabolism is a common feature of all the biological systems. The description of these processes can be used as the initial point for the simulation when the biological system is viewed in totality as a population.

When a process within the biological system or its part is viewed, the food, energy, heat, time or other balance can be used as the initial data. These can be viewed independently of each other or in relation.

As it is necessary to take into consideration many functional correlations relating the variables of the biological system $b_1,...b_K$ to the variables of the biological system and environment $b_1,...b_K$ and $v_1...v_S$, the initial model is developed by means of the topological modelling. In this stage of the development of the model cooperation of the experts of the biological system and knowledge engineers is necessary.

The algorithm for the development of the BCS model M_b is shown in Figure 1. The description of the operations contained in the algorithm **(in bold)** has been provided for every step of the algorithm.

Definition of the control targets is intended for the specialisation of the model from the point of view of control system to be developed.

The control task is being solved to satisfy the set of the control targets $G\{g_1,...,g_q\}$

$G=F_g(b_k, v_s, t),$ (2)

where k=l,K; s=l,S.

The control targets G can be clearly defined in the definition of the control task, or these should be reduced to the particular parameters characterising the system when the targets have been defined generally. Further detailed study of the system will be devoted only to the processes related to the control target thus permitting to reduce the extent of the model to the minimum required.

The development of the model starts with the application of the topological simulation (Osis, 1967). Use of topological modelling is caused by its flexibility regarding implementation of changes. That is very important in circumstances of insufficient amount of information, which requires possibility of easy and quick structure change of the model.

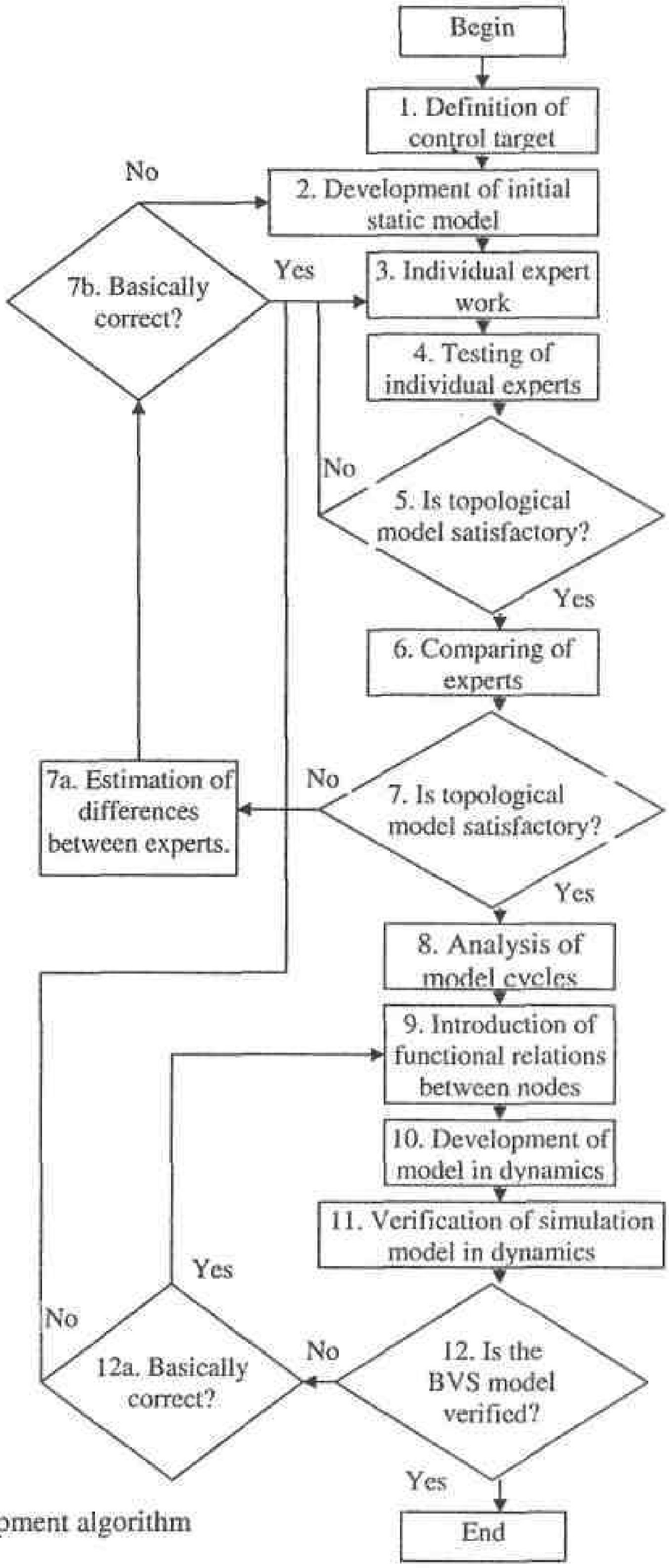

Figure 1. Development algorithm of BCS model.

The initial static topological model is the first iteration of the following topological model

$M_t = F_t(b_1,...b_k,...b_K; v_1,...,v_s,...v_S)$ (3)

It is necessary as the basis for further statements by the experts at the stage of the expert survey. The initial model is developed referring to the data in the literature or with the participation of some of the experts to be invited later on.

Further improvement of the model is done by the experts introducing the changes to the model M, (Stalidzans and Markovics, 2000). Incidence matrix and the topological model as the kinds of the information reflection are applied for making the model more precise by experts in iterative process first individually (cycle: **individual expert work, testing individual experts, satisfactory model).** Individual expert work is followed by **comparing of experts.** If the result is not **satisfactory model** and after **estimation of differences between experts** does not appear **basically correct** the initial topological model can be changed.

The evaluation of the information provided by the experts based upon the level of the concord of the experts is made depending on the type of the survey: direct estimation or comparison of pairs.

In case of the direct estimation of the parameters the level of concord of the experts is evaluated based upon the concordation coefficient W_t (Kendall, 1955, Djakova and Krug, 1966) in compliance to the following formula:

$$W_t = \frac{12\sum_{i=1}^{n}\left\{\sum_{j=1}^{m} r_{ij} - \frac{1}{2}m(n+1)\right\}^2}{m^2(n^3-n)} \qquad (4)$$

where n - number of estimated objects in the group,
m - number of experts,
rij – rank of object i accordingly to estimation of expert

In case of the comparison of the pairs the level of concord of the experts is determined based upon the concordation rate W_p in compliance to the following formula (Kendall, 1955, Djakova and Krug, 1966):

$$W_p = \frac{4\left(\sum \partial_{lk} - m\sum \partial_{lk} + C_m^2 C_s^2\right)}{m(m-1)s(s-1)} \qquad (5)$$

where ∂_{lk} - numbers in the table of pair comparison;
1=1,...s; k=l,...s - indexes of comparable objects;
s - number of comparable objects;

m - number of experts;
C_m^2 - number of conformities from m each 2;
C_s^2 - number of conformities from s each 2.

The value of the concordation coefficients W_t and W_p varies within the scale $0 \leq W \leq 1$, and W=0 of there is no relation between the ranks and it is 1, if all the experts have rated the objects the same. The value $W \geq 0,5$ is considered sufficient for the concordation rate when it is considered that the concord between the experts is sufficiently high. In case when the concordation coefficients are satisfactory the obtained average values or the weight rates can be used.

When the number of the experts m is small the role of every expert increases. Consequently the inaccuracy of any single expert's view strongly influence the average arithmetic value. Another methodology for obtaining the resulting assessment is applied for the prevention of this effect. It is known that the essence of the evaluation by the experts is obtaining an unknown value as an incidental value the distribution of which is judged based upon the individual evaluations by the experts. Thus the initial data massive of the experts' views should be processed based upon the mathematical statistics concepts. In case when the number of experts is small the average arithmetic value is not the best way for obtaining the resulting assessments.

Therefore the evaluation of every i parameter should be defined as the mathematic expectation of the average value C which is calculation on iterative bases where the formula for q iteration is (Voronin, 1974).

$$C_q = \frac{\sum_{j=1}^{m} C_j \exp\left[-\frac{1}{2\partial^2}(C_{q-1} - C_j)^2\right]}{\sum_{j=1}^{m} \exp\left[-\frac{1}{2\partial^2}(C_{q-1} - C_j)^2\right]} \tag{6}$$

Where Cj - evaluation of expert j of the object i,
C_{q-1} - result of previous iteration,
q=l,...,μ - iterations,
∂ - standard deviation,
m - number of experts.

On the first iteration it is recommended to apply the average arithmetic value

$$C_1 = \frac{1}{m}\sum_{j=1}^{m} C_j \tag{7}$$

Then in compliance to the procedure of iterations the exact value should be found. The iterative process has been completed when the changes of the value between iterations are lower than the permitted error.

Following the development of the topological model **the analysis of the cycles of the model** should be performed defining the particular BCS loops in the biological system itself.

If the experts think that the topological model *M,* sufficiently well depicts the relation of the biological system and the environment parameters the study of the system should be continued in the dynamics and **the introduction of the functional relations between the nodes** is required. The topological model developed for the application case (the model for the microclimate control of wintered bee colony) can be seen in Figure 2.

The static topological model $M_{,}=F_1(b_1,...b_k,...b_K;\ v_1,...,v_s,...v_S)$ is homomorphly changed into the dynamic model $M_b=F_b(b_1,...b_k,...b_K;\ v_1,...,v_s,...v_S;t)$ applying the software package *Powersim Constructor 2.51.* The parts of the dynamic model can be seen in Figures 3 and 4 correspondingly in the form of diagrams and equations. Choice of *Powersim Constructor 2.51* dynamic modelling software is determined by its flexibility in relation to the changes in a model, simple user interface and possibility to connect with the *Microsoft Excel* program for information exchange.

Under the conditions when sufficient information on the relations between the nodes is not available the surely known data to be expressed in the form of equation become the most valuable basic information of the model. These can become the tools for turning down the low quality data as deficient. Instead of the unknown relations it is necessary to introduce very approximate functions initially and they can be updated in the process of simulation.

Development of the simulation model in dynamics (model M_b) comprises one of the most important stages of the work - tuning the model on which the level of similarity of the model to the simulated processes in the biological system depends.

Verification of the simulation model in dynamics should be performed by the data collected in the nature and registered.

The verification operation is intended for checking the correctness of the simulated data of the model. It is necessary to minimise the deviations of the model from the measurements obtained in the field tests $Mi=F_1(b_l,...b_k,...b_K;\ v_1,...,v_s,...v_S;\ t)$.

$$\Delta_{ver} \geq \left|M_b - M_1\right| = F_b(b_k, v_s, t) - F_1(b_k, v_s, t), \qquad (8)$$

where A_{ver} - difference between the field measurements M_1 and the system model M_b,

k=l,K; s=l,S.

The maximum permitted verification error δ_{mver} can be specified separately for every parameter of the set B:

$$\delta_{veri} \geq \left|F_b(b_k) - F_1(b_k)\right|, k = 1, K. \qquad (9)$$

It is necessary to attempt to minimise the deviations from the measurements performed in the nature paying major attention to the comparison of the tendencies (growth, decrease, stagnation). When the difference between the test data M| and the model data M_b has become lower than the permitted Δ_{ver}, the **BCS model verification** has been performed and the model of the biological system $M_b= F_b(b_1,...b_k,...b_K;\ v_1,...,v_s,...v_S;\ t)$ can be considered as established. In the further operations this will replace the biological system.

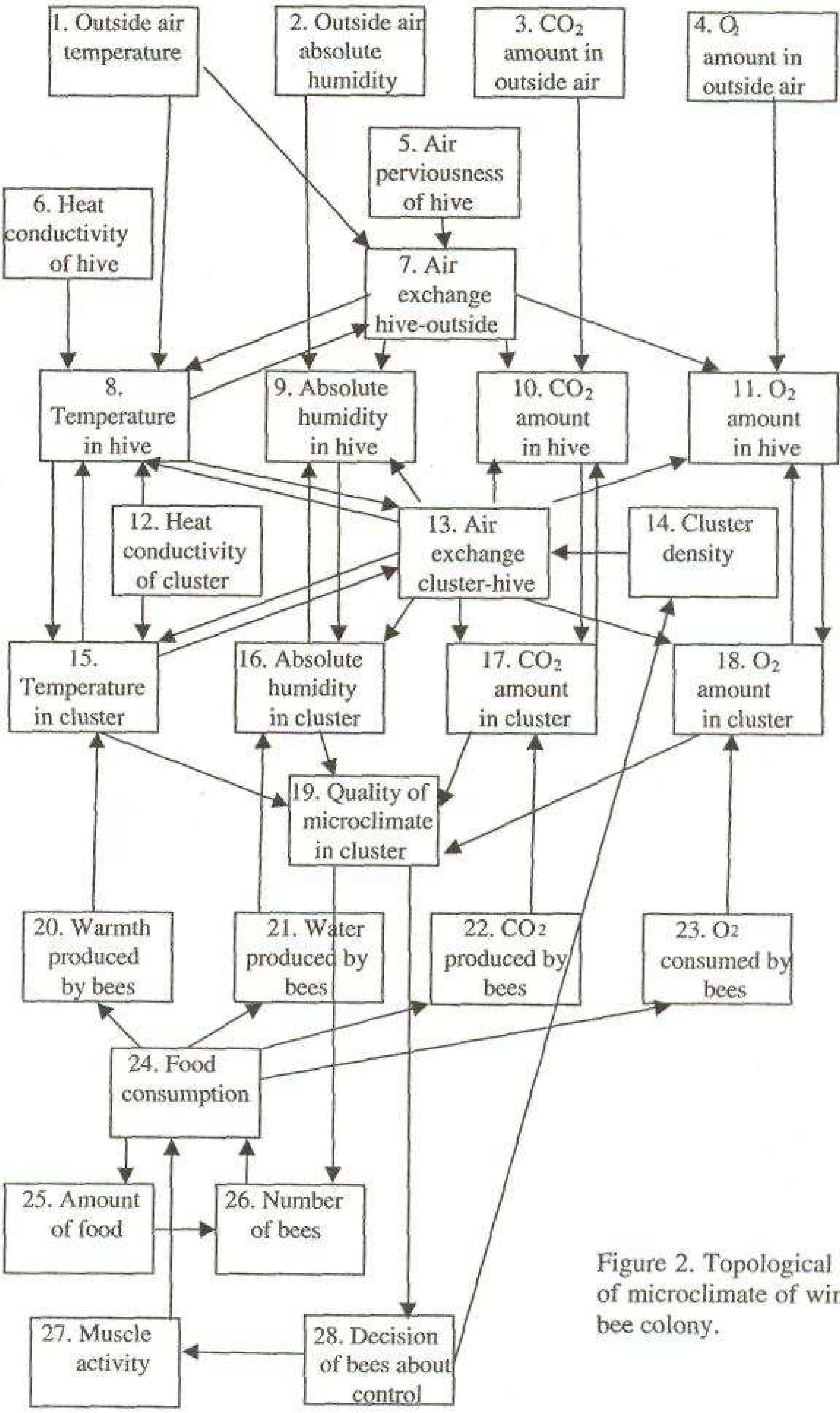

Figure 2. Topological model of microclimate of wintering bee colony.

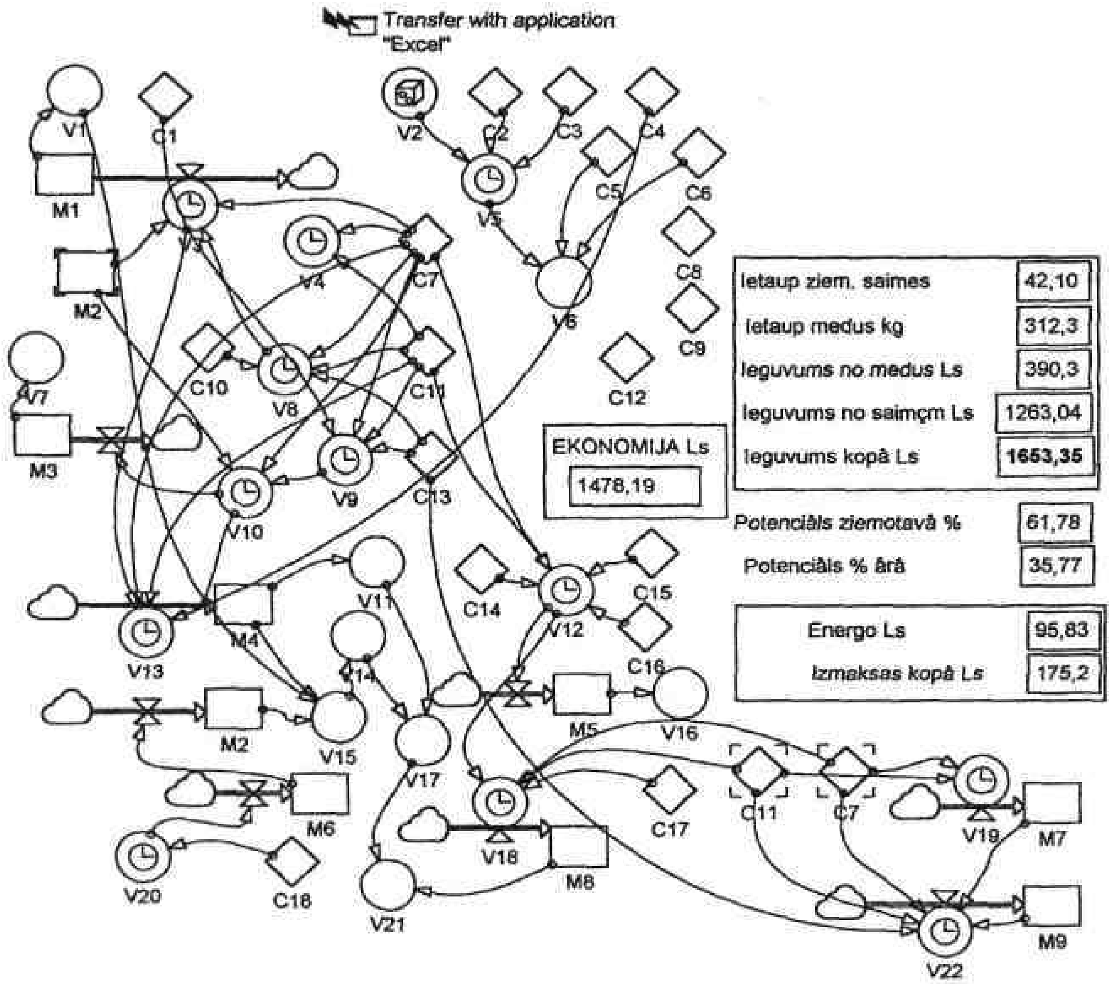

Figure 3. Part of microclimate model of bee colony in form of diagram (Powersim C 2.51).

```
M6
    0
    +dt*V20
    Dzimšanas grafiks. Nobīde laikā starp dēšanu un dzimšanu nav parādīta
M1
    0.6*20007
    -dt*V3
    Ziemojošo bišu kopējais potenciāls izteikts medus gramos. 0.6 grami ir vienas bites dzīves enerģētiskais
       potenciāls. 20007 - programmā lietotais ziemojošo bišu skaits. Potenciāls nemainās pēc bišu izņemšanas
       no ziemotavas.
V10
    IF(TIME>C7,0,IF(V9<=8, -0.014*V9+0.185, 0,061*V9-0,41))*M2*0,007571
    Aprēķins apēstā medus daudzumam saimēm ārā gaisā (kontrole) atkarībā no temperatūras. 0,007571 -
       pārrēķins no watu dienām uz medu. Balstās uz 1kg=3,17 kWh.
V12
    IF(TIME>=C11 AND TIME<=C7, (C14+C15+C16)*24/1000, 0)
    Kopējā patērējamā elektriskā jauda. 24/1000 - pāreja no W/d uz kWh. Šeit ierēķinē arī pastāvīgā ventilatora
       izmaksas.
V13
    IF((C11<=TIME) AND (TIME<=C7), (V10-V3)*0.001*C4, 0)
    Starpība barības patēriņā starp ziemotavas un ārā bitēm. Starpības nav, kamēr abas grupas atrodas ārā.
```

Figure 4. Part of microclimate model of bee colony in form of equations (Powersim C 2.51).

Verification is done by software *Powersim Solver 2.0,* which works with model created on *Powersim Constructor 2.51.* It provides model flexibility and changes done in the BCS model does not need to be changed for *Powersim Solver 2.0.*

Example of application. As application of development of the BCS model a topological model and dynamic model in software *Powersim Constructor 2.51* is made for a hive-wintered bee colony BCS of four parameters of microclimate in the winter cluster of bees. For creation of the topological model in the circumstances of insufficient information an expert evaluation is executed participating 12 experts. The "brainstorm" and methods of direct evaluation are applied. Methods for getting of functional relations between parameters in the circumstances of insufficient information are demonstrated. Software *Powersim Solver 2.0* is used for verification of dynamic model.

Section Three (The methodology for developing the artificial control system (ACS).)
For the purpose of implementing the control of the biological system - collaboration with BCS - it is necessary to establish ACS, which would be able to control the first one.

ACS usually is a technical system the structure of which depends on the task set for it (minimisation, maximisation, prevention of fluctuations, or the combination of these tasks for the sets of the parameters of the biological system).

The control task is being solved to satisfy the set of the control targets $G\{g_1,...,g_q\}$. A part of this algorithm (figure 5) comprises the study of the usefulness of the ACS model

$$M_c=F_c(c_1,...c_z,...c_Z;\ b_1,...b_k,...b_K;\ v_1,...,v_s,...v_S;\ t), \qquad (10)$$

where c_z - ACS parameters (z=l,Z),

without getting into detail of the transitional processes which would require a more detailed analysis of the system. The algorithm in essence has to establish whether the introduction of the ACS can be useful assuming that there will be no difficulties in the transitional processes.

The criteria of efficiency of ACS are set in the task definition or with the help of experts.
There is a set of possible solutions of the ACS establishment X. Its permitted solutions x_i, i=l,...,n form the set of the permitted solutions D_x.

The quality of every solution or its efficiency is assessed based upon the scalar criteria Vj, j=l,...,m, which jointly form the vector of efficiency

$$Y=(y_1,...,y_j,...,y_m.). \qquad (11)$$

Most often the Y components are the criteria of economic character combined with the criteria of other kinds. A few examples of the possible criteria which can be defined simultaneously: minimisation of the human work force, ecology, maximum speed for reaching the target, minimum deviations from the target value, etc.

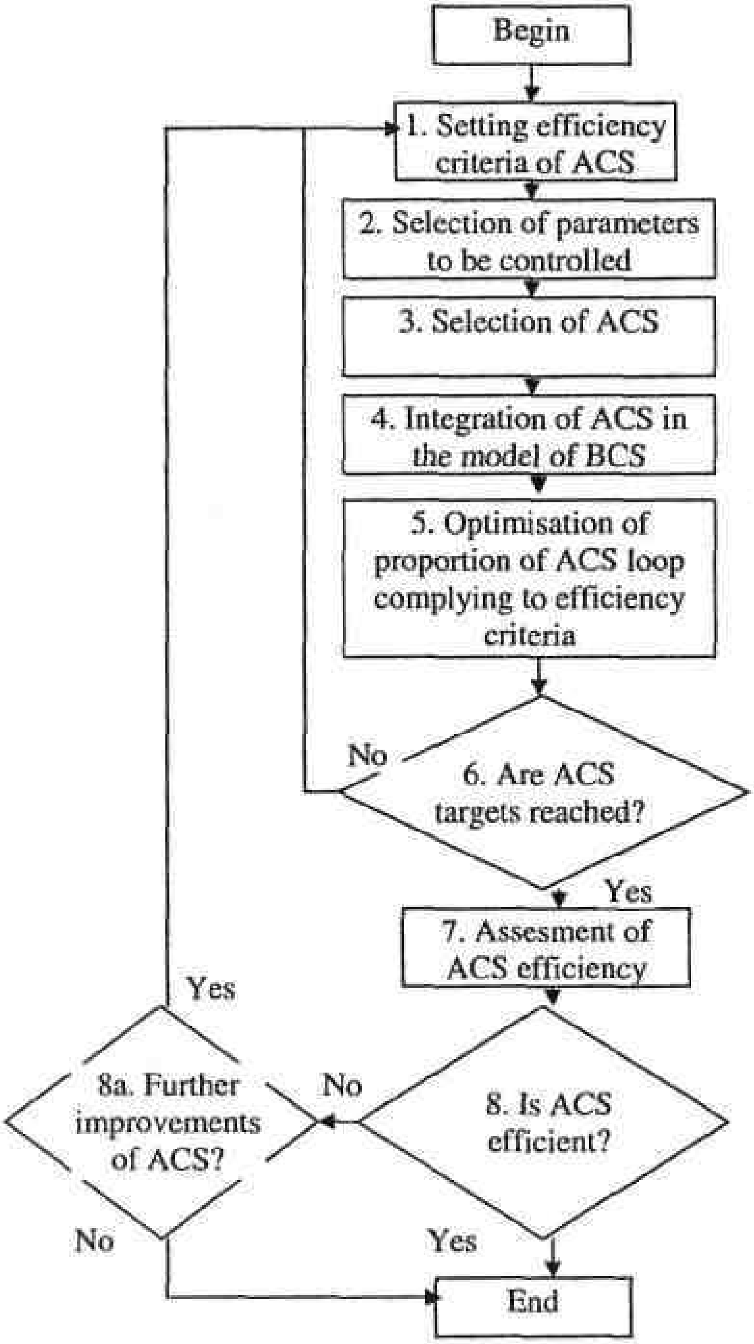

Figure 5. Algorithm of ACS development.

The selection of the parameters to be controlled is determined mostly by the technical possibilities - the measurability of the parameter and possibility to influence it, as well as the set of the control targets G and the efficiency vector Y.

The aim of **the selection of ACS** is to define the technical means to be able to control and supervise the selected parameters.

It is necessary to **integrate ACS in the model of BCS** to perform the simulations of the efficiency of its introduction. In this stage the model can be sufficiently simple because more detailed analysis of it will take place if it turns out that the implementation is useful.

Optimisation of the proportion of the ACS loop in compliance to the efficiency criteria usually is related to the search for compromises because not everything a man can do for reaching the control targets complies with the criteria of efficiency in the particular case.

The efficiency vector Y is related to the resolutions with the help of the reflection function

$$F(X) = X \rightarrow Y, \quad (12)$$

which can be set analytically, statistically or heuristically. The optimum solution X° should be found which would satisfy two conditions:

1. the solution should be feasible, i.e. it should belong to the set of the permitted solutions D_x,
2. the solution should be the best in the meaning that it should optimise the vector of efficiency Y(X).

The general form of the optimisation model is as follows (Borisovs, 1972):

$$X^0 = F^{-1}[optY(x)],$$
$$X \in D_x,$$

where *opt* - the optimisation operator of the efficiency vector,
F^{-1} - reverse reflection $Y \rightarrow X$.

The classic vectorial optimisation theory is related to 3 problems.

First of them is the selection of the optimisation principles which determines in what respect the optimum resolution *X*° is better than all the other permitted resolutions. In the model it means deciphering the essence of the optimisation vector *opt* leading to the scalar criterion, which, in turn, is the function of the local criteria.

The second problem is rationing of the local criteria.

The third problem is related to the evaluation of the weight coefficients A of the local criteria $\Lambda=\{\lambda_j\}$, j=l,...,m.

When the optimum resolution *X*° is found the optimum ACS model M_c° is defined.

The optimisation of the efficiency is performed based upon the proportion X of the ACS loop, which is expressed as percentage. The target of the ACS usually it to take over, ease or promote a function of the biological system for the purpose of satisfying some particular targets. Assuming that the maximum technically possible effect of ACS is 100% of the proportion of the ACS loop (X=100%) and the case when the ACS is not introduced at all is X=0%, it is possible to optimise efficiency of the system implementation. In case of one or several consistent criteria the optimum can be found by simple methods.

A more difficult compromise solution should be searched for in cases when the quality of every single local solution is assessed based upon several (at least two) criteria which are mutually conflicting, i.e. when the assessment of the solution becomes higher based upon one criterion it decreases based upon the other. It is a vectorial optimisation situation well known in the technical sciences when the global optimum should be searched for as a compromise solution.

"Fair compromise" optimisation method is selected for searching for the compromise (Borisov, 1972 and Jeme]janov, 1973).

In the search for the optimum solution X° the first step is to find the subset of the compromises based upon Pareto. For this purpose the $\Gamma_{x} \in D_x$ subset with the following characteristics is referred to as the subset of compromises: the solutions forming this subset cannot be corrected at once based upon all the criteria contained in the vector Y. Thus any two solutions of X_1, $X_2 \in \Gamma_x$ have contradicting assessments based upon at least one local criteria. If this condition is not complied with the search for the optimum is turned into the simple search for the maximum within the area of the compliant criteria.

The second step is to find the optimum solution X° in the subset Γ_x. The "fair compromise" method generally defines that the compromise (particular solution) is fair when its relative quality increase based upon one criterion does not exceed the relative quality decrease based upon another criterion.

The application of this thesis for the comparison of two solutions X_1 and X_2 can be described by Figure 6 where the quality assessments of the set of the solutions Γ_x based upon the local criteria y_1 and y_2 have been shown.

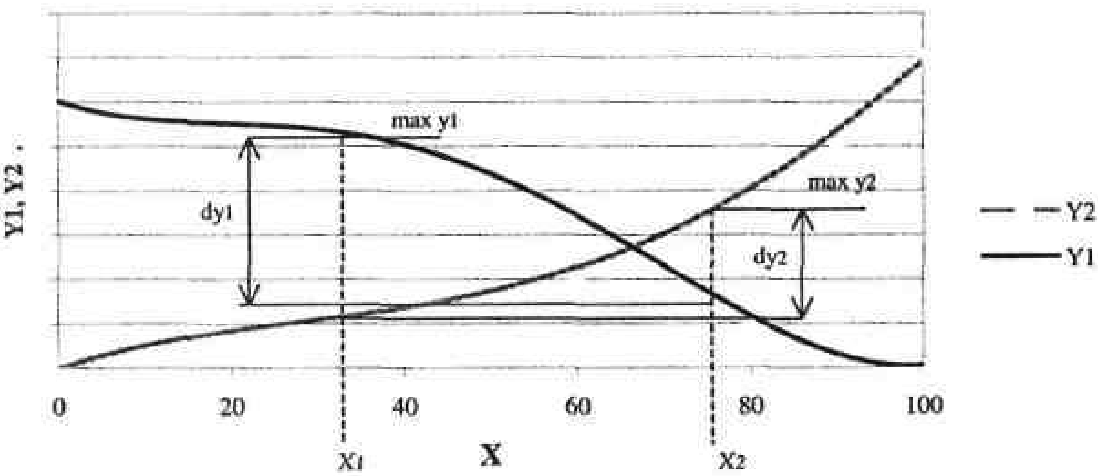

Figure 6. Geometric interpretation of "fair compromise" principle.

In this example the solution X_1 is of higher quality than X_2 based upon the criterion y_1 and of lower quality based upon the criterion y_2. However, generally the solution X_1 is of higher quality than X_2 only if $Y(X_1)>Y(X_2)$.

To compare both solutions following parameters are used:

$$\chi_1 = \frac{dy_1}{\max\limits_{x_1 x_2} y_1(x)} un \chi_2 = \frac{dy_2}{\max\limits_{x_1 x_2} y_2(x)}, \qquad (13)$$

where dy_1 and dy_2 - changes of quality accordingly to criteria comparing from one solution to another.

When $\chi_1 > \chi_2$, the solution Xi is preferred because the decrease of the quality dy_1 exceeds the quality increase dy_2, when we go from the solution Xi to the solution X2.

The optimisation model in this case is

$$\mathrm{X}^0 = F^{-1}[\max_j \prod_j y_j(x)] \quad (14)$$

or

$$\mathrm{X}^0 = F^{-1}[\max_{x\in\Gamma x} \sum_j \log y_j(x)], \quad (15)$$

which should be applied when all the local criteria are equally important corresponds to the above referred equations. When the criteria are not equally important and they have certain importance rates $\Lambda = (\lambda_1, \lambda_2,..., \lambda_n)$,, the optimisation model is

$$\mathrm{X}^0 = F^{-1}[\max_{x\in\Gamma x} \prod_j y_j^{\lambda_j}(x)] \quad (16)$$

or

$$\mathrm{X}^0 = F^{-1}[\max_{x\in\Gamma x} \sum_j \log_j^{\lambda_j}(x)] \quad (17)$$

Following the optimisation of the proportion of the ACS loop (finding the ACS model M_c° corresponding to X°) the collaboration of BCS and ACS should be analysed again by performing simulations with the optimised ACS (M_c°), to establish whether the target set for **ACS has been reached.**

Following the **assessment of ACS efficiency** of the optimised it can turn out that **further improvement of ACS** is necessary. In opposite case **ACS is effective** and development of ACS and optimisation of its efficiency is completed.

Now the algorithm for the coordination of the BCS and ACS control loops in the transitional processes has to be performed.

Example of application. ACS for bee wintering in bee wintering building with four controlled parameters of microclimate is developed. The system is optimised after the contradictory criteria of efficiency - maximal profit and maximal simplicity of ACS. In the ACS model 10 parameters of wintering process can be changed.

Section Four (The methodology for coordination of the operation of BCS and ACS). When the implementation of the ACS has turned out to be useful it is necessary to ensure the stable operation of the BCS and ACS to reach the control target and not to damage or destroy the system to be controlled in the transitional processes. The algorithm is shown in Figure 7.

For the purpose of evaluating the control process it is necessary **to combine BCS and ACS models in the real time including the transition processes.**

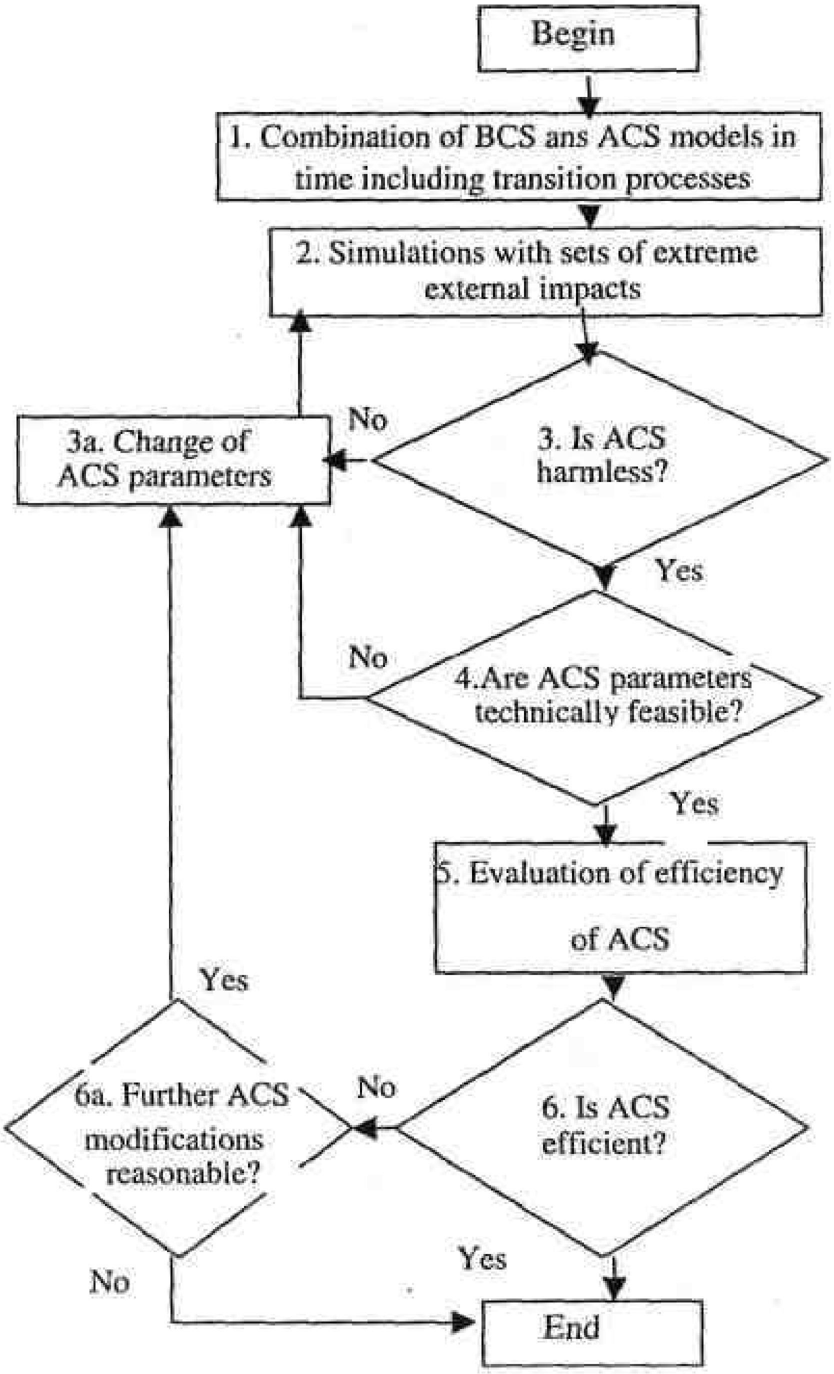

Figure 7. Algorithm for coordination of the operation of BCS and ACS.

Following the combination of the models the **simulations with sets of extreme real external impacts** is necessary. The extreme external impact for the purpose of transfer processes are the cases when the environment parameters V varies with maximum speed and thus requires also a fast reaction of the BCS which in natural conditions in most cases can ensure the survival of the system.

When the biological system is controlled the ACS must be correctly designed for extreme changes of the external parameters. The system must not be damaged during collaboration of BCS and ACS.

The permitted range of the changes of the system parameters under the natural conditions, i.e. without the influence from ACS may be set as the criteria of **ACS harmlessness** of the system to be controlled $J=\{j_1,...,j_h)$. Restrictions can be set also in the definition of the task:

$$J=Fj(b_k). \quad (18)$$

If simulations with sets of extreme external impact does not extend outside the range of the system parameters seen under the natural conditions the collaboration between BCS and ACS can be considered as harmless. Of course, the criteria of harmlessness can differ in their interpretation depending on the specific of the task because even killing the biological system can be set as a task for ACS (for instance: pest control).

In case when the criteria of harmlessness are not satisfied it is necessary to **change the ACS parameters** until the system generally complies with the harmlessness criteria on the level of simulations. Following the ensuring of the harmlessness it is necessary to check whether the new ACS **parameters are technically feasible.** When it is necessary to change the parameters of ACS for reaching the parameters found in the simulations a repeated **evaluation of the efficiency of corrected ACS** is necessary taking into account the performed corrections. The possible results of the ACS efficiency evaluation can be as follows 1) **further ACS modification** attempts are necessary to reach the harmlessness and efficiency of the system, 2) the conclusion that the task cannot be fulfilled and further search is not efficient, or 3) the conclusion that the complete task of ACS development has been fulfilled.

Example of application. The model of simulation of the BCS and ACS collaboration is created in software *Powersim Constructor 2.51.* With *Powersim Solver 2.0* software the ACS parameters are found, which satisfies the criteria of harmlessness.

Section Five (Conclusion.)

The **main results** (see the section in this Summary) are described.

The conclusions of the value of the Paper and the development perspectives have been summarised:

1) On the simulations based development of control system in case of the biological system diminishes necessary time and resources and carries considerable part of tuning of control system from the field experiments on computer simulations. Not of less importance is a complex understanding for the problem of control, which a model gives for each particular case.

2) The developed methodology is especially important in cases when the complexity of the system or lack of information to be studies determines the necessity for the collaboration and coordination of a big number of the computer experts and biologists. The algorithms for developing the models allow both the knowledge

engineer and the biological expert to perform their model development procedure minimising the subjective influence by other experts.

3) The methodology is able to include the most up-to-date science facts on the system to be simulated and this is ensured by the flexibility of both - the topological simulation and the applied simulation software package.

4) The developed methodology has wide area of application in industries - biotechnology, pharmacy, food processing industry and agriculture.

5) The methodology may be applied for the evaluation and possible optimisation of the control systems of operating biological systems.

6) The methodology can be adapted for the study of the interrelation of the complex biological systems to evaluate the consequences of the acts planned or performed by man also without the intentions of control.

7) Further development of the methodology could be directed towards the complex control of several biological systems - by developing the control system for fulfilling the targets in several biological systems by implementing different targets in relation to them, for example, to encourage the reproduction of a particular species at the same time harming another not needed species.

8) The methodology for the control of one biological system with the help of another biological system thus not applying the artificial system established by a man can turn out to be an interesting direction, for example, biological pest control.

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