PARAMETRIC ADAPTATION OF MODELS DESCRIBING STRUCTURE-DYNAMICS CONTROL PROCESSES IN COMPLEX TECHNICAL SYSTEMS (CTS)

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ABSTRACT

In this paper, a dynamical multiple criteria model of integrated adaptive planning and scheduling for complex technical system (CTS) is presented. Various types of CTS are used nowadays, for example: virtual enterprises, supply chains, telecommunication systems, etc. Hereafter, we mostly interpret CTS as the systems of the above-mentioned types. The adaptation control loops are explicitly integrated with the analytical-simulation model. The mathematical approach is based on a combined application of control theory, operations research, systems analysis, and modeling and simulation theory. In particular, a scheduling problem for CTS is considered in a dynamical interpretation. New procedures of dynamic decomposition help to find the parameters value of models adaptation. The example demonstrates a general optimization scheme to be applied to the problem of competencies division between the coordinating and operating levels of CTS via parametric adaptation of models describing structure-dynamics control processes.

INTRODUCTION

In practice the processes of complex technical systems (CTS) operation are non-stationary and nonlinear. It is difficult to formalize various aspects of CTS. The CTS models have high dimensionality. There are no strict criteria of decision making for CTS managing and no a priori information about many CTS parameters. Besides, the CTS operation is always accompanied by external and internal, objective and subjective perturbation impacts. The perturbation impacts initiate the CTS structure-dynamics and predetermine a sequence of control inputs compensating the perturbation.

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In other words we always come across the CTS structure dynamics in practice. There are many possible variants of CTS structure dynamics control (Ohtilev et al., 2006).

The above-mentioned CTS peculiarities do not let produce an adequate description of structure-dynamics control processes in existing and designed CTS on a basis of single-class models. That is why the concept of integrated modeling (comprehensive simulation) that was proposed by the authors can be useful here. Possible directions of its realization were considered in (Ohtilev et al., 2006, Zaychik et al., 2007). In this paper we propose new approach to the problem of parametric adaptation of models describing CTS structure-dynamics control. Existence of various alternative descriptions for CTS elements and control subsystems gives an opportunity of adaptive models selection (synthesis) for program control under changing environment.

Mathematical research of control processes in CTS can be divided into three primary approaches: optimization, simulation, and heuristics. *Optimization* is an analysis method that determines the best possible method of designing a particular complex system. Earlier literature presents several optimization-based approaches to CTS operation planning and scheduling. For instance, (Wu et al., 1999; Ko et al., 2001; Ip et al., 2004; and Wu and Su, 2005) have applied integer programming in supporting partner selection. (Ip et al., 2004) presented a branch and bound algorithm for subcontractor selection in agile manufacturing environment.

Simulation is imitating the behaviour of one system with another. By making changes to the simulated adaptive supply chains (ASC), one expects to gain understanding of the ASC dynamics. Simulation is an ideal tool for further analyzing the performance of a proposed design derived from an optimization model. Regarding the ASC complex adaptive systems (CAS) and multi agent systems (MAS) are one of the most popular simulation techniques (Swaminanthan et al. 1998; Rabelo et al., 2002). The past research on utilization of the MAS to the ASC have been mostly dealing with agent based frameworks and software architectures. It is mostly underestimated that these paradigms offer a valuable theoretical perspective on decentralized network management. (Nillson and Darley, 2006) proposed to combine CAS and MAS and to use the CAS as theoretical approach and MAS the implementation method. (Kuehnle, 2007) considers agents as a part of the complex of interrelated models for ASC planning.

Heuristics are intelligent rules that often lead to good, but not necessarily the best solutions. Heuristic approaches typically are easier to implement and require less data. However, the quality of the solution is usually unknown. Unless there is a reason that optimization cannot be used, heuristics are an inferior approach. In the ASC settings the nature based heuristics such as genetic algorithms (Huang et al., 2005) and ACO (Ant Colony Optimization) (Teich, 2003) are usually used. For instance, (Fischer et al., 2004) elaborated an approach for optimizing the selection of partners in production networks based on an ACO-algorithm.

In this paper we present a new integrated approach to planning control process in CTS. It accumulates three above-mentioned approaches.

Our investigations are based on results of the CTS adaptive control theory which is being developed now by Professor Skurihin V.I in Ukraine (Skurihin et al., 1989). The analysis of known investigations on the subject (Skurihin et al., 1989, Rastrigin, 1981, Bellman, 1972, Fleming, 1975, Nillson and Darley, 2006), confirms that the traditional tasks of CTS control should be supplemented with procedures of structural and parametric adaptation of special control software (SCS) (see fig.1 blocks 3, 7). Here the adaptive control should include the following main phases:

– parametric and structural adaptation of structure-dynamics control (SDC) models and algorithms to previous and current states of objects-in-service (SO), of control subsystems (CS), and of the environment (see fig.1, blocks 1,2,3);

– integrated planning and scheduling of CTS operation (construction of SDC programs) (blocks 4,5);

– simulation of CTS operation, according to the schedules, for different variants of control decisions in real situations and analysis of planning and scheduling simulation (blocks 6);

– structural and parametric adaptation of the schedule, control inputs, models, algorithms, and SDC programs to possible (predicted by simulation) states of SO, CS, and of the environment (blocks 7),

– realization of CTS structure-dynamics control processes (blocks 8).

To implement the proposed concept of adaptive control let us consider two groups of parameters (Skurihin et al., 1989, Rastrigin, 1980, 1981) for CTS SDC models and algorithms: *parameters that can be evaluated on the basis of real data available in CTS; parameters that can be evaluated via simulation models for different scenarios of future events*.

The adaptation procedures can be organized in two blocks (models) (Ohtilev, 2006, Skurihin et al., 1989): *external adapter of planning and scheduling models; internal adapter of planning and scheduling models*.

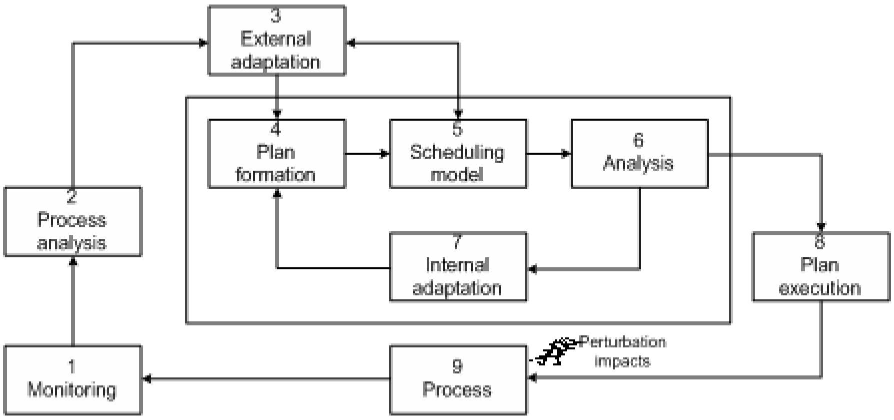
When the parametric adaptation of SCS does not provide simulation adequacy then the structural transformations can be needed. Two main approaches to structural model adaptation are usually distinguished (Bellman, 1972, Rastrigin, 1980, 1981). The first approach lies in the selection of a model from a given set. The model must be the most adequate to SO and CS. The second approach stands for CTS SDC model construction of elementary models (modules) in compliance with given requirements. The second approach provides more flexible adjustment of SO and CS for particular functioning conditions. However, the first one is faster and can be effective if the application knowledge base is sufficiently large.

Both approaches need active participation of system analysts and decision-makers who interact with special control software of simulation system (SIS) and consider hard-formalizing factors and dependences within the general procedure of CTS SDC program selection.

Let us consider formal statement of structural and parametric adaptation problems for CTS SDC models and after that we are going to investigate the problem of parametric adaptation for models describing CTS structure-dynamics control. Adaptation of algorithms and control software does not belong to the scope of this paper.

We have implemented the conceptual model and technology of parametric and structural adaptation of models describing CTS SDC processes via original simulation system (SIS). This simulation system consists of the following elements (Moiseev, 1974, Sowa, 2002): a) simulation models (the hierarchy of models); b) analytical models (the hierarchy of models) for a simplified (aggregated) description of objects being studied; c) informational subsystem that is a system of data bases (knowledge bases); d) control-and-coordination system for interrelation and joint use of the previous elements and interaction with the user (decision-maker).

In this paper we want to describe and to investigate concrete algorithm of parametric models adaptation via integrated modeling and simulation procedures which are realized in the SIS.



Figures 1: Conceptual model of parametric and structural adaptation (Skurihin et al., 1989)

PROBLEM STATEMENT

We assume that there are several variants of CTS SDC models inscribed in the set $\overline{\overline{M}} = \{M_1, M_2, ..., M_W\} = \{M_\Theta, \Theta \in I\}$, $I = \{1, ..., W\}$, moreover the vector $\vec{\beta}$ of CTS parameters includes the subvector $\vec{\beta}_0$ of fixed CTS characteristics and besides of it the subvector $\vec{w} = \| \vec{w}^{(1)\mathrm{T}}, \vec{w}^{(2)\mathrm{T}}, \vec{w}^{(3)\mathrm{T}} \|^{\mathrm{T}}$ of parameters being adjusted through SS external/internal adapter or defined within structural adaptation. According to (Skurihin et al., 1989), these parameters can be divided into the following groups: $\vec{w}^{(1)}$ is a vector of parameters being adjusted through the internal adapter; $\vec{w}^{(2)}$ is a vector of parameters being adjusted through the external adapter; $\vec{w}^{(3)}$ is a vector of parameters being adjusted within structural adaptation of CTS SDC models.

Now we can present the modified multiple-model multi-criteria description of CTS SDC problems:

$$\vec{J}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\beta}, \vec{\xi}(t), t\right) \to \underset{\vec{u}(t)\in\Delta_\Theta}{\mathrm{extr}}, \qquad (1)$$

$$\Delta_\Theta = \{\vec{u}(t) \mid \vec{x}(t) = \vec{\varphi}_\Theta\left(T_0, \vec{x}(T_0), \vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right)\}, \qquad (2)$$

$$\vec{y}(t) = \vec{\psi}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right), \qquad (3)$$

$$\vec{x}(T_0) \in X_0(\vec{\beta}_\Theta), \quad \vec{x}(T_f) \in X_f(\vec{\beta}_\Theta), \qquad (4)$$

$$\vec{u}(t) = \| \vec{u}_{pl}^{\mathrm{T}}(t), \vec{v}^{\mathrm{T}}\left(\vec{x}(t), t\right) \|^{\mathrm{T}};$$

$$\vec{u}_{pl}(t) \in Q_\Theta\left(\vec{x}(t), t\right);$$

$$\vec{v}(t)\left(\vec{x}(t), t\right) \in V_\Theta\left(\vec{x}(t), t\right);$$

$$\vec{\xi}(t) \in \Xi_\Theta\left(\vec{x}(t), t\right); \; \vec{\beta}_\Theta \in \mathrm{B};$$

$$\vec{x}(t) \in X\left(\vec{\xi}(t), t\right);$$

$$\vec{\beta}_\Theta = \| \vec{\beta}_0^{\mathrm{T}} \; \vec{w}^{\mathrm{T}} \|^{\mathrm{T}};$$

$$\vec{w} = \| \vec{w}^{(1)\mathrm{T}} \; \vec{w}^{(2)\mathrm{T}} \; \vec{w}^{(3)\mathrm{T}} \|^{\mathrm{T}} \; . \qquad (5)$$

The formulas define a dynamic system describing CTS structure-dynamics control processes. Here $\vec{x}(t)$ is a general state vector of the system, $\vec{y}(t)$ is a general vector of output characteristics. Then, $\vec{u}(t)$ and $\vec{v}\left(\vec{x}(t), t\right)$ are control vectors. Here $\vec{u}(t)$ represents CTS control programs (plans of CTS functioning), $\vec{v}\left(\vec{x}(t), t\right)$ is a vector of control inputs compensating perturbation impacts $\vec{\xi}(t)$). The vector $\vec{\beta}_\Theta$ is a general vector of CTS parameters. The vector of CTS effectiveness measures is described as (6).

$$\vec{J}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right) = \| \vec{J}_\Theta^{(g)\mathrm{T}}, \vec{J}_\Theta^{(o)\mathrm{T}}, \vec{J}_\Theta^{(k)\mathrm{T}}, \vec{J}_\Theta^{(p)\mathrm{T}}, \vec{J}_\Theta^{(n)\mathrm{T}}, \vec{J}_\Theta^{(e)\mathrm{T}}, \vec{J}_\Theta^{(c)\mathrm{T}}, \vec{J}_\Theta^{(\nu)} \| \qquad (6)$$

Its components state control effectiveness for motion, interaction operations, channels, resources, flows, operation parameters, structures, and auxiliary operations (Ivanov et al., 2006). The indices «*g*», «*o*», «*k*», «*p*», «*n*», «*e*», «*c*», «ν» correspond to the following models: models of order progress control ($M_{<g,\Theta>}$); models of operations control ($M_{<o,\Theta>}$); models of technological chains control ($M_{<k,\Theta>}$); models of resources control ($M_{<p,\Theta>}$); models of flows control ($M_{<n,\Theta>}$); models of operations parameters control ($M_{<e,\Theta>}$); models of structures control ($M_{<c,\Theta>}$); models of auxiliary operations control ($M_{<\nu,\Theta>}$). In (5) the transition function $\vec{\varphi}_\Theta\left(T_0, \vec{x}(T_0), \vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right)$ and the output function $\vec{\psi}_\Theta\left(\vec{x}(t), \vec{u}(t), \vec{\xi}(t), \vec{\beta}_\Theta, t\right)$ can be defined in analytical or algorithmic form within the proposed simulation system; $Q_\Theta\left(\vec{x}(t), t\right)$, $V_\Theta\left(\vec{x}(t), t\right)$,

$\Xi_{\Theta}(\vec{x}(t),t)$ are correspondingly allowable areas for program control, real-time regulation control inputs, perturbation inputs; B is a area of allowable parameters; $X(\vec{\xi}(t),t)$ is an area of allowable states of CTS structure-dynamics. Expression (4) determines end conditions for the CTS state vector $\vec{x}(t)$ at time $t = T_0$ and $t = T_f$ (T_0 is the initial time of a time interval the CTS is being investigated at, and T_f is the final time of the interval).

The problem of CTS structure-dynamics control includes tasks of three main classes: ***Class A problems*** (problems of structured analysis, problems of CTS structure-dynamics analysis under or without perturbation impacts); ***Class B problems*** [estimation (observation) problems, monitoring problems, problems of CTS structural state identification]; ***Class C problems*** (problems of control-inputs selection and problems of CTS parameters selection, i.e., multi-criteria control problems for CTS structures, modes, and parameters, and multi-criteria problems of CTS structure-functional synthesis). In a general case the formal statement of CTS structure-dynamics control problem can be written as follows.

We are given: space-time, technical, and technological constraints (2)-(5) determining variants of CTS SDC at the operation phase; vector (1) of CTS effectiveness measures.

We should determine: $\vec{u}_{pl}(t)$, $\vec{v}(\vec{x}(t),t)$, and $\vec{\beta}_{\Theta}$ meeting the constraints (2)-(5) and returning optimal value to the general effectiveness measure $J_{\Theta}^{(ob)} = J_{\Theta}^{(ob)}(\vec{x}(t),\vec{y}(t),\vec{\beta}_{\Theta},\vec{u}(t),\vec{\xi}(t))$.

There are two main groups of methods to be used for choice $\vec{\beta}_{\Theta}$ (Skurihin et al., 1989, Rastrigin, 1980, 1981, Bellman, 1972, Zypkin, 1969, Bryson, 1969): identification methods of parametric adaptation; simulation methods of parametric adaptation. In this paper we propose integrated procedure which helps us to find only vector $\vec{w}^{(1)}$. Others results which interrelate with parametric models adaptation are described in the book (Ohtilev et al., 2006).

ALGORITHM OF PARAMETRIC ADAPTATION OF MODELS DESCRIBING STRUCTURE-DYNAMICS CONTROL PROCESSES

The input data for the CTS planning and scheduling models adaptation is being gathered during the CTS functioning at the state S_{i-1} and is being receives to the state S_i. Thus we get formulas (Ohtilev et al., 2006, Moiseev, 1974, Chernousko, Zak, 1985, Singh, Titli, 1978):

$$P_H = P_H\left(\vec{x}(t),\vec{u}_{pl}(t),\vec{v}\left(\vec{x}(t),\vec{\xi}\right),\vec{\xi}\right) \to \max_{\vec{u}\in\Delta}, \quad (7)$$

$$\Delta = Q(\vec{x}(t)) \times V\left(\vec{x}(t),\vec{\xi},t\right), \quad \vec{u} = \vec{u}_{pk}(t)\times\vec{v}\left(\vec{x}(t),\vec{\xi}\right) \quad (8)$$

where P_H is an index of CTS efficiency, $\vec{x}(t)$ is a state vector, $\vec{u}_{pk}(t)$ is the main vector of control inputs, in other words it is a control program for the CTS dynamics, $\vec{v}$ is a vector of control inputs compensating perturbation impacts over the control program; $Q(\vec{x}(t))$ and $V\left(\vec{x}(t),\vec{\xi},t\right)$ are the sets allowable controls $\vec{u}_{pk}(t)$ and $\vec{v}\left(\vec{x}(t),\vec{\xi}\right)$ respectively; $\vec{\xi}(t)$ is a vector of perturbation impacts, where $\vec{\xi}(t) \in \Xi(\vec{x}(t),t)$.

The general efficiency measure (7) can be evaluated as a functional of $\left(\vec{x}(t),\vec{u}_{pl}(t),\vec{v}\left(\vec{x}(t),\vec{\xi}\right),\vec{\xi}\right)$ via simulation experiments with the CTS operation model. Unfortunately, direct analytical expressions cannot be received. Therefore, the search for concrete control programs $\left(\vec{u}_{pl}(t)\right)$ is very difficult, since the high dimensionality of the vectors $\left(\vec{x}(t),\vec{v}\left(\vec{x}(t),\vec{\xi}\right),\vec{\xi}\right)$ hinder optimization through directed simulation experiments. This is why we propose the following heuristic decomposition of models (7)-(8). The decomposition is based on the structural peculiarities of these models.

The general efficiency measure of the forecasted states can be evaluated as a functional of the enumerated values via simulation experiments with the CTS operation model. In this case the following group of tasks substitutes for the initial problem of the CTS control problem (7), (8):

$$P_H = P_H\left(\vec{x}(t,\vec{\lambda}'),\vec{u}_{pl}(t,\vec{\lambda}'),\vec{v}\left(\vec{x}(t,\vec{\lambda}'),\vec{\xi}\right),\vec{\xi}\right) \to \max_{\vec{\lambda}'\in\Delta'} \quad (9)$$

$$\Delta' = \{\vec{\lambda}' \mid \vec{u}_{pl}(t,\vec{\lambda}')\times\vec{v}\left(\vec{x}(t,\vec{\lambda}'),\vec{\xi}\right) \in Q\left(\vec{x}(\vec{\lambda}')\right)\times V\left(\vec{x}(\vec{\lambda}'),\vec{\xi}\right)\}, \quad (10)$$

$$\sum_{\gamma'\in\Gamma'} \lambda'_{\gamma'} J_{\gamma'}(\vec{x}_{\gamma'}) \to \underset{\vec{x}_{\gamma'}\in D_{\gamma'}\left(T_f,T_0,\vec{x}_{\gamma'}(T_0)\right)}{extr}, \quad (11)$$

$$\sum_{\gamma'\in\Gamma'} \lambda'_{\gamma'} = 1,\ \lambda'_{\gamma'} \geq 0,\ \vec{x}_{\gamma'} = \| \vec{x}^{(\gamma')\mathrm{T}} \vec{x}^{(o)\mathrm{T}} \|^{\mathrm{T}},\ \gamma' \in \Gamma'. \quad (12)$$

Here the vectors $\vec{x}_{\gamma'}(T_f)$ returning optimal values to function (16) are being searched for, while the vector $\vec{\lambda}'_{(l)}$ is fixed ($l = 0,1,2,...$ is the number of the current iteration). The set Δ' includes indices of analytical models obtained via the proposed decomposition. The received problems of mathematical programming have several important features. The search for components of the vector $\vec{x}_{\gamma'}^{(l)}$ can be fulfilled over subsets of the *attainability sets* $D_{\gamma'}\left(T_f,T_0,\vec{x}_{\gamma'}(T_0)\right)$ rather than over the whole sets of allowable alternatives. The subsets include non-dominated alternatives of the enumerated models. The non-dominated alternatives can be received via the orthogonal projection of the goal sets to the *attainability sets* $D_{\gamma'}\left(T_f, T_0, \vec{x}_{\gamma'}(T_0)\right)$. Each particular model include the state vector $\vec{x}^{(o)}$ of the operations model $M_{<o>}$ besides own state vectors $\vec{x}^{(g)}$, $\vec{x}^{(k)}$,..., $\vec{x}^{(c)}$. The above-mentioned structural features of problem (11), (12) let use decomposition and overcome problem of high dimensionality.

When the vector $\vec{x}^{(l)}_{\gamma'}(T_f)$ is known, the optimal programs $\vec{u}^{(l)}_{pl}(t, \vec{\lambda}'_{(l)})$ for the CTS control can be defined within each analytical model $M_{\gamma'}$, $\gamma' \in \Gamma'$ via numerical methods (for example, via Krylov and Chernousko's method (Chernousko, Zak, 1985, Petrosjan, Zenkevich, 1996, Roy, 1996). The programs $\vec{u}^{(l)}_{pl}(t, \vec{\lambda}'_{(l)})$ are used for evaluation of a new approximation of the vector $\vec{\lambda}'_{(l+1)}$ in the simulation model $M_{<u>}$ describing the CTS functioning under perturbation impacts.

The problem of $\vec{\lambda}^*$ search is similar to the problem of optimal experiments design. Here elements of the vector $\vec{\lambda}'$ are endogenous variables and the efficiency measure (14) is an exogenous one. Different methods can be used for optimal design of experiments, for example the method of quickest ascent, the methods of random search. In conclusion we note that components of the vector $\vec{\lambda}'$ can define the preferable control inputs $\vec{v}\left(\vec{x}(t, \vec{\lambda}'), \vec{\xi}\right)$ for compensation of mismatch of the planned trajectory of CTS dynamics with the predictable (via simulation) trajectory. Finally we propose example which illustrates one aspect of analytical-simulation procedure (9)-(12).

Structure-dynamics control processes in CTS (see formulas (1)-(5)) depend upon internal and external stochastic factors. These factors should be described through more detailed simulation models of CTS operation. These models include a deterministic component $\left(\vec{u}_{pl}(t), \vec{v}\left(\vec{x}(t), \vec{\xi}\right)\right)$ describing schedules of activities and a stochastic component $\left(\vec{\xi}\right)$ describing random events (see (5)). The considered activities contributed to managerial and work and documentation. These activities could be performed at different nodes of CTS, however the sequence of activities was strictly determined within a previously obtained schedule (plan). The stochastic factors included random background and unexpected operations diverting personnel from the plan. The stochastic factors and complex interrelations of activities necessitated application of simulation. Hence, CTS optimization was to be performed via series of simulation experiments. In this situation analytical models were used to narrow parameters variation range.

This example demonstrates a general optimization scheme to be applied to the problem of competencies division between the coordinating and operating levels of CTS. The network included a coordinating level (center) and six operating levels (subsystems). Here the structural adaptation of the CTS models implied testing of different plans. The parametric adaptation of the models requires a determination of the optimal ratio of competencies (functions or tasks) expressed in man-hours. Thus, $\lambda'_{\gamma'}$ (see (11)) expresses the share of node γ' in the total amount of work. The optimization was carried out in order to reduce the plan duration. The simulation system GPSS World 4.3.5 (Minuteman Software) was used. The results presented below describe dependencies between the goal value (plan duration, hours) and the factor (competencies ratio).

The following general scheme of computations was used.

1) Problem Definition. The following global optimization problem is considered:

$$F(P_1, P_2, \ldots, P_n) \to min, \qquad (13)$$

where $PL_i \le P_i \le PM_i,\ i=1,\ldots,n.$

The parameters P_i correspond to the values $\lambda'_{\gamma'}$ in (11).

In this example the function *F()* expresses the plan (project) duration to be minimized.

The function (13) is defined through a simulation model. The value of the function is a probabilistic characteristic (the expectation of a plan duration) to be obtained in simulation runs.

The arguments $P_1, P_2, \ldots, P_n$ are model parameters (the ratio of competencies) to be varied in order to receive the minimal (the best) value of function (13).

2) Computing. The first phase. Simulation runs are being carried out. The greater total number of runs the higher is the accuracy of a solution. The run number k corresponds to a random point $(P_{1k}, P_{2k}, \ldots, P_{nk})$ of even distribution, where $PL_i \le P_{ik} \le PM_i,\ i=1,\ldots,n.$ The values $P_{1k}, P_{2k}, \ldots, P_{nk}$ and $F(P_{1k}, P_{2k}, \ldots, P_{nk})$ are stored for each k. In the GPSS World system the runs are being conducted via the "Experiment" tool of the PLUS language. The DoCommand Method is used.

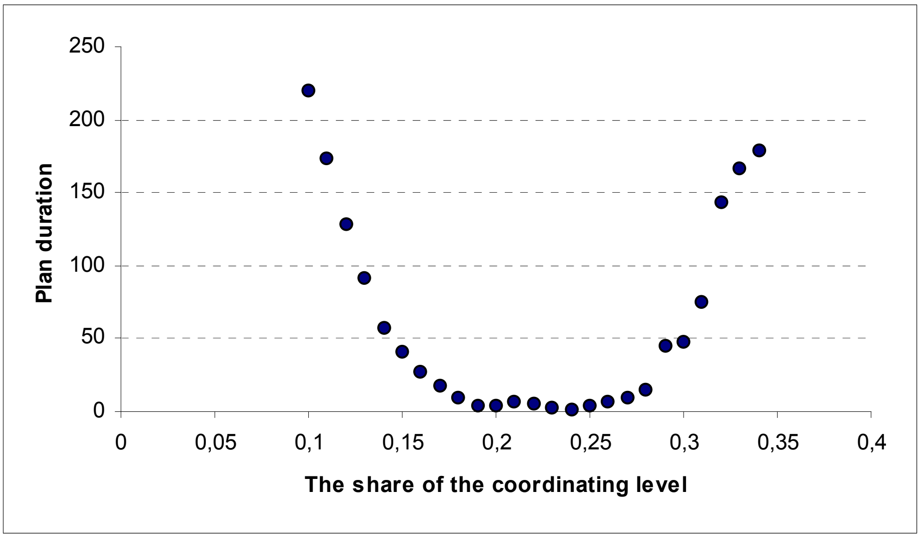
3) Computing. The second phase. The functions $f(s)$, $H(s)$ are being approximated for the stored sample. Here $f(s)$ is a measure of the set

$Q_s=\{(q_1, q_2, \ldots, q_n) | F(q_1, q_2, \ldots, q_n) <= s, PL_i \le q_i \le PM_i,\ i=1,\ldots,n\}$,

$H_i(s)$ is the average value of the parameter P_i over the set Qs.

It is assumed that the smallest s^* such that $f(s^*)=0$ is the minimal value of the function $F(\bullet)$, and $P_i^* = H_i(s^*)$, $i=1,\ldots,n$ are the optimal values of parameters.

If there holds $|F(P_1^*,P_2^*,\ldots,P_n^*)-s\ |>e$, where e is a given level of accuracy then additional simulation runs are needed. The results of calculations are illustrated in fig. 2. Here we assume that the operating levels are unified and receive equal amounts of work, so the share of the coordinating level is to be obtained. Hence the n-tuple $(q_1,q_2,\ldots,q_n)$ was substituted for the scalar value q. It holds $0<=q<=1$. Here the left point of the graph (see fig. 2) provides the best ratio (0.23) of coordinator - executors competencies, i.e. the coordinating level receives 23% of the total amount of work.



Figures 2. Value-factor dependency, increased number of runs for a selected interval

Fig. 2 illustrates the optimization problem with non-unimodal goal function. The proposed computational scheme provides global extremum for this case.

CONCLUSIONS

The proposed approach to structure-dynamics description lets adapt heterogeneous models to the changing environment.

Dynamic decomposition of control problems helps to determine parameters of models adaptation.

There are following advantages of the proposed approach.

Joint use of diverse models (optimization, simulation, and heuristic) in the framework of poly-model systems, allows one to improve the flexibility and adaptability of planning processes in CTS, as well as to compensate the drawbacks of one class of models by the advantages of the other.

The adaptive plans (programs) of CTS functioning include transition programs as well as programs of stable CTS operation in intermediate multi-structural macro-states. One of the main opportunities of the proposed method of CTS SDC program construction is that besides the vector of program control we receive a preferable multi-structural macro-state of CTS at the end point. This is the state of CTS reliable operation in the current (forecasted) situation.

Father investigations should include an analysis of the influence of external factors upon the convergence of the planning procedures. Attributes of Pareto's set of the multi-criteria problem (see formulas (11)-(12)) will be analyzed.

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