# *"Planning and scheduling by optimal control: fundamentals and applications for cyber-physical and Industry 4.0 systems"*


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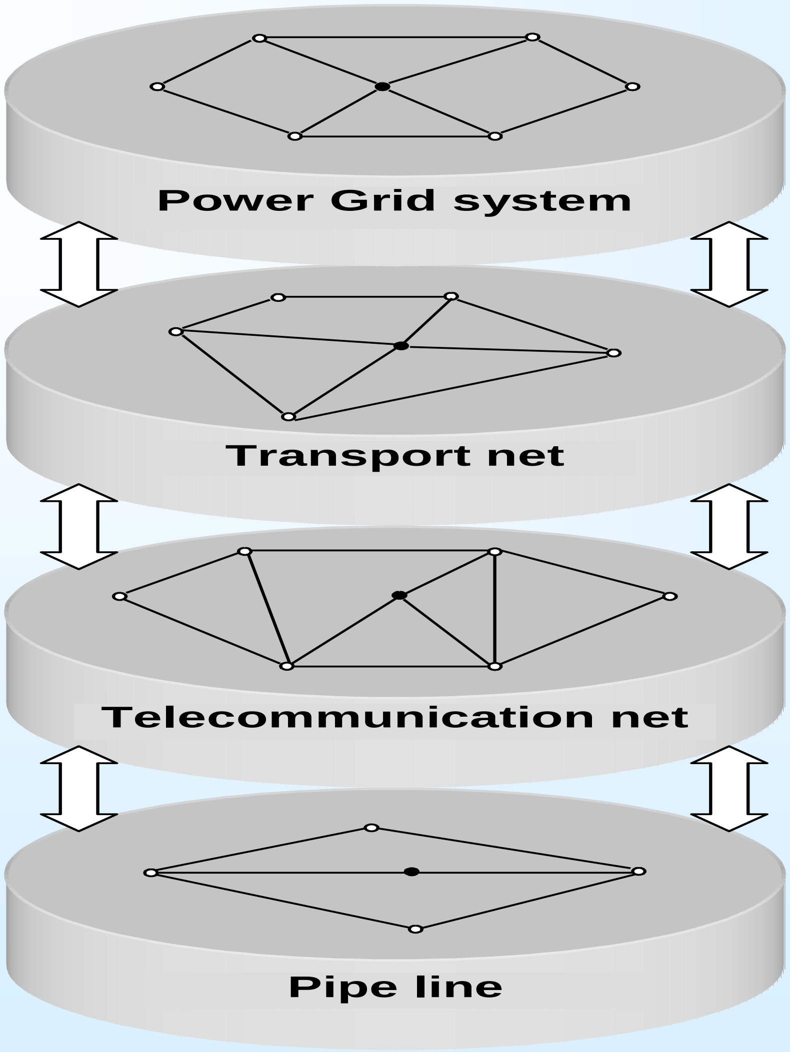
# Presentation Outline

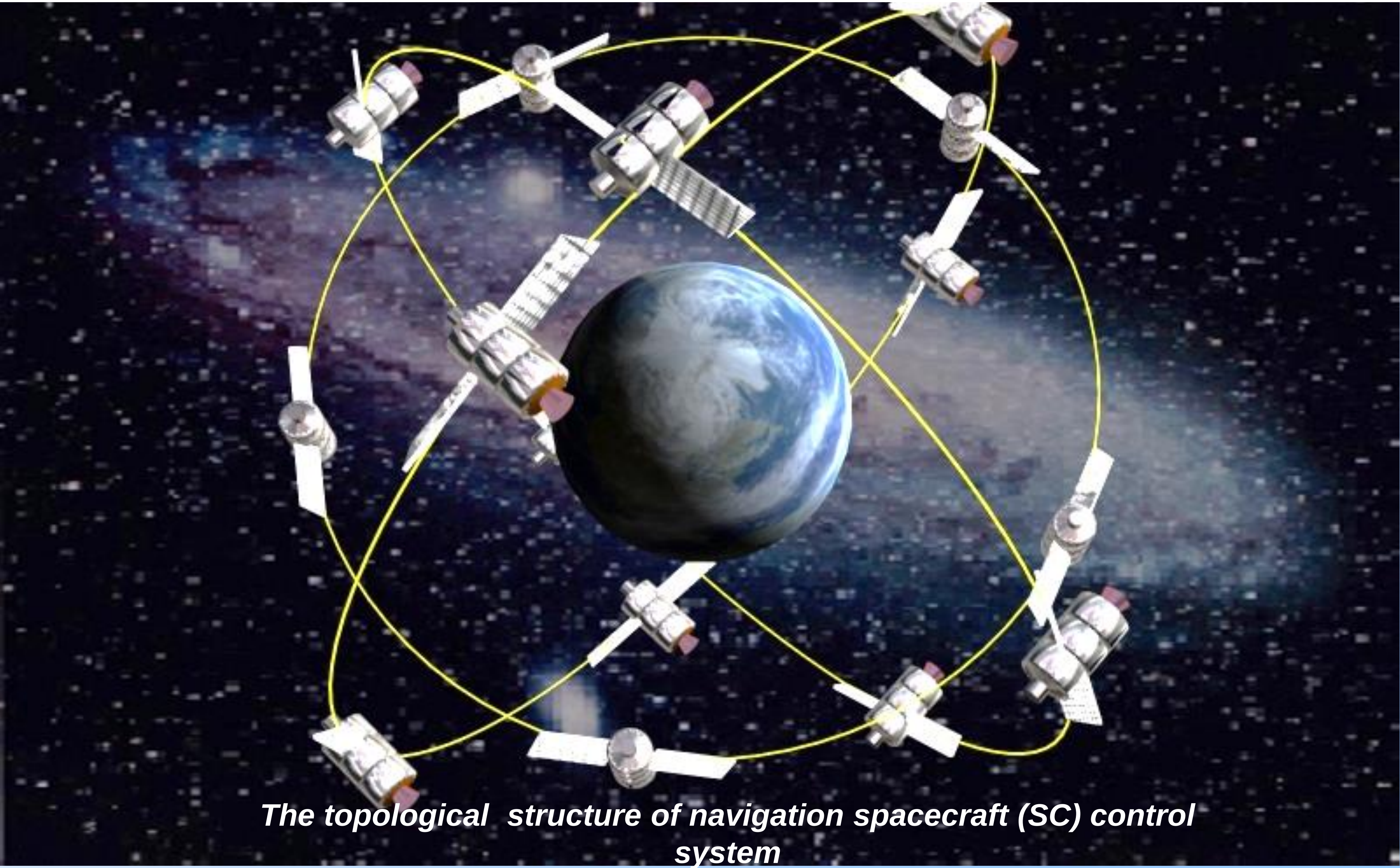
1. *Introduction*
2. *Concept and Formal Level of Complex Object (CO) Planning and Scheduling Problem*
3. *Methodological Basis of CO Planning and Scheduling by Optimal Control*
4. *Examples of CO Planning and Scheduling by Optimal Control*
5. *Conclusion*

# Main subject of research – complex objects (CO)

## (Example 1)

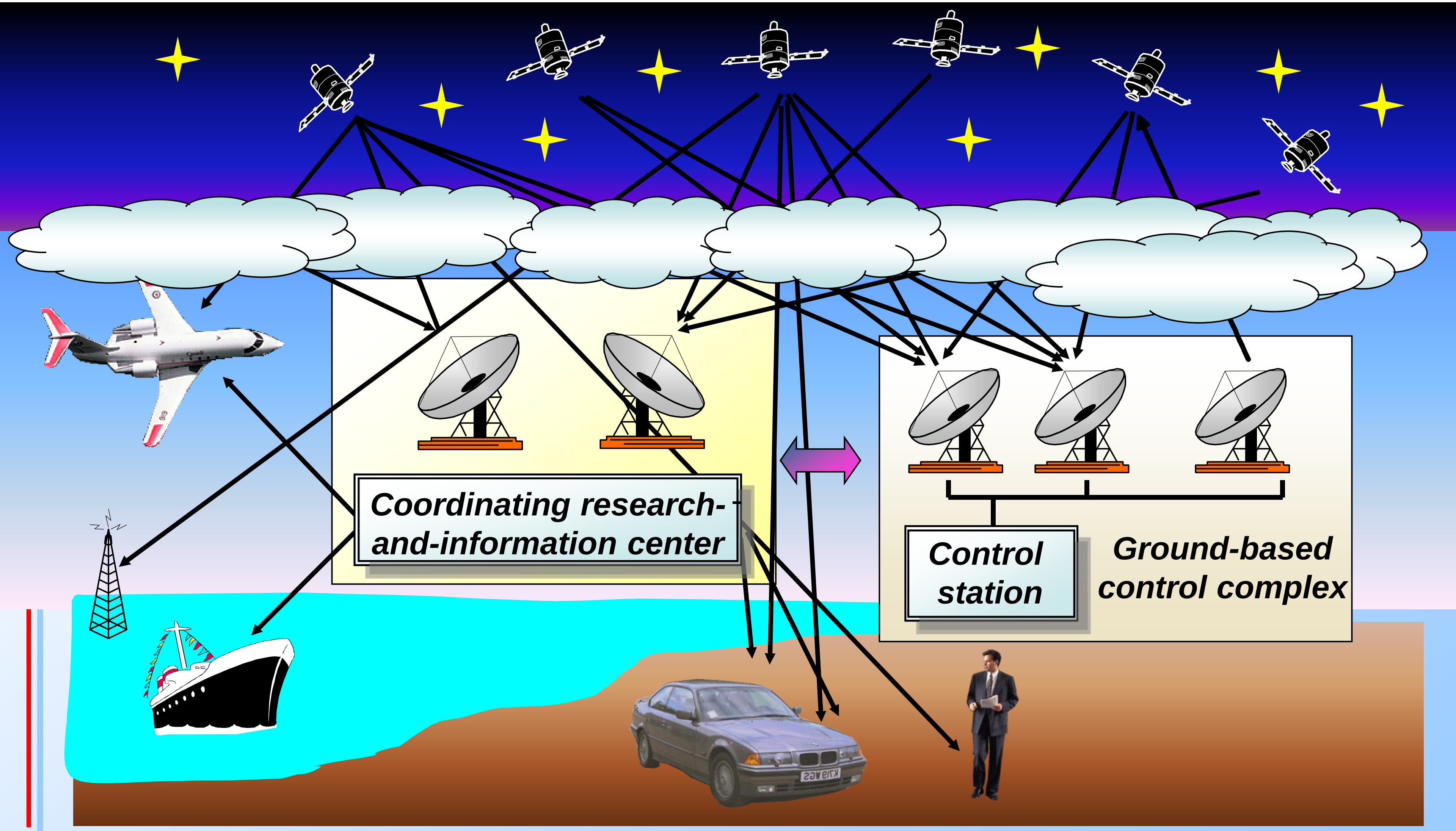


# Main subject of research – complex objects (CO)
**(Example 2)**



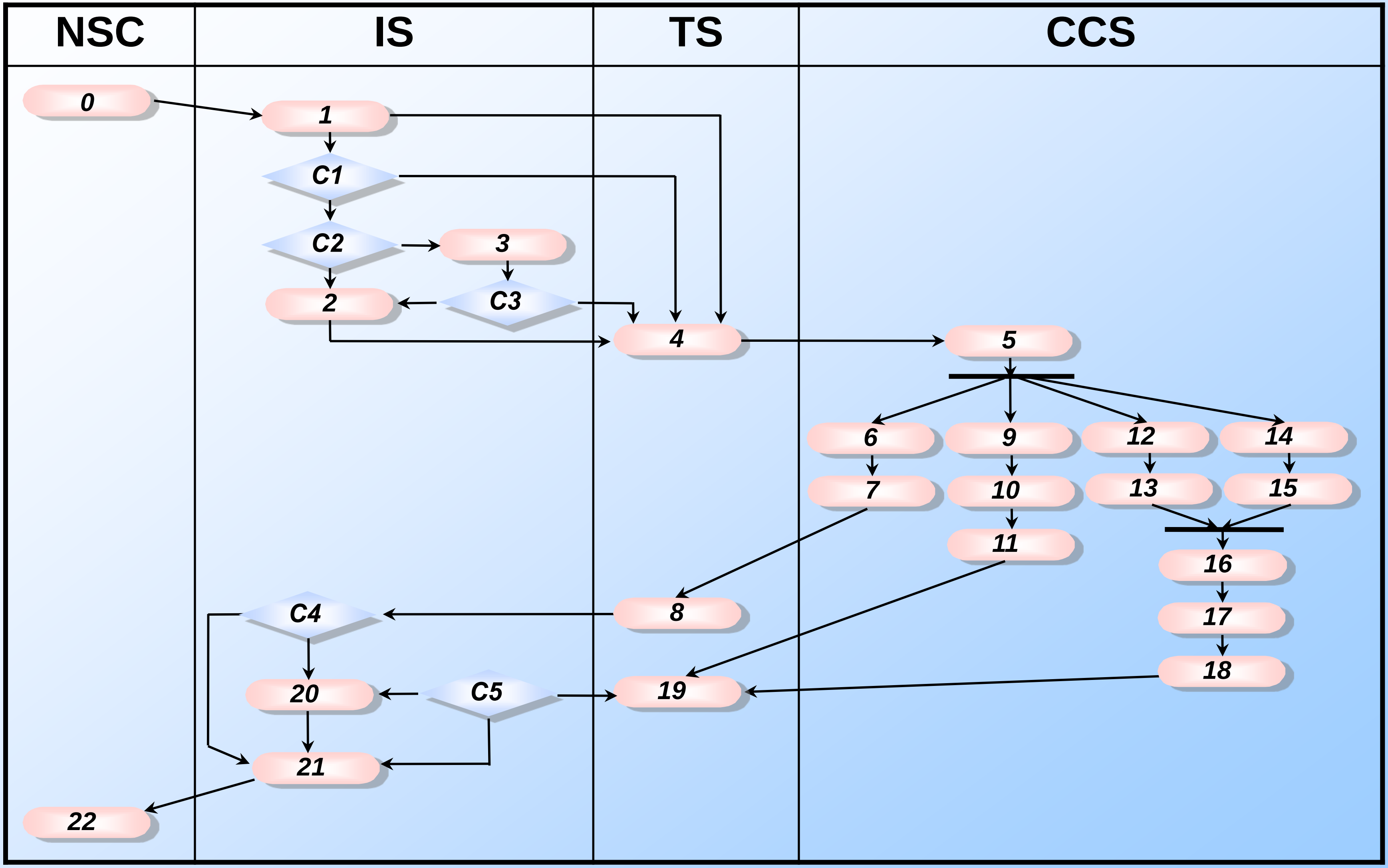
*The topological structure of navigation spacecraft (SC) control system*

# Main subject of research – complex objects (CO)
## (Example 2)



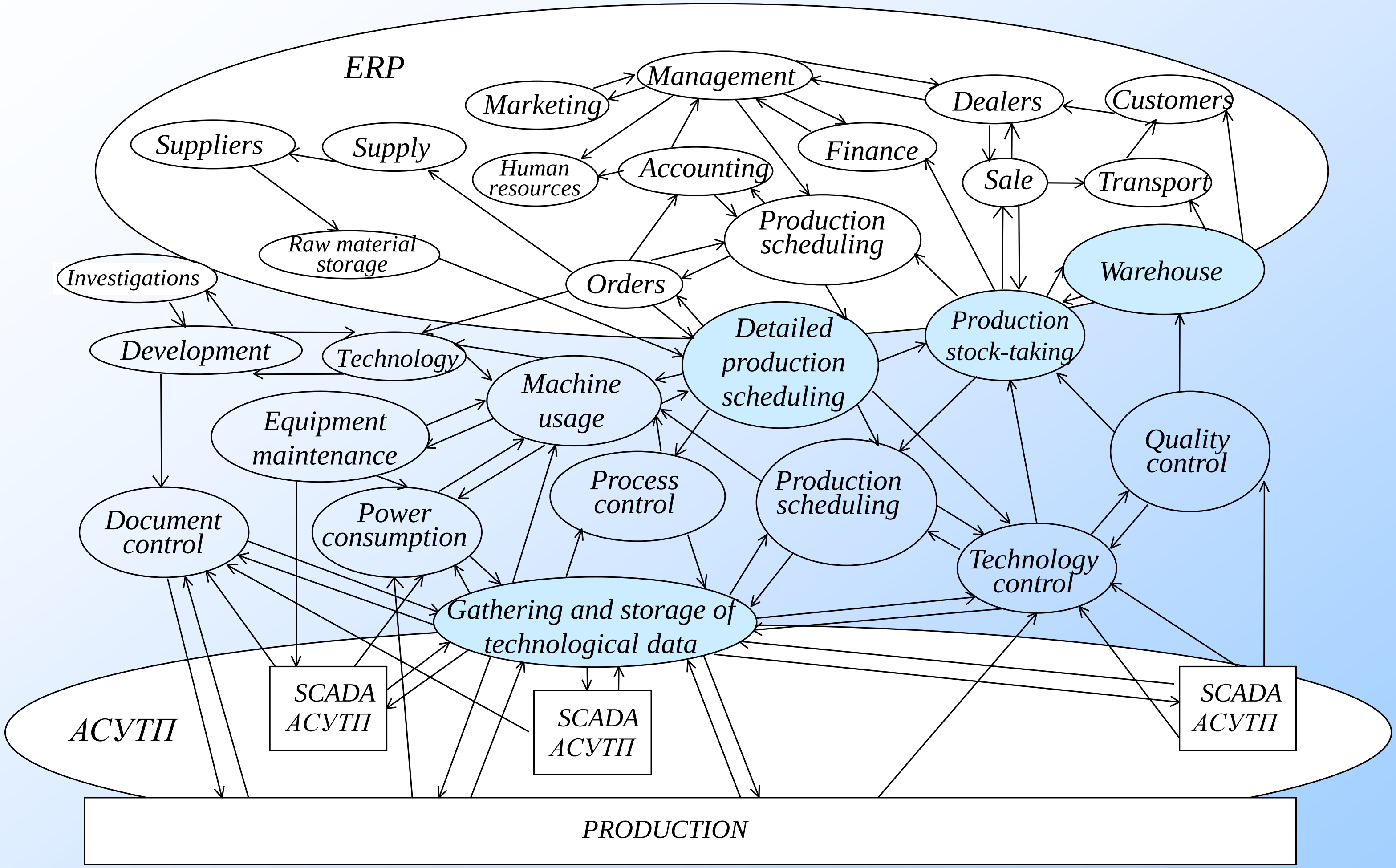

*Technical-organizational structures of Navigation Spacecraft Control System (CS)*

# Main subject of research – complex objects (CO)
## (Example 2)




*The functional structure of Navigation Spacecraft Control System*

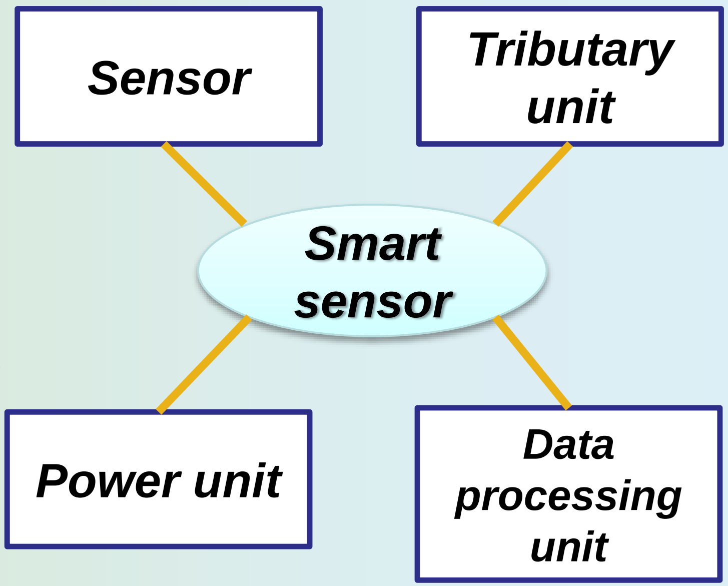
# Automated Control Systems of Enterprise
# Main subject of research – complex objects (CO). (Example 3)




***ERP** - Enterprise Resource Planning System, **MES** -Manufacturing Execution Systems, **SCADA** -Supervisory for Control and Data Acquision.*

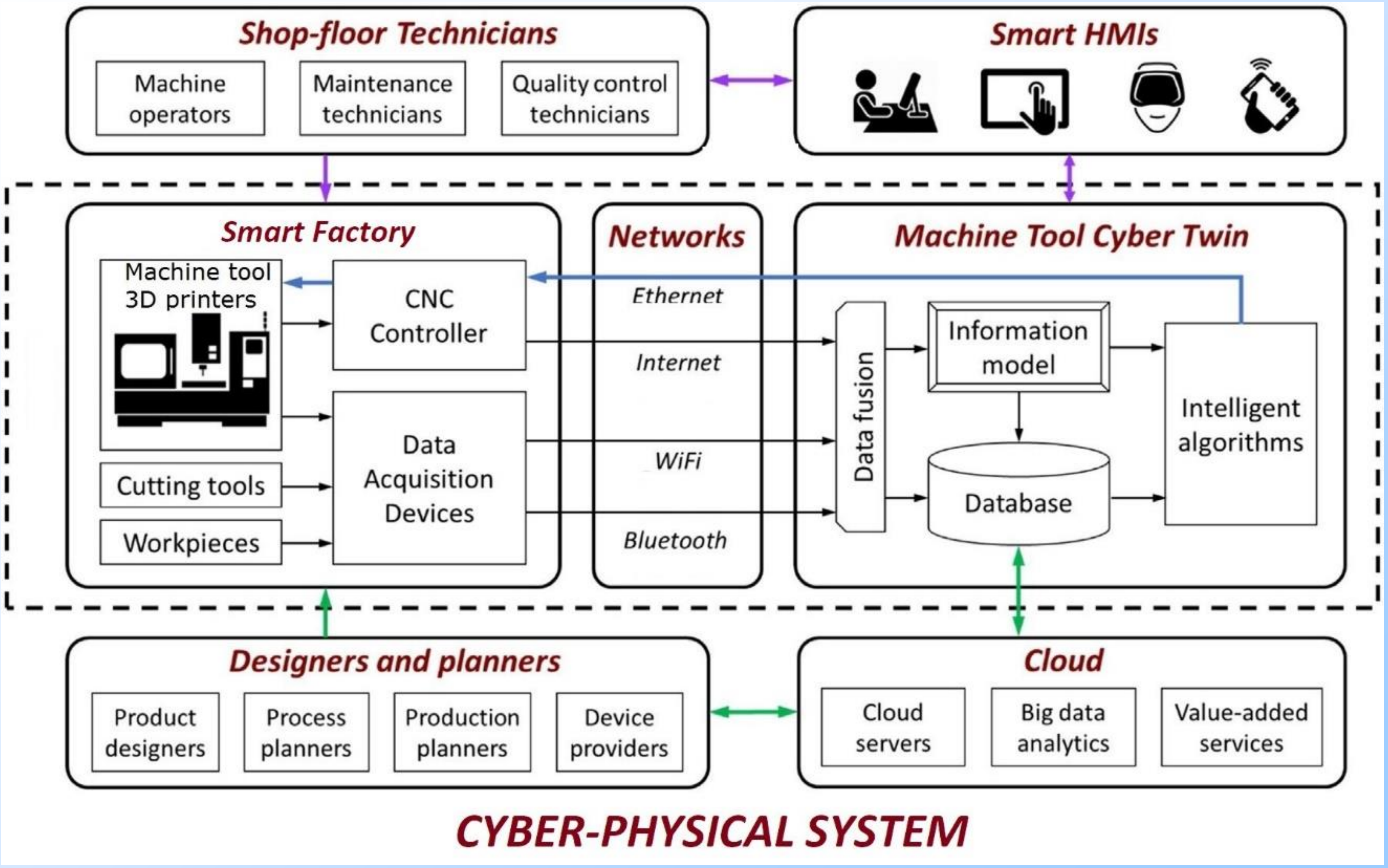
# Cyber-physical systems

*The CPS allow to realize principles and technologies of feed-back control not only for technical objects but also for other types of complex objects*




*Currently management and control of CFS interactions are not yet fully formalized*

# Cyber-physical systems and Smart Factory



# The place of planning and scheduling phases in CO automation control system (ACS) generalized technology (part 1)

*Planning and scheduling are essential functions in complex object management and control technology.*

***Planning stage***

*- preliminary aggregated evaluation of the possibility for performing the given sets of CO operations on the given sets of CO resources*

***Scheduling stage***

*- concrete distributions of CO tasks, jobs, works, operations, and flows among the CO resources in time*

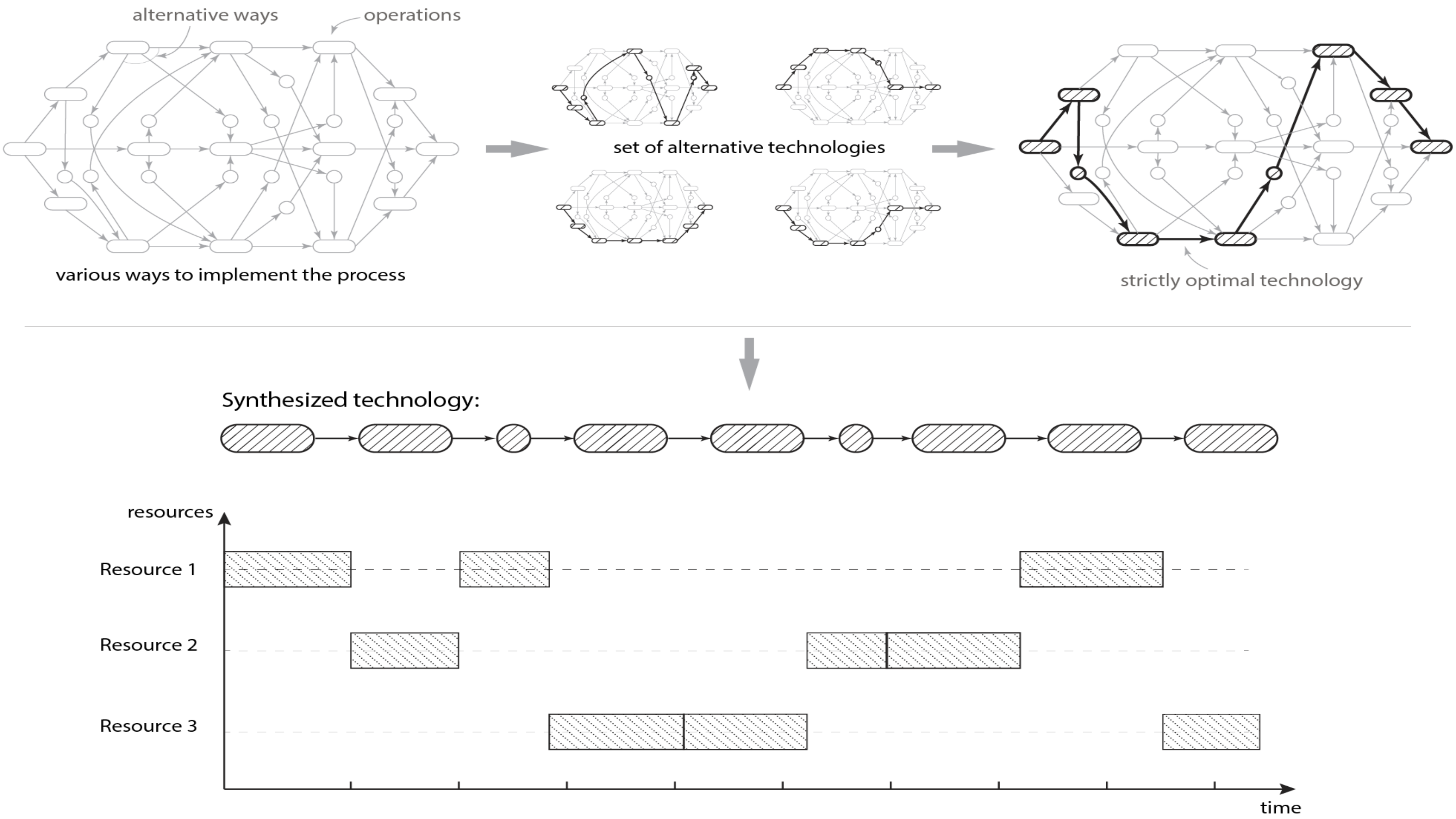
# The place of planning and scheduling phases in CO automation control system (ACS) generalized technology

***Now in the sphere of CO planning and scheduling are distinguished different types of tasks:***

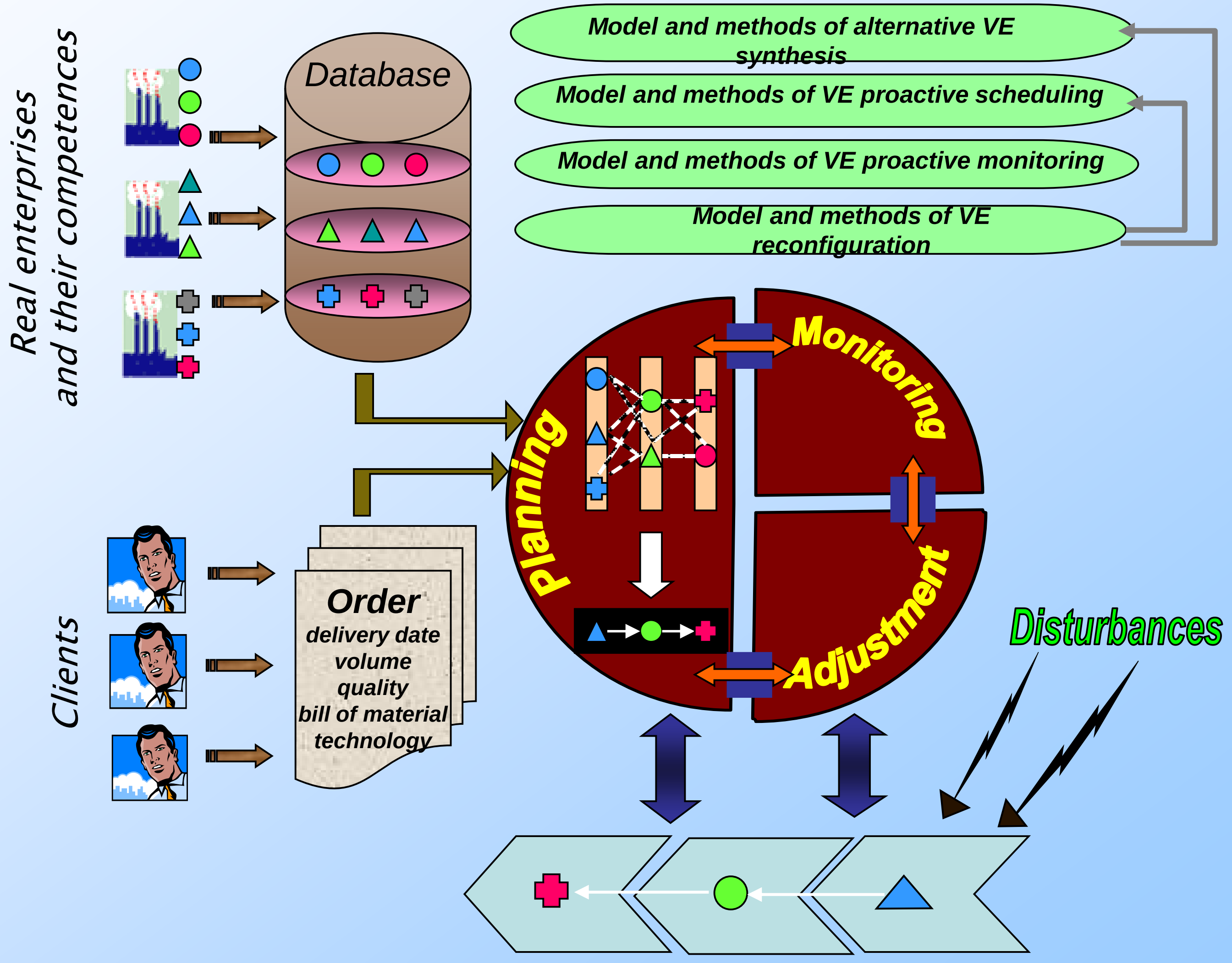
- ***Open shop*** *planning and scheduling tasks;*
- ***Job shop*** *planning and scheduling tasks;*
- ***Flow shop*** *planning and scheduling tasks;*
- ***Release dates*** *planning and scheduling tasks;*
- ***Recourse Constrained Project*** *planning and scheduling tasks****.***

***We propose to expand the last generalized class of CO planning and scheduling tasks adding up the tasks of parallel synthesis of production technologies, production management, and control technologies***

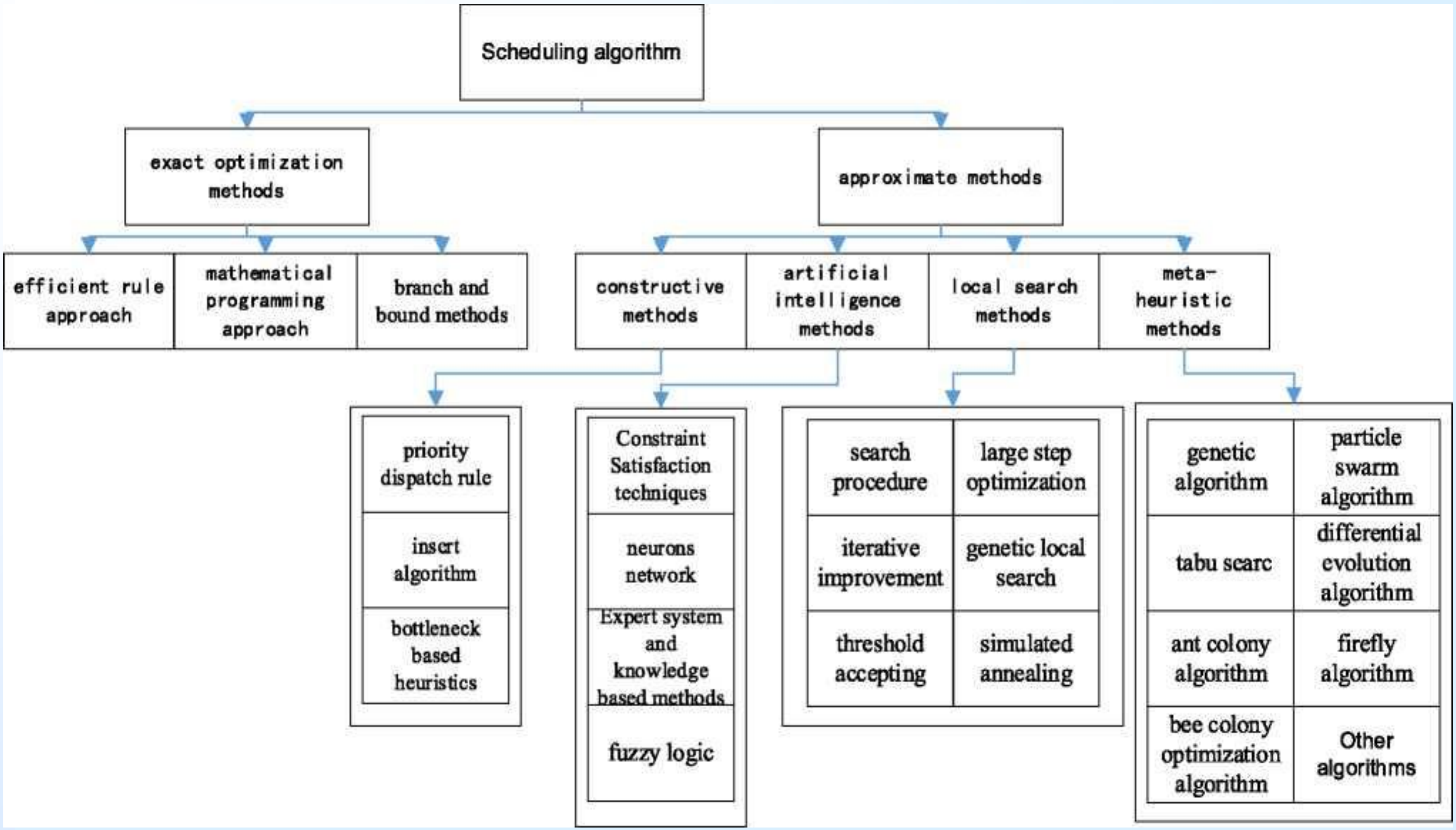
# The interconnection tasks of synthesis production technologies, production management and control technologies synthesis with tasks of planning and scheduling in Industrial Internet of Things



# The interconnection tasks of synthesis production technologies, production management and control technologies synthesis with tasks of planning and scheduling in Industrial Internet of Things



# The exist methods and algorithms for solving CO planning and scheduling problems



# Fundamental problems of CO planning and scheduling

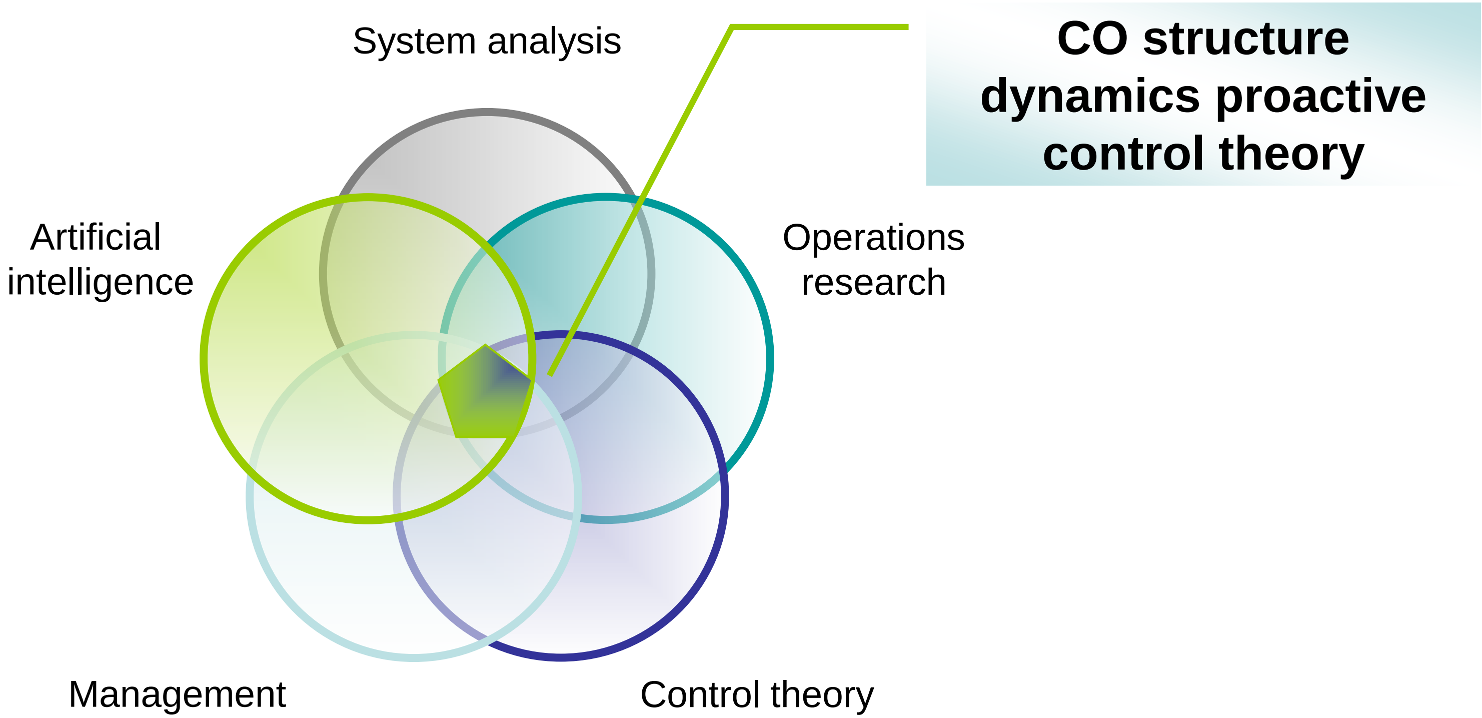
- *problem of* ***high dimensionality non-linearity****,* ***and non-stationarity*** *of CO models;*
- ***problem of uncertainty factors description;***
- ***problem of multi-criteria decision making*** *on the basis of multiple-model complex****;***
- ***problem of parallel synthesis of*** *production technologies, production management (control) technologies and CO plan, schedule* ***;***

*The main features and difficulties of the problems belonging* ***to the last class*** *are following:*

- *optimal control programs for CO main elements and subsystems can be implemented* ***only when the list of functions and algorithms for control is known****.*
- *In its turn, the distribution of the functions and algorithms among the CO elements and subsystems* ***depends on the control laws*** *actual for these elements and subsystems.*

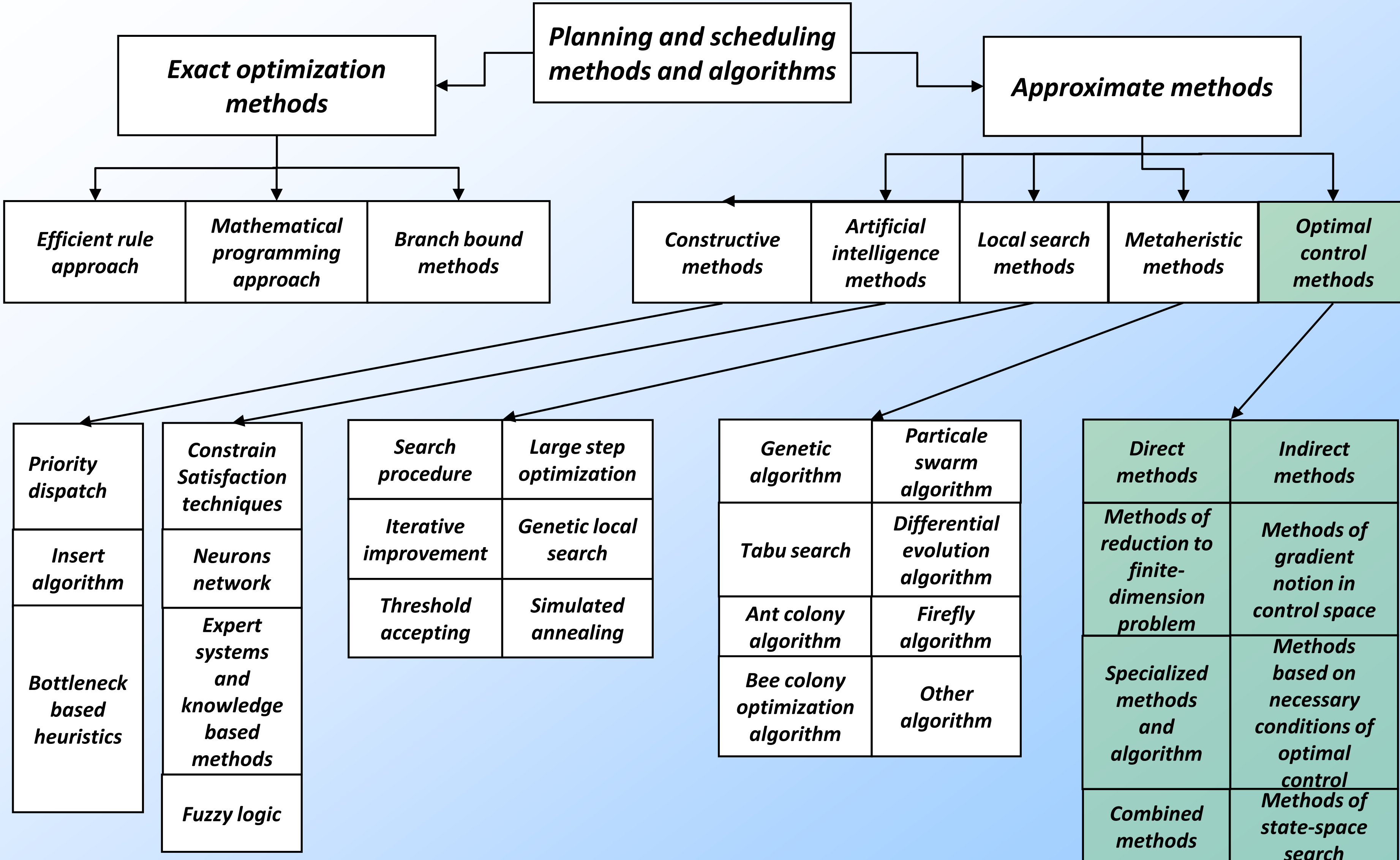
# Our solution for CO planning and scheduling problems by optimal control

***We propose a new applied theory of complex objects structural dynamics proactive control which is accumulats the main fundamental and practical results of different modern theories: system analysis, operation research, artificial intelligence, management, control theory***

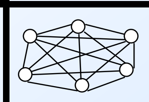
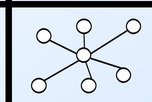
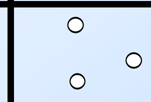
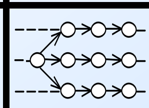
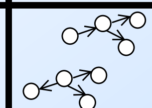
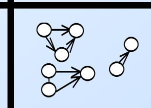
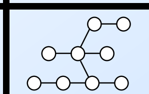
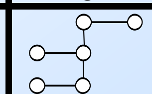
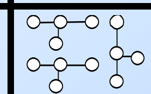
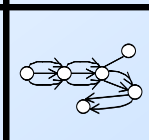
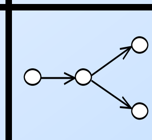
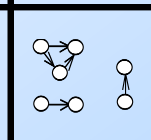
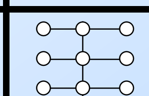
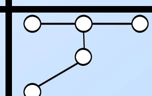
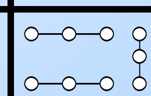
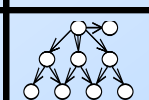
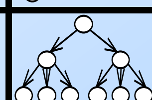
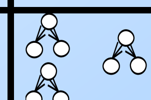


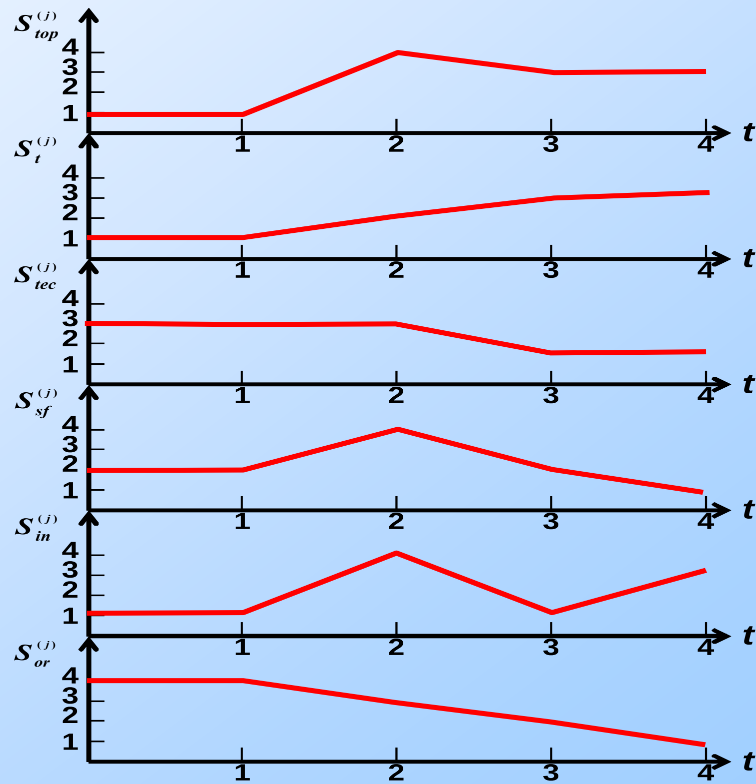

***The theory of CO structure-dynamics proactive control as a scope of interdisciplinary researches***

# Proposed methods and algorithms for solving CO planning and scheduling problems



# *Processes of Complex Objects Structure-Dynamics Control*

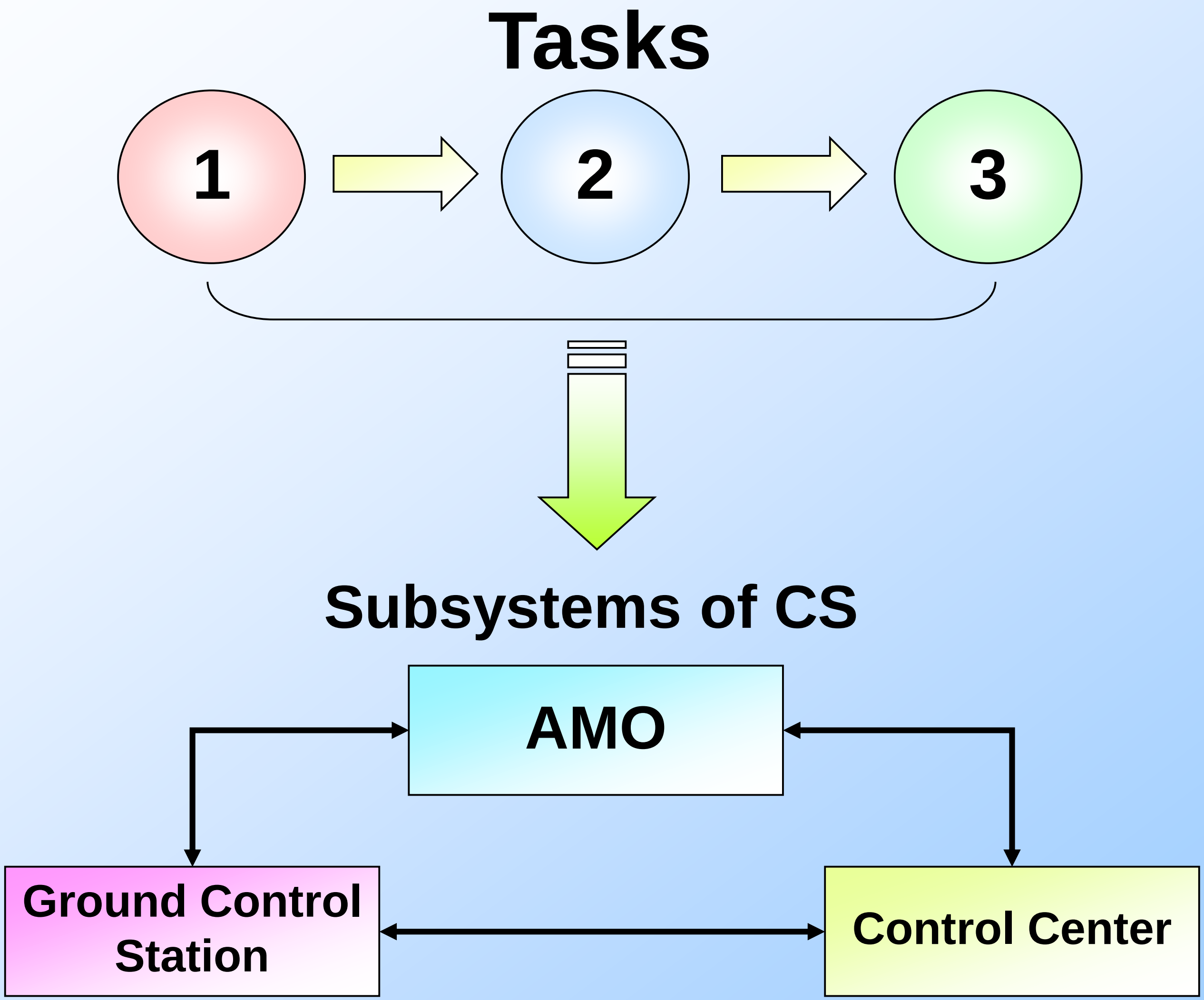
| Types of structures \ Variants of multi-structural states | *j* h level of CO | | | |
|---|---|---|---|---|
| | $S_0^{(j)}$ | $S_1^{(j)}$ | … | $S_K^{(j)}$ |
| **Topological structure** $S_{top}^{(j)}$ |  |  | … |  |
| **Technology structure** $S_t^{(j)}$ |  |  | … |  |
| **Technical structure** $S_{tec}^{(j)}$ |  |  | … |  |
| **Structure of special software and mathematical tools** $S_{sf}^{(j)}$ |  |  | … |  |
| **Information structure** $S_{in}^{(j)}$ |  |  | … |  |
| **Organizational structure** $S_{or}^{(j)}$ |  |  | … |  |



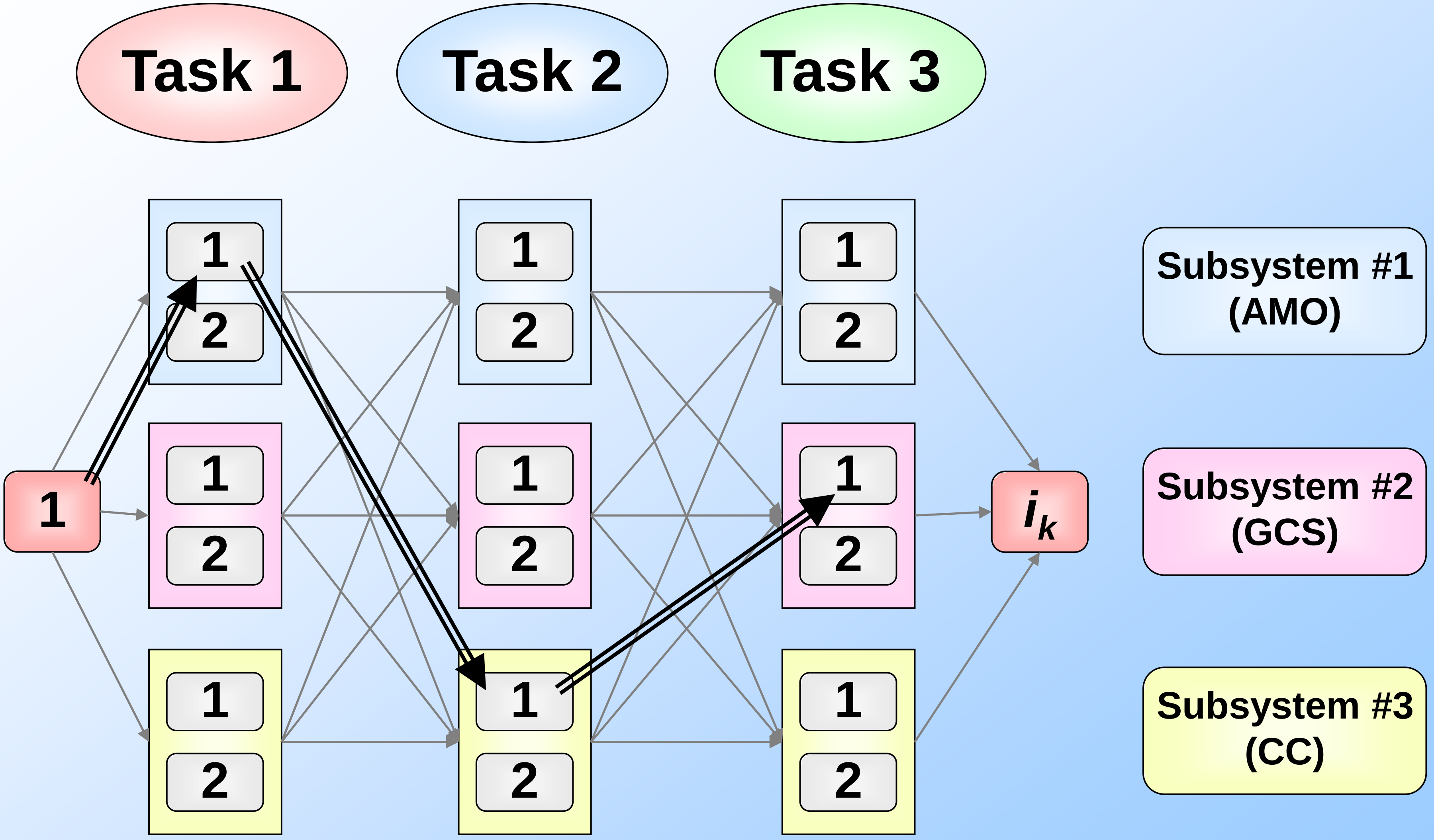

***CO structure dynamics control***

***Possible variants of CO structure dynamics control scenarios***

# *Redistribution of functions, problems and control algorithms among CO levels*



# Redistribution of functions, problems and control algorithms among CO levels



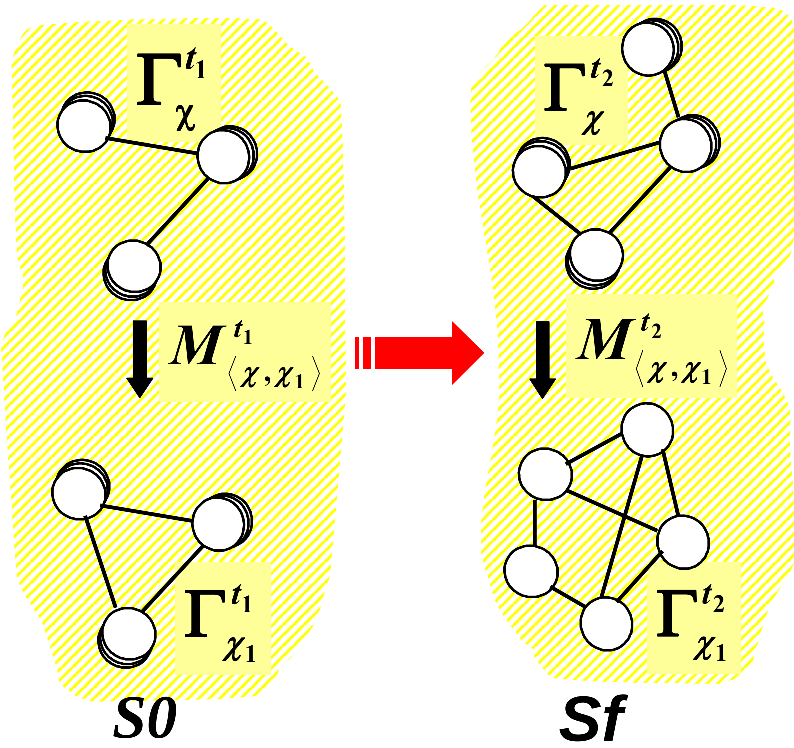
# Set-theory Based Description of CO Planning and Scheduling Problem as a Structure-Dynamics Control Problem

*To interconnect the structures the following* ***dynamic alternative multi-graph*** *(DAMG) can be*

$$G_{\chi}^{t} = \left\langle X_{\chi}^{t}, F_{\chi}^{t}, Z_{\chi}^{t} \right\rangle,$$

*where the subscript $\chi$ characterizes the CO CS structure type, $\chi \in NS$ = = {1,2,3,4,5,6} (here 1 indicates the topological structure, 2 indicates the functional structure, 3 indicates the technical structure, 4 and 5 indicate the structures of mathematical and software tools, 6 indicates the organizational structure, the time t belongs to a given set T;* $X_{\chi}^{t} = \{x_{\chi l}^{t}, l \in L_{\chi}\}$ *is a* ***set of elements of the structure*** $G_{\chi}^{t}$ *(the set of DAMG vertices) at the time point t;* $F_{\chi}^{t} = \{f_{<\chi,l,l'>}^{t}, l, l' \in L_{\chi}\}$ *is a* ***set of arcs of the DAMG*** $G_{\chi}^{t}$*; the arcs represent relations between the DAMG elements at time t;* $Z_{\chi}^{t} = \{f_{<\chi,l,l'>}^{t}, l, l' \in L_{\chi}\}$ *is a* ***set of parameters*** *that characterize relations numerically.*

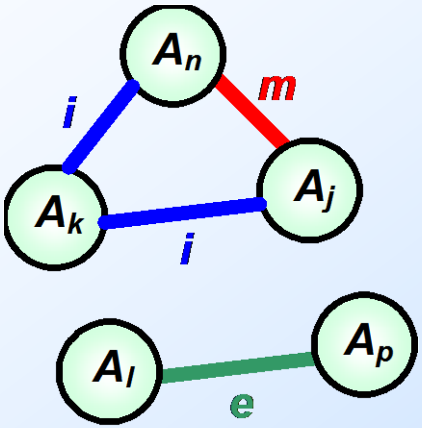
# Set-theory Based Description of CO Planning and Scheduling Problem as a Structure-Dynamics Control Problem



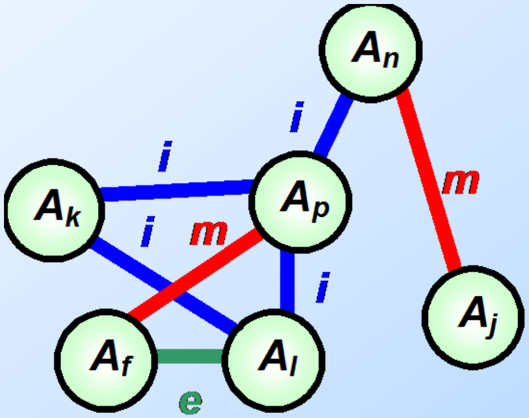

*The problem of **CO** structure-dynamics control can be regarded as a problem of **selection** an optimal multi-structural macro-state **Sf** and **synthesis of optimal program** (plan and schedule) for **CO** transition from initial multi-structural macro-state **S0** to multi-structural macro-state **Sf**.*

*The results of this **optimal program selection** can be presented as an **optimal production, management and control technology,** and **optimal program (plan and schedule)** for CO functioning.*

# Description of Concept Model for CO Structure-Dynamics Control Processes <u>in the Flows Space</u>




$t = t_s$




$t = t_{s+1}$

$A_n$ – subsystem of CO number "n"

m – material flows

e – energy flows

i – information flows

# Methodological Basis of CO Planning and Scheduling by Optimal Control

***Methodological basis includes:***

- *methodology of generalized system analysis*
- *methodology of CO modern optimal control theory*

***Methodologies include following concepts and principles. The main are:***

- *concept of integrated modelling and simulation*
- *concept of proactive control and management*
- *principle of goal programmed control*
- *principle of external complement*
- *principle of necessary variety*
- *principles of multiple-model and multi-criteria approaches*
- *principle of new problems*

# Methodological Basis of CO Planning and Scheduling by Optimal Control

*The concept of complex modeling and simulation supposes the implementation of methodology and technologies of CO* ***multiple-model description*** *and* ***combined use*** *of methods, algorithms and techniques*

*of* ***multi-criteria*** *analysis, synthesis and decision making under various conditions of dynamically changing environment*

**We can compensate disadvantages of one class of models with advantages of other class of models**

# Methodological Basis of CO Planning and Scheduling by Optimal Control

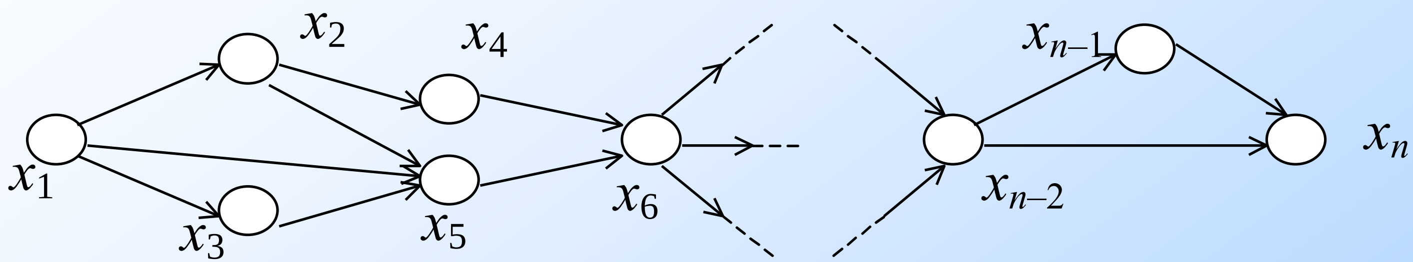
| Models of CO SDC / Procedures of CO SDC tasks solving | $f_0^{(a)} \to \underset{\Delta^{(a)}}{\text{extr}}$ | $f_0^{(a)} \to \underset{\Delta^{(u)}}{\text{extr}}$ | $f_0^{(a)} \to \underset{\Delta^{(a)} \cap \Delta^{(u)}}{\text{extr}}$ | $f_0^{(u)} \to \underset{\Delta^{(a)}}{\text{extr}}$ | $f_0^{(u)} \to \underset{\Delta^{(u)}}{\text{extr}}$ | $f_0^{(u)} \to \underset{\Delta^{(a)} \cap \Delta^{(u)}}{\text{extr}}$ |
|---|---|---|---|---|---|---|
| AOM→AN→C | + | | | | | |
| SOM→AN→C | | | | + | + | + |
| AOM→SOM→AN→C | | + | + | | | |
| (AOM⊂SOM)→AN→C | | | + | | | |
| (SOM⊂AOM)→AN→C | | | + | | + | + |
| $\begin{pmatrix} \text{AOM}_1 \\ \cup \\ \text{SOM} \\ \cap \\ \text{AOM}_2 \end{pmatrix} \to$ AN → C | | | | + | + | + |

***AOM-analytical optimization modelling, SOM-simulation optimization modelling, AN- analysis of received results, C- correction of obtained solution,***

$\Delta^{(a)} \cap \Delta^{(u)}$ ***sets of allowable alternatives which are described analytically or algorithmically***

*The schemes of coordination for models and measures of effectiveness can differ in**: <u>methods of solution generation in CO SDC tasks; rules of constraints verification for analytical and algorithmically constraints; variants of interactive elimination of allowable alternatives</u>***

## Dynamic interpretation of operations execution




***Traditional approach* to operation description is the program evaluation-and-review technique (PERT) based on static models**

$$x_i \Leftrightarrow T_i = \frac{Q_i}{v_i}$$

*where:*

*$x_i$ is the state of operation (activity);*

*$T_i$ - is the duration of operation;*

*$Q_i$ – is the volume of operation (a transaction),*

*$v_i$ is the speed of operation execution*

# Dynamic Model of Operation Control ($M_1$)

***The execution dynamics of the job (operation) can be***

$$\frac{dx_{i\mu}^{(o)}}{dt} = \dot{x}_{i\mu}^{(o)} = \sum_{j=1}^{n} \varepsilon_{ij}(t) u_{i\mu j}^{(o)} \qquad (1)$$

***Equation (1) describes the job execution in time***

$$\dot{x}_{j}^{(o)} = \sum_{i=1}^{\bar{n}} \sum_{\substack{\eta=1 \\ \eta \neq i}}^{\bar{n}} \sum_{\mu=1}^{s_i} \sum_{\rho=1}^{p_i} (u_{i\mu j}^{(o)}) \qquad (2)$$

***Equation (2) represents resource utilization in job execution dynamics***

# Dynamic Model of Operation Control ($M_1$)

***The execution dynamics of the job can be expressed as***

$$\frac{dx_{i\mu}^{(o)}}{dt} = \dot{x}_{i\mu}^{(o)} = \sum_{j=1}^{n} \varepsilon_{ij}(t) u_{i\mu j}^{(o)} \qquad \textbf{(1)}$$

***job state variable,***
***(o) means "operation"***

$$\dot{x}_j^{(o)} = \sum_{i=1}^{\bar{n}} \sum_{\substack{\eta=1 \\ \eta \neq i}}^{\bar{n}} \sum_{\mu=1}^{s_i} \sum_{\rho=1}^{p_i} (u_{i\mu j}^{(o)}) \qquad \textbf{(2)}$$

***Equation (2) represents resource utilization in job execution dynamics***

# Dynamic Model of Operation Control ($M_1$)

***The execution dynamics of the job can be expressed as***

$$\frac{dx_{i\mu}^{(o)}}{dt} = \dot{x}_{i\mu}^{(o)} = \sum_{j=1}^{n} \varepsilon_{ij}(t) u_{i\mu j}^{(o)} \qquad \textbf{(1)}$$

***control input that is equal to 1 if the job "i", operation "m" is being executed on resource "j"and equal to 0 if not***

# Dynamic Model of Operation Control ($M_1$)

***The execution dynamics of the job can be expressed as***

$$\frac{dx_{i\mu}^{(o)}}{dt} = \dot{x}_{i\mu}^{(o)} = \sum_{j=1}^{n} \varepsilon_{ij}(t)\, u_{i\mu j}^{(o)} \qquad (1)$$

***preset matrix function of time assigning time-spatial constraints***

***MOTU WE TH FR SASU***

# Dynamic Constraints

$$\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i} u_{i\mu j}^{(o)}(t) \le 1, \forall j; \ \sum_{j=1}^{n} u_{i\mu j}^{(o)}(t) \le 1, \forall i, \forall \mu \quad (2)$$

*allocation problem constraint according to the problem statement (i.e., only a single operation can be processed by single resource at any time by the manufacturer)*

$$\sum_{j=1}^{n} u_{i\mu j}^{(o)}\left[\sum_{\alpha\in\Gamma_{i\mu_1}^{-}}(a_{i\alpha}^{(o)} - x_{i\alpha}^{(o)}) + \prod_{\beta\in\Gamma_{i\mu_2}^{-}}(a_{i\beta}^{(o)} - x_{i\beta}^{(o)})\right] = 0 \quad (3)$$

*this constraint implies the blocking of current operation until the previous operation(s) have been executed*

$$u_{i\mu j}^{(o)}(t) \in \{0,1\}; \quad (4)$$

*controls contain the values of the Boolean variables*

$$x_{i\mu}^{(o)}(T_0) = 0; \ x_{i\mu}^{(o)}(T_f) = a_{i\mu}^{(o)}; \quad (5)$$

*initial and end conditions*

# Dynamic Model of Flow Control ($M_2$)

***Mathematical model of flow control in the form of equation:***

$$\dot{x}_{i\mu j}^{(f)} = u_{i\mu j}^{(f)} \qquad \dot{x}_{ij\eta\rho}^{(f)} = u_{ij\eta\rho}^{(f)} \qquad \textbf{(6)}$$

***Processing flow on resource*** ***Transferring flow***

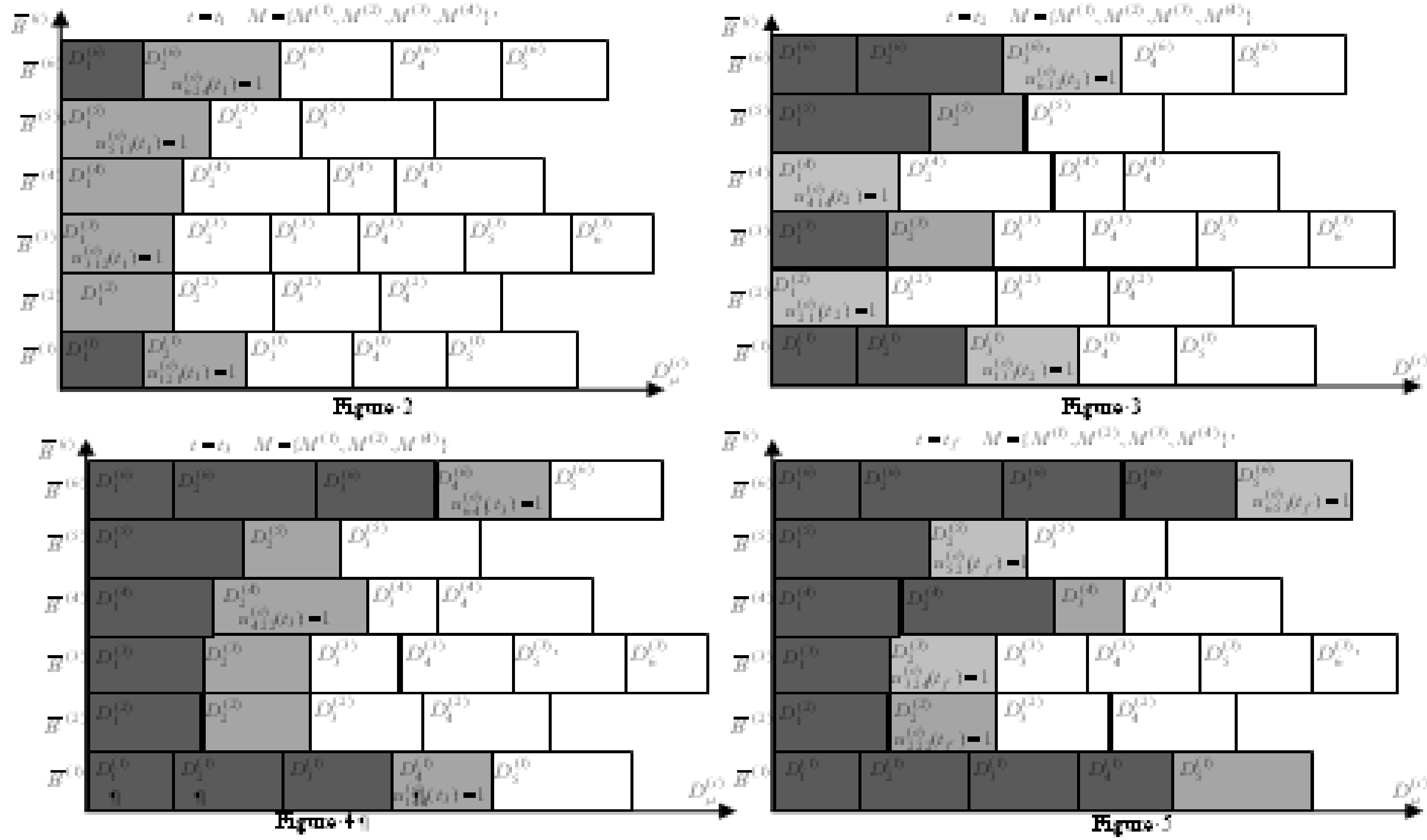
***Constrains***

$$\sum_{i=1}^{\bar{n}} \sum_{\mu=1}^{s_i} u_{i\mu j}^{(f)}(t) \le \tilde{\tilde{R}}_{1j}^{(f)} \qquad \sum_{\rho=1}^{p_i} u_{ij\eta\rho}^{(f)}(t) \le \tilde{\tilde{R}}_{1j\eta}^{(f)} \qquad \textbf{(7)}$$

***total potential intensity of flow processing*** ***maximal potential intensity of flow transferring***

$$0 \le u_{i\mu j}^{(f)}(t) \le c_{i\mu j}^{(f)} \cdot u_{i\mu j}^{(o)} \qquad 0 \le u_{ij\eta\rho}^{(f)}(t) \le c_{i\eta\rho j}^{(f)} \cdot u_{i\eta\rho j}^{(o)} \qquad \textbf{(8)}$$

***potential intensity of processing flow on resource*** ***potential intensity of flow transferring with unit***




Figures 2–5 Dynamic representation of the scheduling model

***The current dimension** of CO planning and scheduling tasks is determined by **the front of active work, marked <u>in gray</u>.***
***Completed work,** marked in **<u>black</u>, and work that,** according to logical conditions, cannot begin**, are not included in the current dimension.** With traditional approaches**, all the works** define the current dimension of the planning and scheduling task**.***

# Performance Indicators

***Accuracy of the end conditions accomplishment***

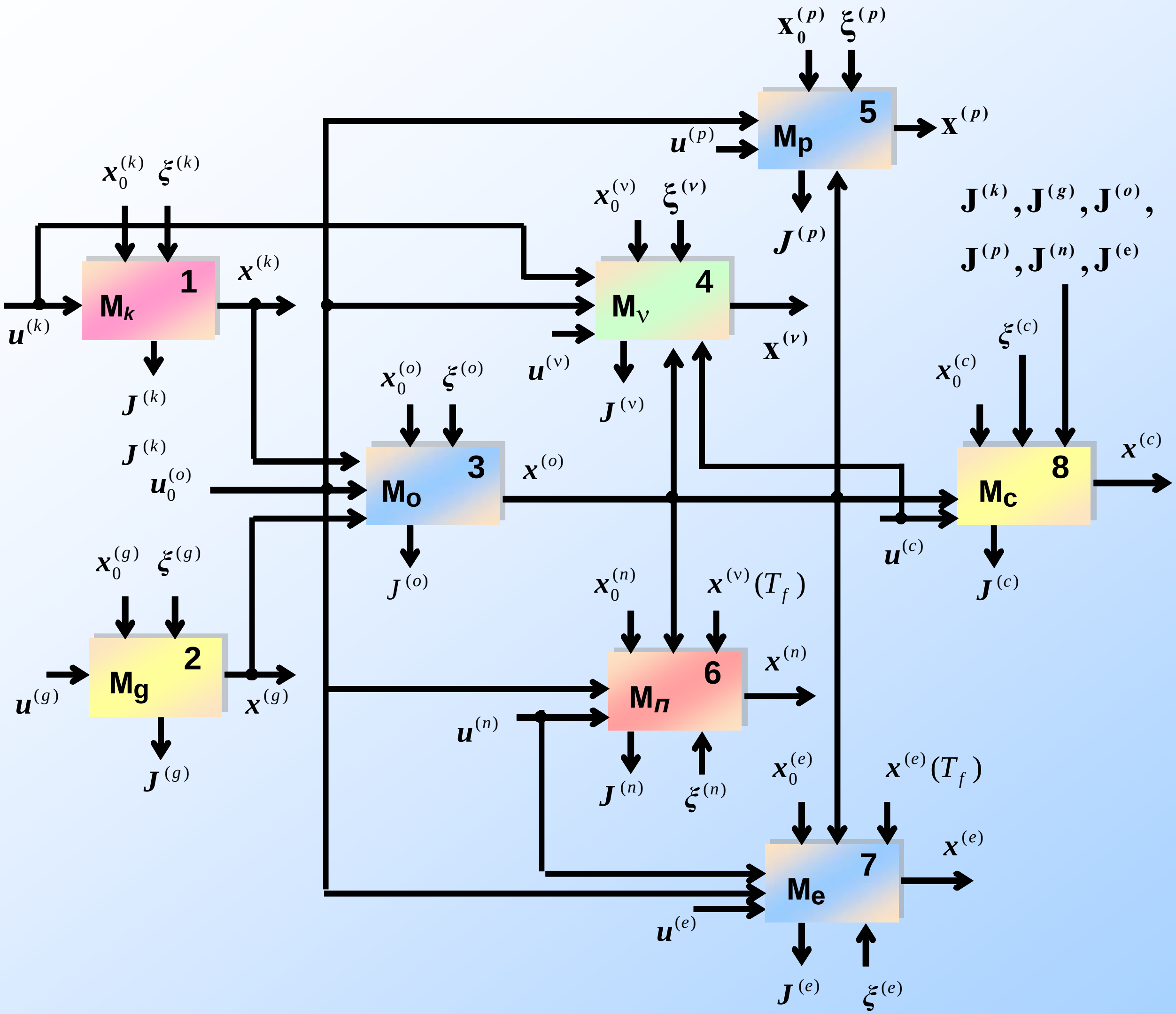
$$J_1^{(o)} = \frac{1}{2}\sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}[(a_{i\mu}^{(o)} - x_{i\mu}^{(o)}(T_f))^2] \qquad (9)$$

***Estimation of an operation execution time with regard to the preferable intervals***

$$J_2^{(o)} = \sum_{i=1}^{\bar{n}}\sum_{\mu=1}^{s_i}\sum_{j=1}^{n}\int_{T_0}^{T_f}\alpha_{i\mu j}^{(o)}(\tau)u_{i\mu j}^{(o)}(\tau)d\tau \qquad (10)$$

***Estimation the equal resource utilization of complex object***

$$J_3^{(o)} = \frac{1}{2}\sum_{j=1}^{n}(T - x_j^{(o)}(T_f))^2 \qquad (11)$$




**M_g** – *dynamic model of CO motion control;*
*M_k – dynamic model of CO channel control;*
*M_o – dynamic model of CO operations control;*

*M_n – dynamic model of CO flow control;*
*M_p – dynamic model of CO resource control;*

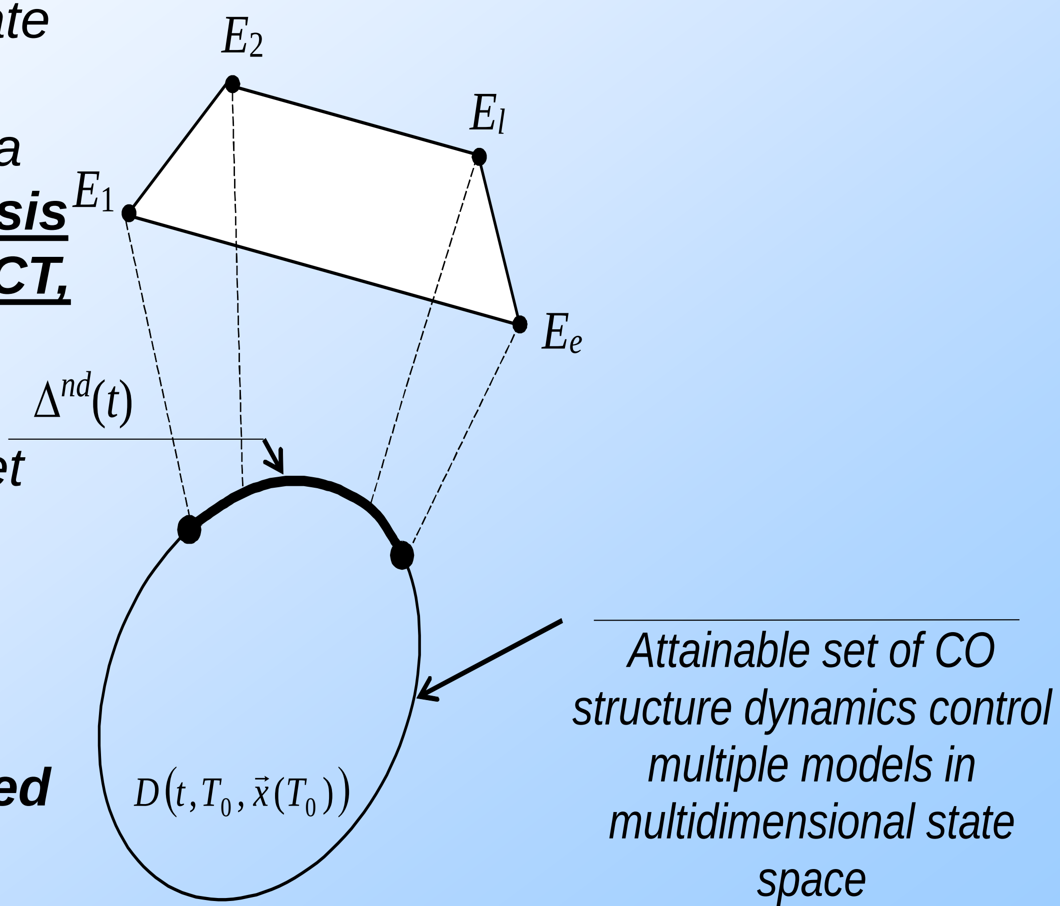
*M_e – dynamic model of CO operation parameters control;*
*M_c – dynamic model of CO structure dynamic control;*
*M_n – dynamic model of CO auxiliary operation control*

*The scheme of CO planning and control multiple models interconnection*

# The Main Phases of CO functional technology and proactive control program synthesis

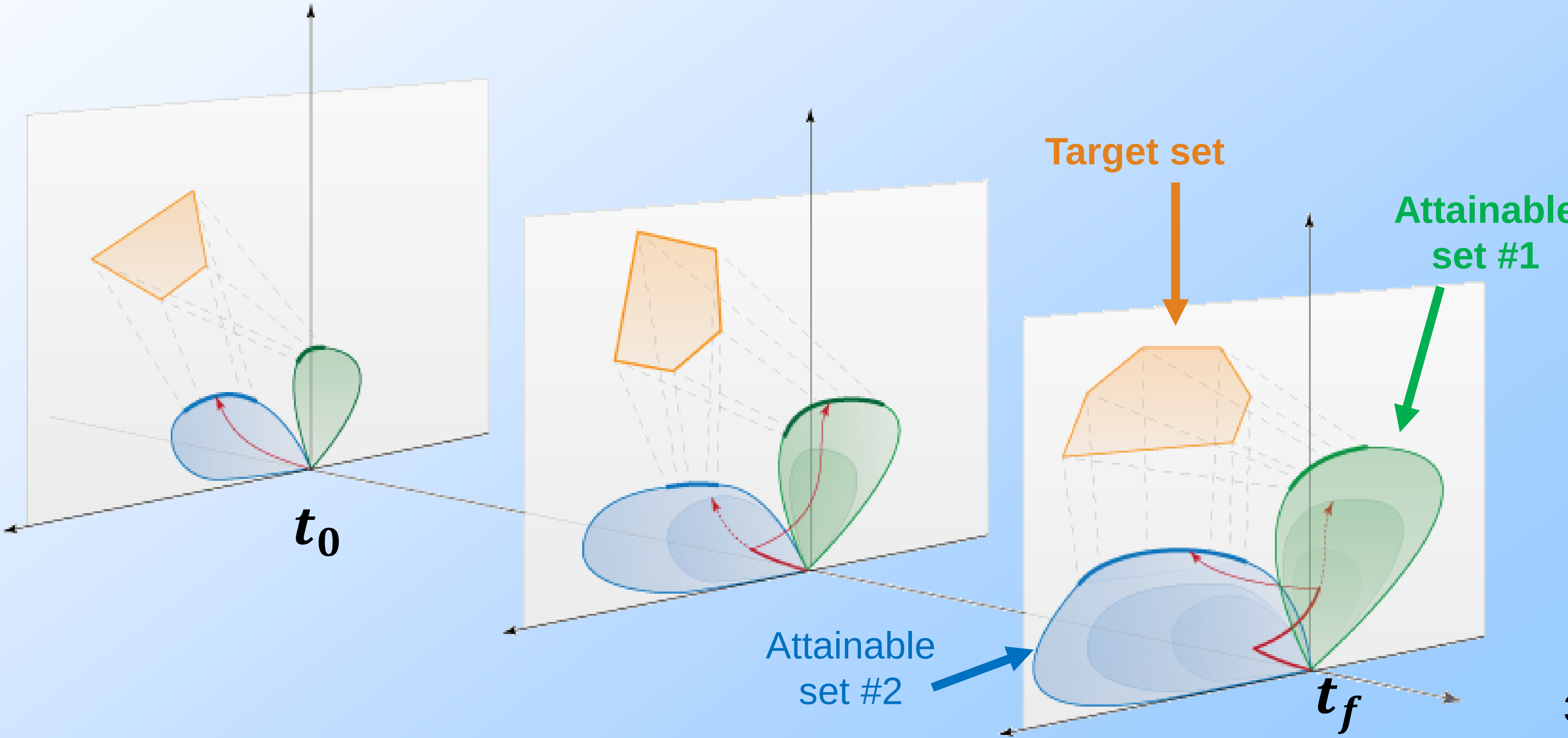
***<u>At the first phase</u> we** generate CO allowable multi-structural macro-states. In other words a **<u>structure-functional synthesis of new variants CO PT, PMCT, should be obtained</u>**.*

*Orthogonal projection of target set of production quality requirements is performed*
*As a result, of projection, we form **a set of Pareto of production process preferred states at the end of the planning interval***
***We have implicitly description of <u>new variants CO PT, PMC</u>***

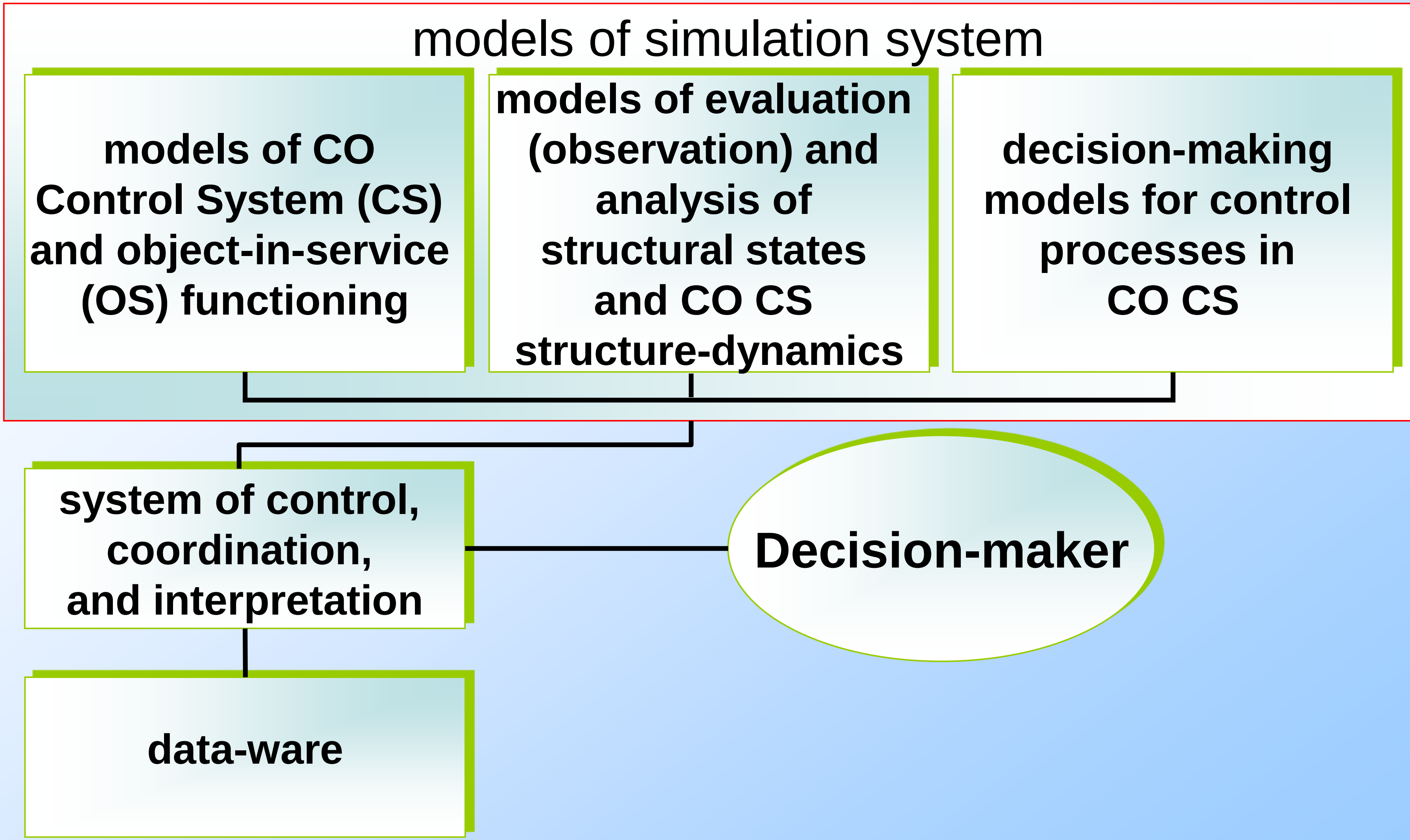


# The Main Phases of CO functional technology and proactive control program synthesis

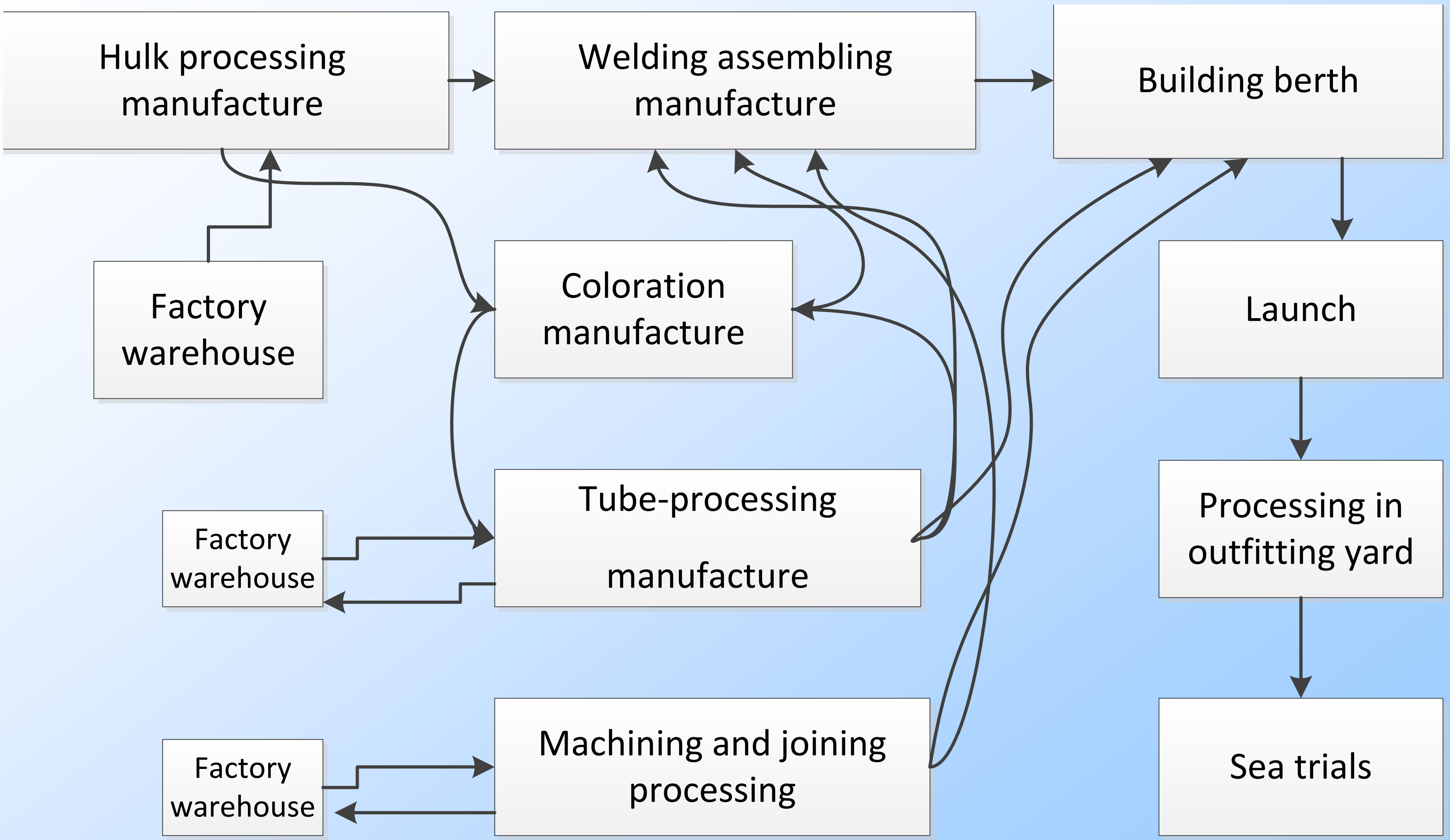
***<u>At the second phase</u>*** *a single multi-structural macro-state is being selected, and adaptive plans (programs, schedule) of* ***CO transition*** *to the selected macro-state are constructed. These plans should specify transition programs, as well as programs of stable CO operation in intermediate multi-structural macro-states.*



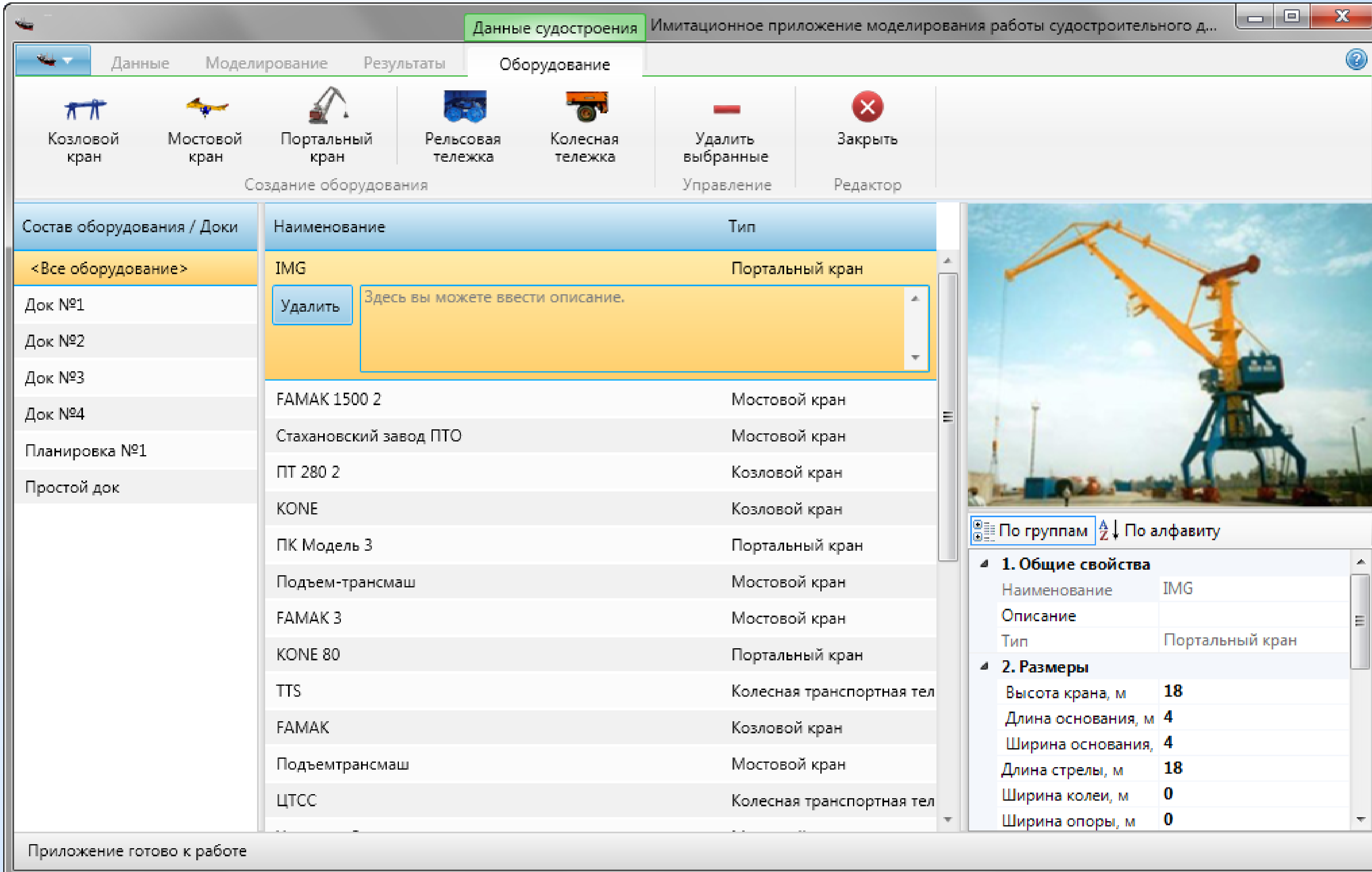
# General Structure of Simulation System (SIS)



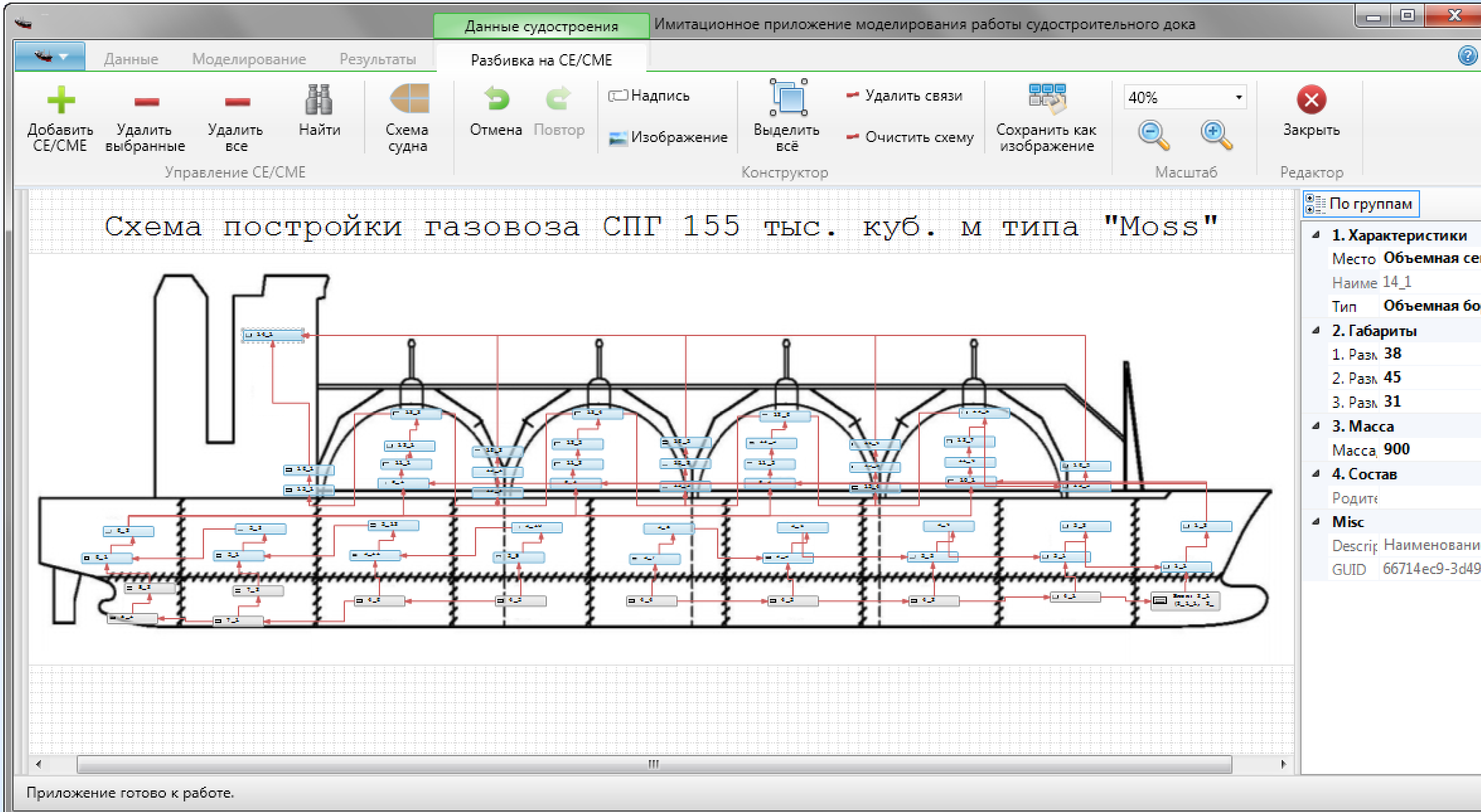
# Conception description of ship building manufacture



# Data and data structure design Implementation. Step 1

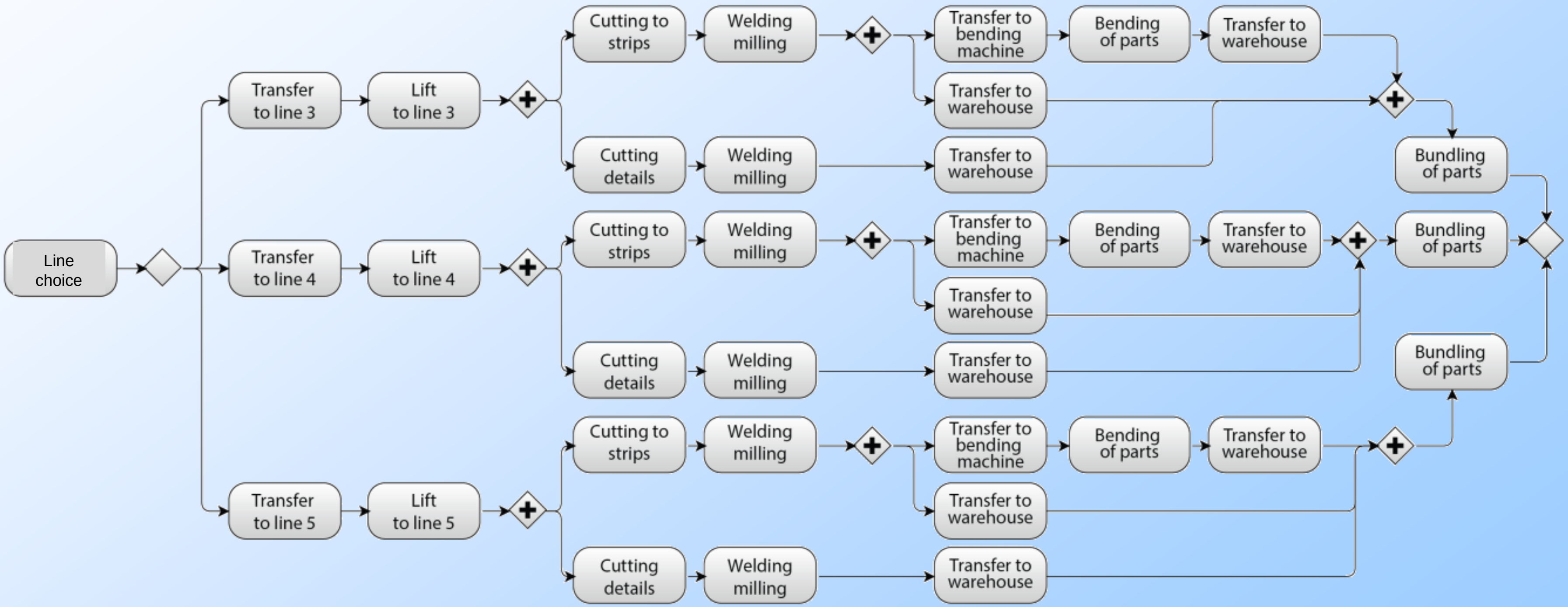


# Data and data structure design Implementation. Step 1



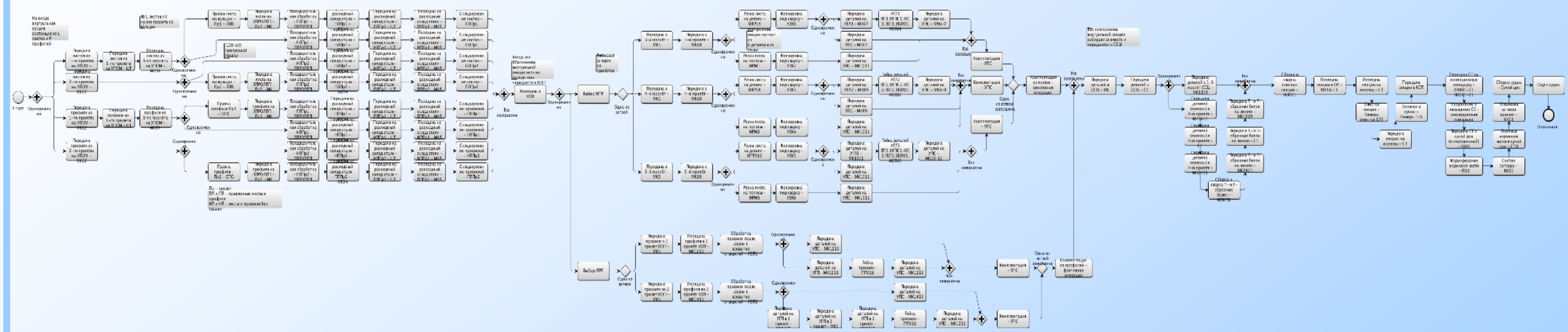
# Implementation. Step 2

A fragment of alternative graph showing variants of ship building production.

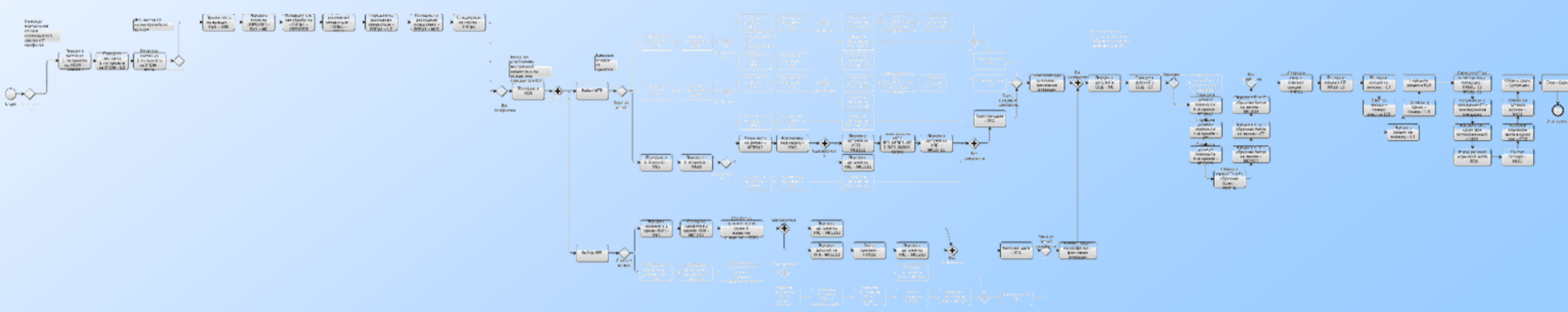


# Implementation. Step 2

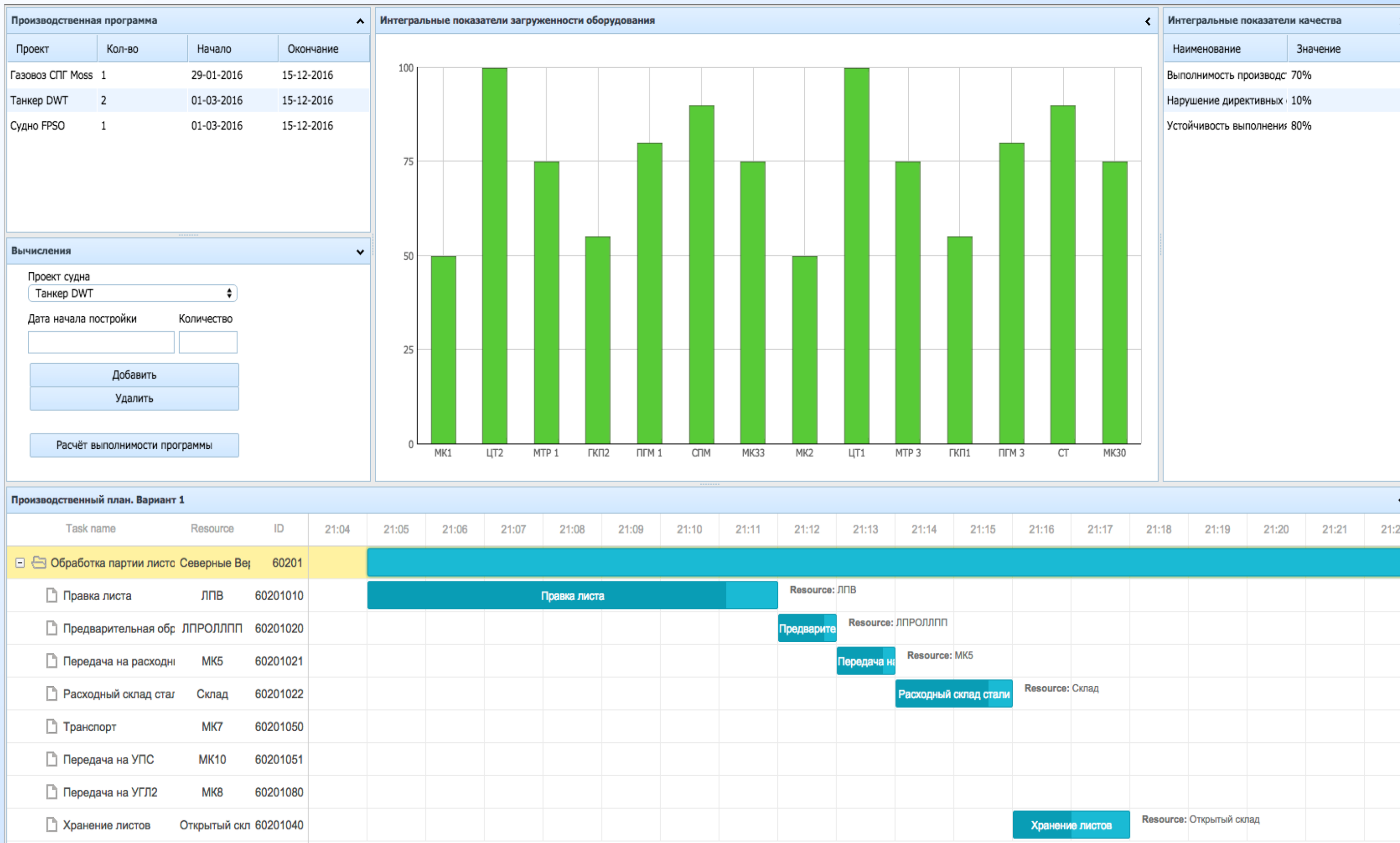
## SBM alternative processes description with BPMN



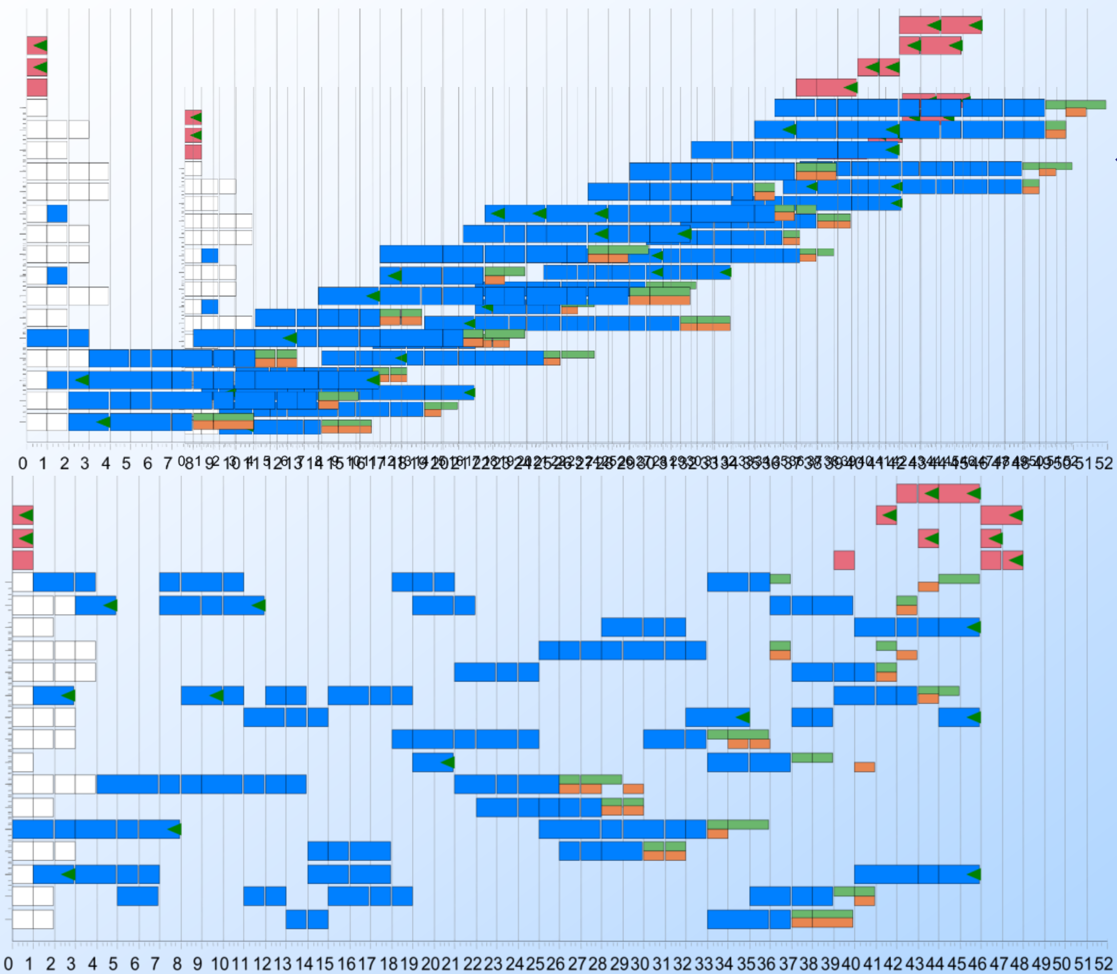
## Preferable choice specific SBM process



# Results of Plans and Schedule Synthesis



# Implementation. Step 3



***Heuristic SBM scheduling***

***Optimal SBM scheduling***

***The <u>optimal production plan</u> is better than the <u>heuristic production plan</u> in terms of the indicator characterizing the <u>total duration of the production process.</u>***

***We reduce duration of the production process by two weeks***

# Implementation. Step 4

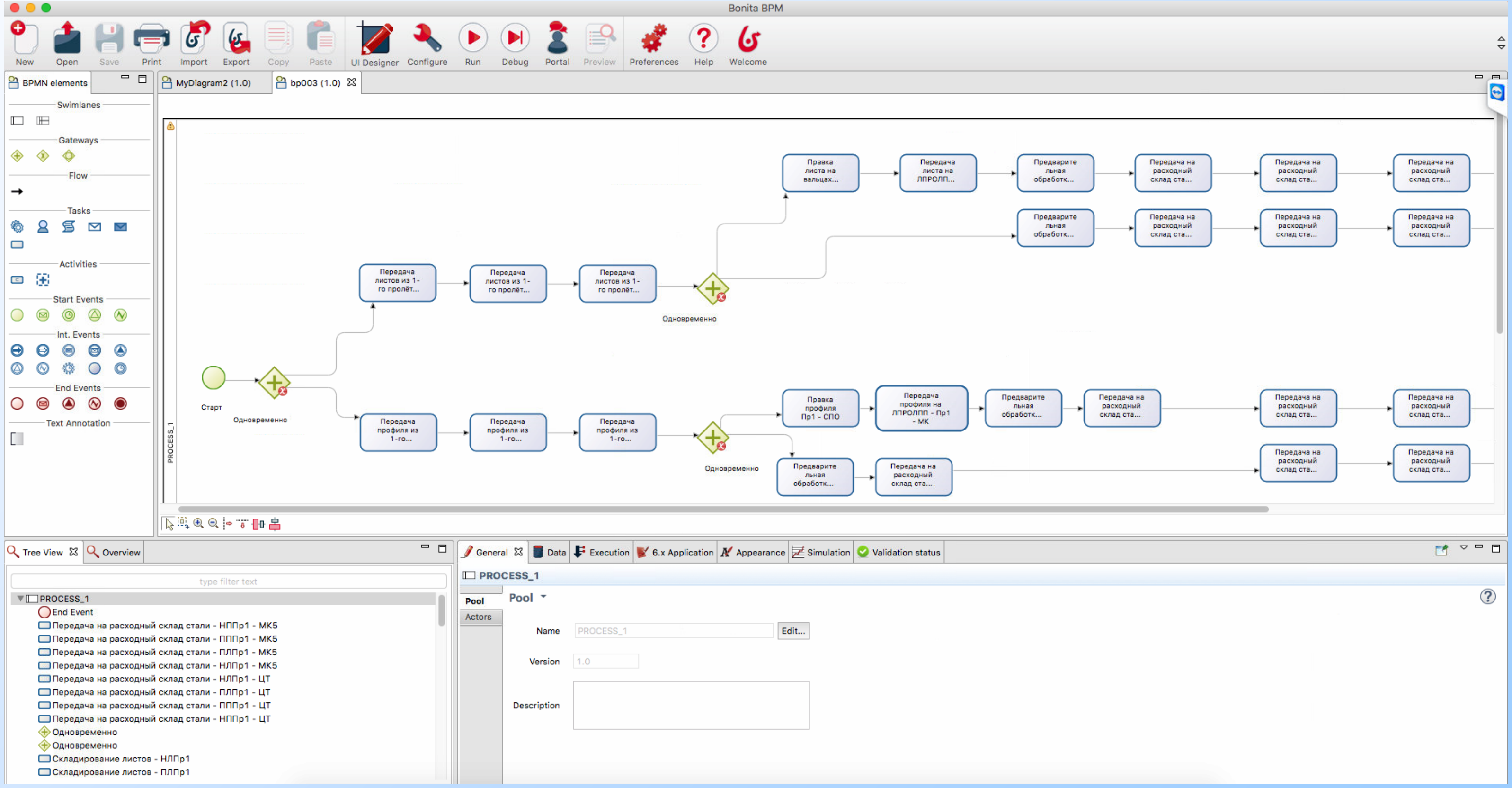
| Models of CO SDC / Procedures of CO SDC tasks solving | $f_0^{(a)} \to \underset{\Delta^{(a)}}{\mathrm{extr}}$ | $f_0^{(a)} \to \underset{\Delta^{(u)}}{\mathrm{extr}}$ | $f_0^{(a)} \to \underset{\Delta^{(a)} \cap \Delta^{(u)}}{\mathrm{extr}}$ | $f_0^{(u)} \to \underset{\Delta^{(a)}}{\mathrm{extr}}$ | $f_0^{(u)} \to \underset{\Delta^{(u)}}{\mathrm{extr}}$ | $f_0^{(u)} \to \underset{\Delta^{(a)} \cap \Delta^{(u)}}{\mathrm{extr}}$ |
|---|---|---|---|---|---|---|
| AOM→AN→C | + | | | | | |
| SOM→AN→C | | | | + | + | + |
| AOM→SOM→AN→C | | + | + | | | |
| (AOM⊂SOM)→AN→C | | | + | | | |
| (SOM⊂AOM)→AN→C | | | + | | + | + |
| $\begin{pmatrix} \mathrm{AOM}_1 \\ \cup \\ \mathrm{SOM} \\ \cap \\ \mathrm{AOM}_2 \end{pmatrix} \to \mathrm{AN} \to \mathrm{C}$ | | | | + | + | + |

***AOM-analytical optimization modelling, SOM-simulation optimization modelling, AN- analysis of received results, C- correction of obtained solution,***

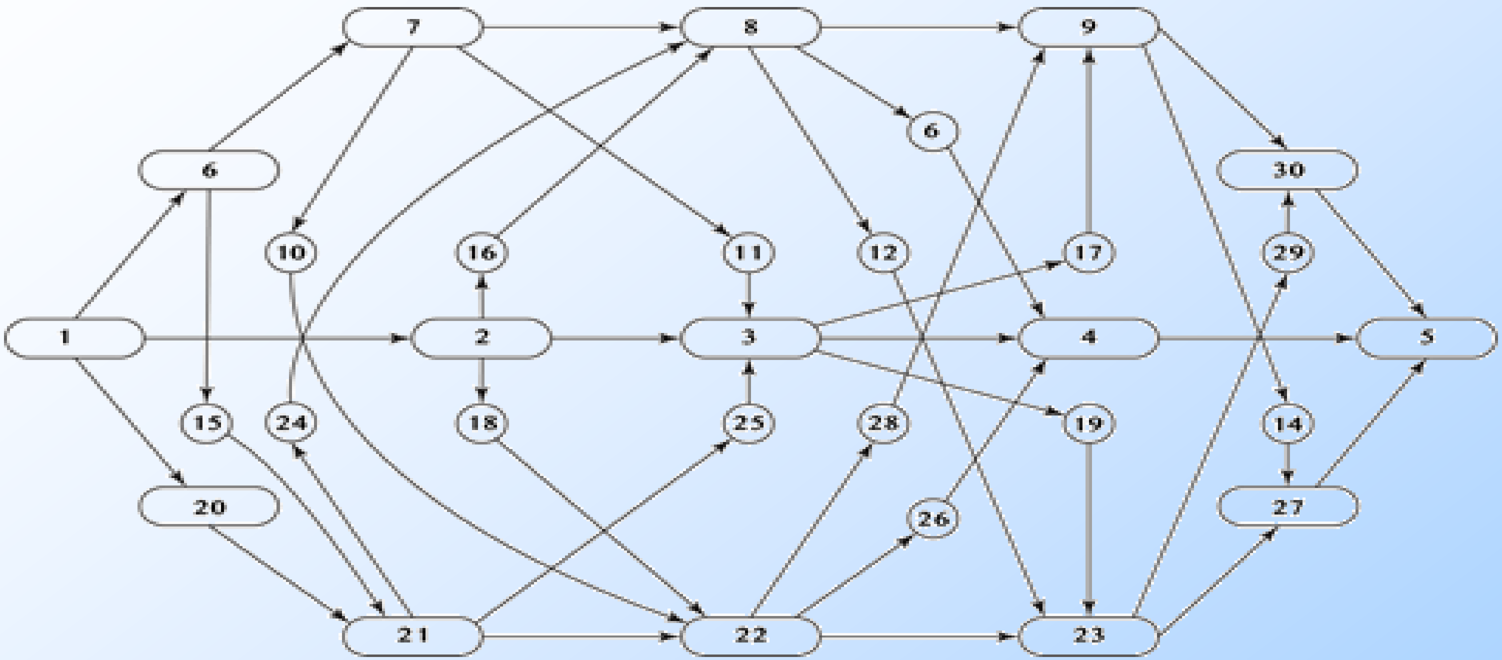
$\Delta^{(a)} \cap \Delta^{(u)}$ ***sets of allowable alternatives which are described analytically or algorithmically***

# Implementation. Step 4

*Simulation modeling CO planning and scheduling implementation with BPSim. Analysis of robustness and stability indicators.*



# *The tasks of synthesis production technology, planning, scheduling of material, data and information processing synthesis in IIT*




| | |
|---|---|
| **1. Data collecting.** | **2. Data preprocessing.** |
| **3. Main data processing.** | **4. Formation of control.** |
| **5. Implementation of control.** | **6. Transfer to the data processing century.** |
| **7. Data preprocessing.** | **8. Main data processing.** |
| **9. Formation of control.** | **10. Data processing century. Cloud.** |
| **11. Data processing century pf the cyber-physical system.** | **12. Data processing century. Cloud.** |
| **13. Data processing century pf the cyber-physical system.** | **14. Data processing century. Cloud.** |
| **15. Data processing century. Cloud.** | **16. Data processing century pf the cyber-physical system.** |
| **17. Data processing century pf the cyber-physical system.** | **18. Data processing century. Cloud.** |
| **19. Data processing century. Cloud.** | **20. Transfer to the cloud.** |
| **21. Data preprocessing.** | **22. Main data processing.** |
| **23. Formation of control.** | **24. Cloud of the data processing century.** |
| **25. Cloud of the cyber-physical system.** | **26. Cloud of the cyber-physical system.** |
| **27. Transfer to the cyber-physical system.** | **28. Cloud of the data processing century.** |
| **29. Cloud of the data processing century.** | **30. Transfer to the cyber-physical system.** |

# The task solution of significantly synthesizing technology, planning, scheduling of data and information processing in IIT

*Number of computing processes: 3*

*For each process:*

- *Number of transactions: 30 basic and 8 subsidiary*
- *Number of logical links: 54*
- *Number of alternative technologies: 120*
- *Number of resources (computing devices): 3*

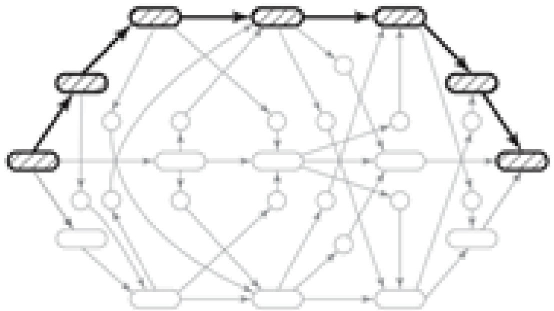
*The volume of the information flow of operations: from 1 to 6 GB*

*Speed of information flow processing resources: from 1 to 3 GB per minute*

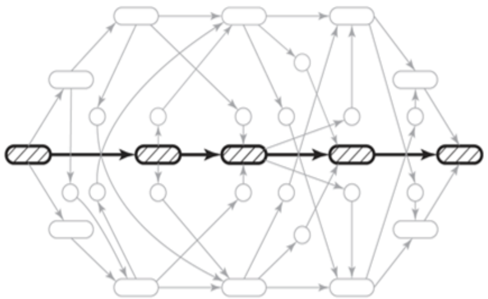
*Operation time: from 20 seconds to 6 minutes*

*Average implementation time: 10 minutes*

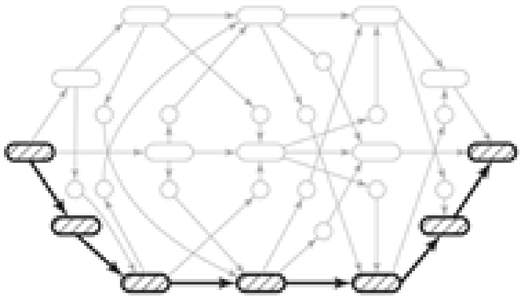
# The task solution of significantly synthesizing technology, planning, scheduling of data and information processing in IIT



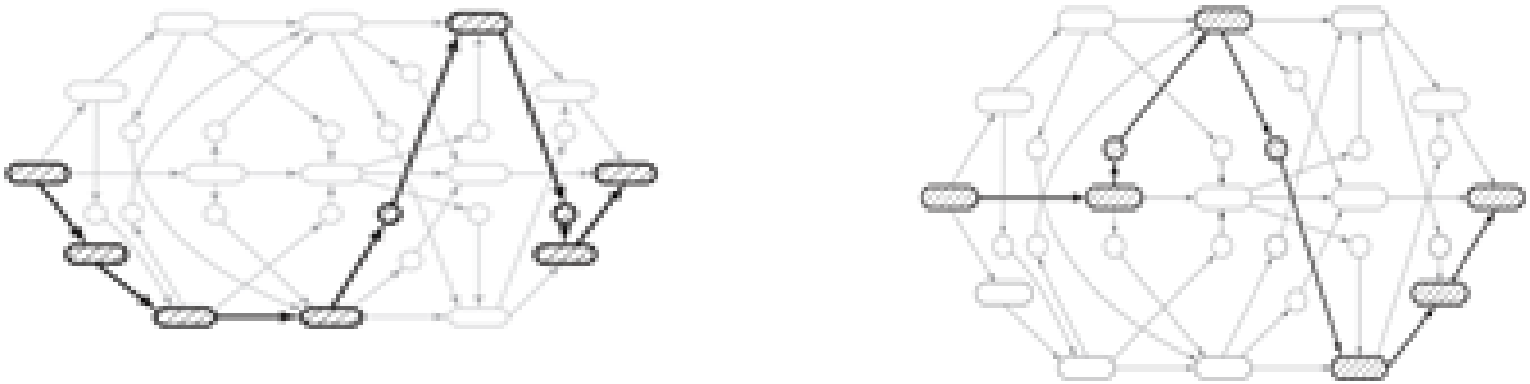
Centralized architecture



Vague architecture



Cloud architecture



Hybrid architectures

*The results of modelling:*

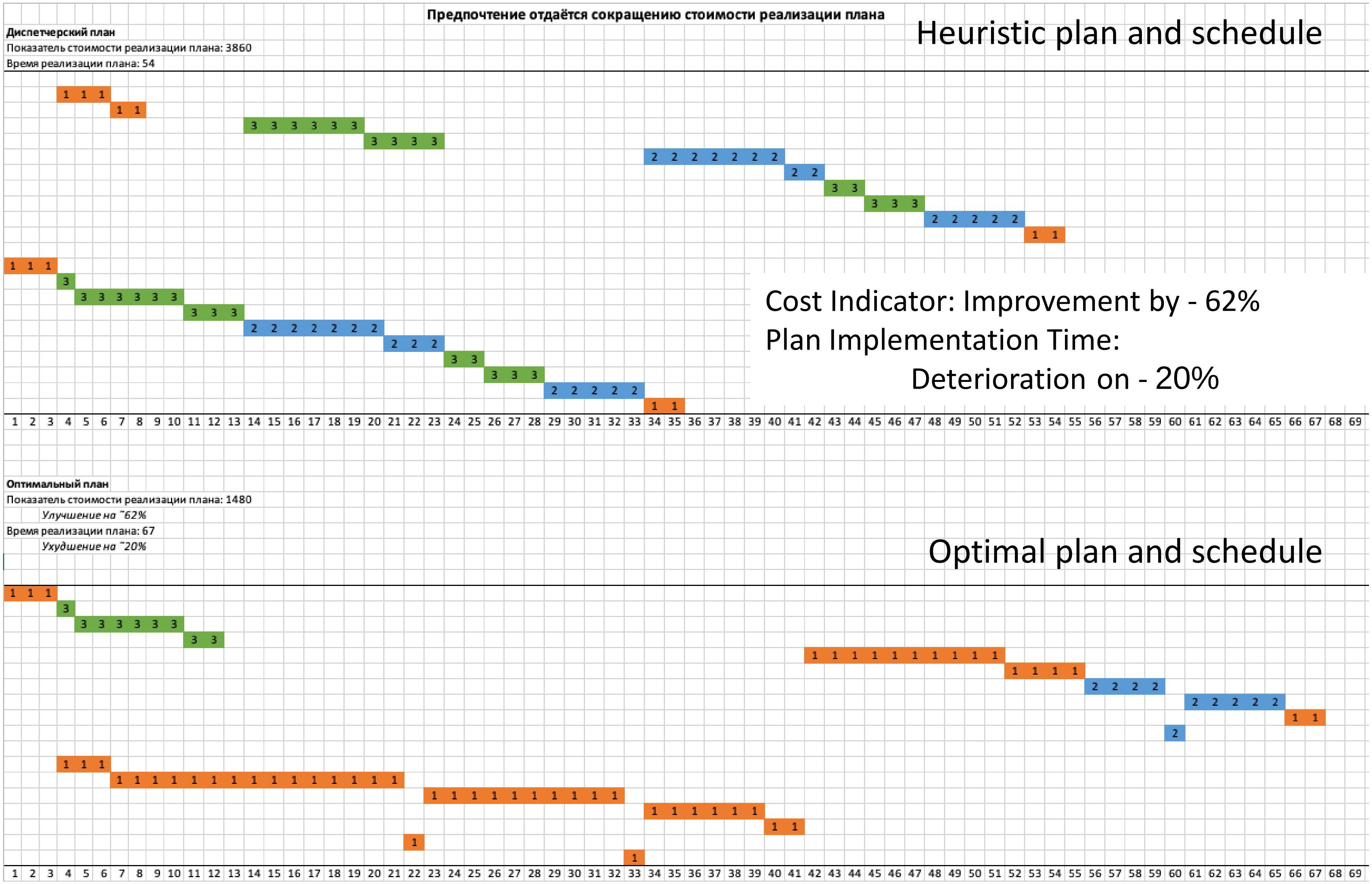
*Energy consumption reduction – on average by 21%*

*Reduction of time of execution – on average by 6%*

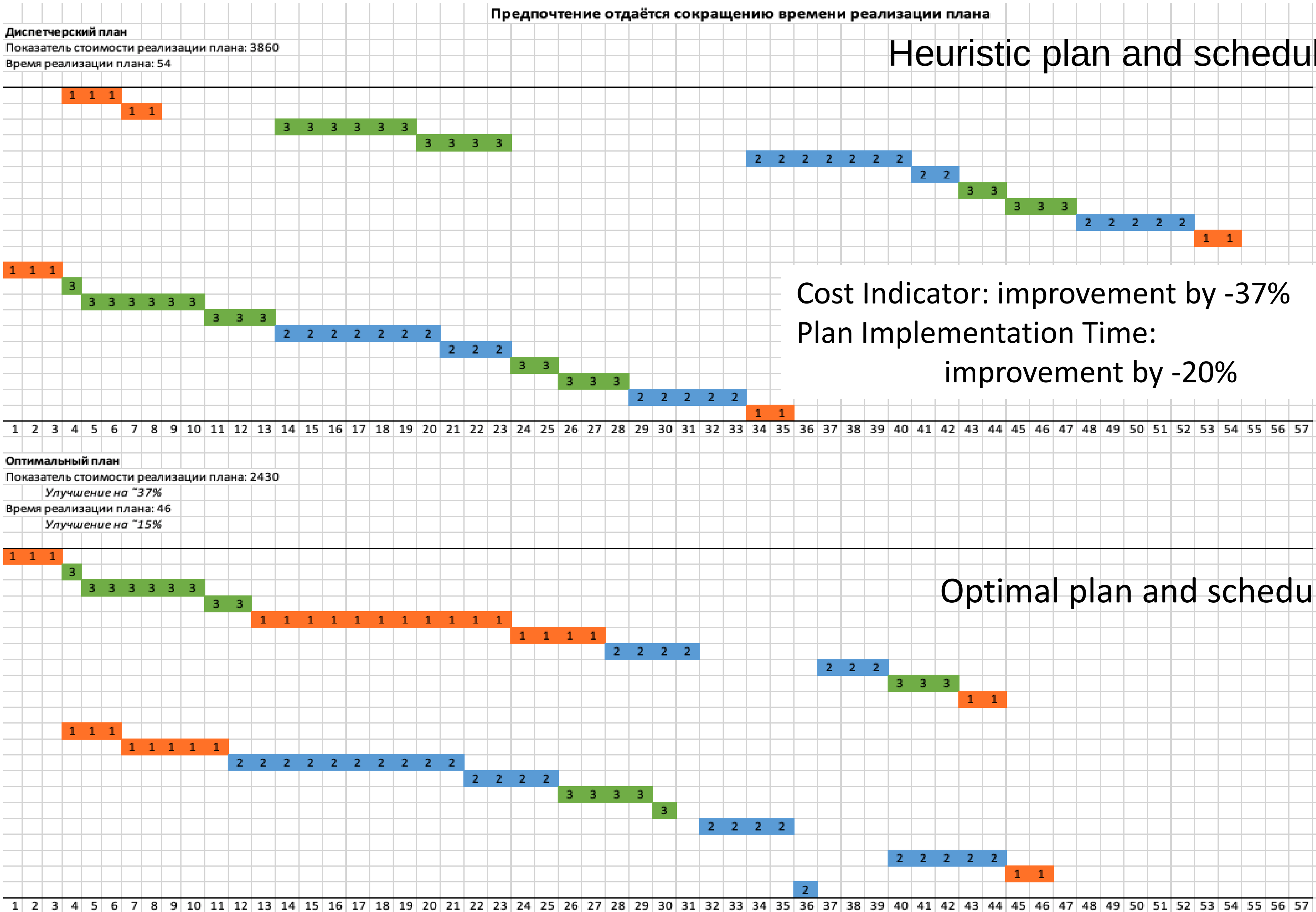
*Increase in uniformity of loading of resources – on average by 14%*

*Improvement of the generalized indicator of quality of the plan – on average by 26%*

# Energy plan and schedule optimization



# Time plan and schedule optimization




Heuristic plan and schedule

Cost Indicator: improvement by -37%

Plan Implementation Time: improvement by -20%

Optimal plan and schedule

# Conclusions

1. *We propose **to expand CO planning and scheduling tasks adding up** the **tasks of production technologies and production control and management technologies synthesis.** We offer to research and solve these new tasks based on common methodological foundations oriented **to modern control theory***

2. *Therefore, **the fundamental and applied scientific results** obtained in the complex technical objects modern control theory **can be extended** to those areas of CO production management that traditionally used the methods of mathematical programming and operations research.*

3. *This approach makes it **possible to improve the quality of CO planning and scheduling processes** as compared with existing approaches, as well as formally describe and solve fundamentally new production planning and scheduling tasks that have never been fulfilled.*

# The implementation of control theory fundamental results for manufactory planning and scheduling processes

| The main results | Implementations of the results |
|---|---|
| Criteria for existence of a solution in CTO structure-dynamics control (SDC) problems | Manufactory (MF) planning and scheduling models verification and validation |
| Criteria for controllability and attainability in CTO SDC problems | Control processes verification for a given time interval/ Determination of the constraints restricting MF goal abilities and information technology abilities |
| Criteria for uniqueness of optimal program control in CTO SDC problems | Analysis of possibility to obtain an optimal MF plan and schedule |
| Necessary and sufficient conditions of optimality in CTO SDC problems | Preliminary analysis of MF optimal plan and schedule structures ; generation of basic formulas for MF planning and scheduling algorithms |
| Criteria for sustainability and sensitivity in CTO SDC problems | Evaluation and estimation of MF plan and schedule sustainability and sensitivity for environmental impacts |

# Methodological Basic of CO Planning and Scheduling Models' Quality Estimation

**Scientific investigations**
*Multiple-model description CO planning and scheduling*

**Problem to be solved**
*Development of theoretical basics for CO planning and scheduling models' quality estimation and models' quality control*

**Methodological basics of theory**

*Concepts: Concepts of comprehensive simulation, of control theory, of knowledge engineering, of quality control.*

*Principles: Principles of requisite variety, of complementation, of immersion.*

*Models requirements: Adequacy, flexibility (adaptability), multi-functionality and unification, availability, intellectuality.*

**Classes of problems**

*Analysis problems (A)*

*Classification of models,estimation of model's and meta-model's characteristics such as adequacy, sensitivity, operability, controllability, attainability, and reliability*

*Observation problems (B)*

*Identification of parameters, observation of current situation*

*Problems of selection (C):*

*Multi-attribute ranking of models, model selection, model's quality control.*

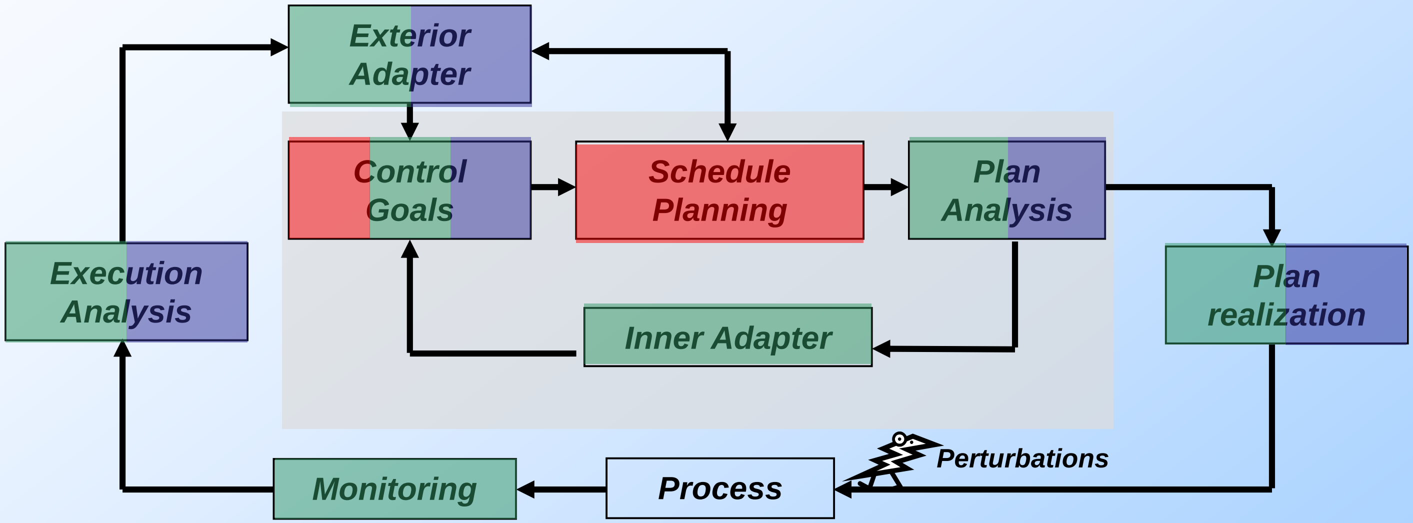
**Methods and models used for decision of the problems (A,B,C)**

- *Methods for construction and reduction of no dominated-alternatives set (A,C)*
- *Methods of multi-attribute utility theory (A,C)*
- *Methods of analytic hierarchy processes (A,B,C)*
- *Methods of multi-attribute alternatives ranking (C)*
- *Methods of verbal analysis (B)*
- *Methods for construction and approximation of attainability set in dynamic systems (A,B,C)*

- *Structure-functional and functor-category description of models and meta-models (A,B,C)*
- *General meta-model, based on dynamic alternative graphs, for CO planning and scheduling models' quality estimation and models' quality control (A,B,C)*
- *Poly-model complexes using Bayesian techniques, Knowledge Based approaches, Artificial Neural Systems, Fuzzy Logic techniques, and Genetic Algorithms techniques (A,B,C)*

*Expected practical results:*
*Qualitative and quantitative estimation of model classes*
*Methods of CO planning and scheduling models' quality estimation and models' quality control*
*Application software prototype for information fusion models quality estimation*
*Expected benefits*
*Improvement of design decisions, enhancement of their validity and quality*
*Design cost saving through errors detection at early phases of models' life cycle*

# The main phases of CO adaptive planning and scheduling




**Task of the plan and schedule processes**

- Linear programming
- Traffic task
- Dynamic programming
- Heuristics

**Operation research**

**Task of the operational control**

- Proactive control
- Feedback control
- Monitoring
- Adaptive control
- Steadiness analysis

**Management and control theory**

**Task of the interaction of supply chain**

- Activities goals and interests coordination
- Taking into account the subjectivity of the decision-making
- Competence modeling
- Active elements modeling

**MAC / KAC**

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# Contacts

## *Thank you for your attention!*

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