Complex large-scale resource-driven discrete-event systems under uncertainty: application for automated research

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Large-scale complex Industrial systems

With the invention of computers, integrated circuits and communications, information and network communication technology are closely combined with industrial process.

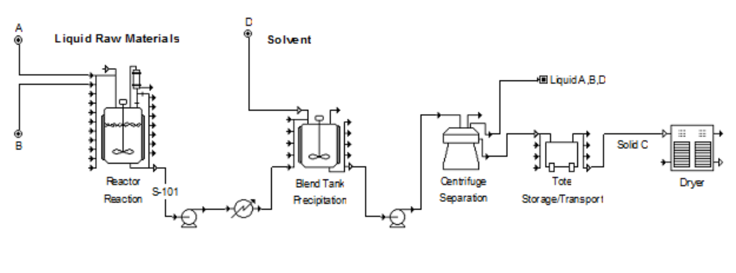
Industrial systems (IS) are union of individual manufacturing and network-computational systems. IS have improved overall operation efficiency and reduced consumption of raw materials.

- 1980-th better production quality thanks to improved management,
- 1990-th better processes organization (reengineering of business processes),
- 2000-th collaborative manufacturing and management the process between counterparties.

Due to the large scale of networked systems, it is difficult to realize the traditional centralized control. The nowadays control structures of large-scale networked industrial processes are **decentralized** and **distributed**. Decentralized control is simpler in structure and more convenient in implementation, but it does not deal with the physical coupling between subsystems. Distributed control deals with **coupling relationship** through communication between subsystems, the quality of the communication implies the quality of control.

Batch processing

There is three basic models of industrial processes: continuous, discrete, and batch processing. The most complex one is the third, the batch processing.



The figures are taken from https://en.wikipedia.org/wiki/Scheduling_(production_processes)

Batch processing

Batch description

```
Unit Procedure 1: Reaction
    Op 1: Charge A & B (0.5 hours)
    Op 2: Blend / Heat (1 hour)
    Op 3: Hold at 80C for 4 hours
    Op 4: Pump solution through cooler to
          blend tank (0.5 hours)
    Op 5: Clean (1 hour)
Unit Procedure 2: Blending Precipitation
    Op 1: Receive solution from reactor
    Op 2: Add solvent, D (0.5 hours)
    Op 3: Blend for 2 hours
    Op 4: Pump to centrifuge for 2 hours
    Op 5: Clean up (1 hour)
Unit Procedure 3: Centrifugation
    Op 1: Centrifuge solution for 2 hours
    Op 2: Clean
Unit Procedure 4: Tote
    Op 1: Receive material from centrifuge
    Op 2: Load dryer (15 min)
Unit Procedure 5: Dry
    Op 1: Load
    Op 2: Dry (1 hour)
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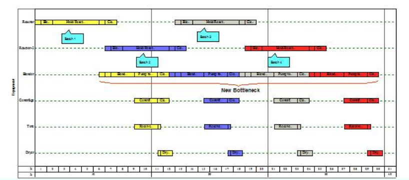

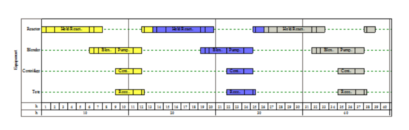

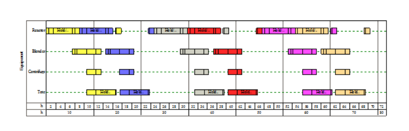

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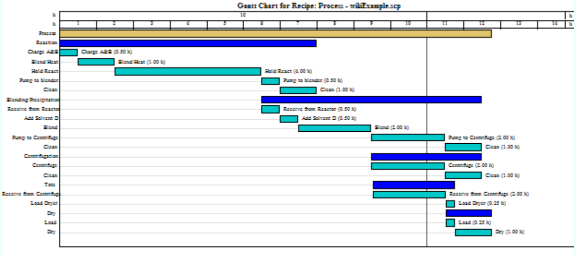
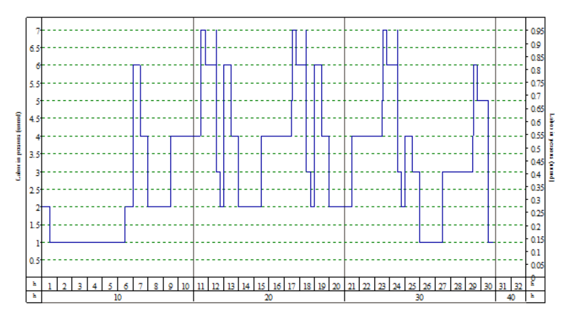
Batch proceedings visualization





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Modeling

Representing industrial system as discrete-event system (DES), as some other technical and natural objects, almost always we deal with consumption, production and concurrent temporal acquiring resources.

Examples of the kind are

1. computer networks;
2. resource allocation in computer cloud systems;
3. automated manufacturing; air traffic control;
4. robotic assembly lines;
5. highly integrated command, control, communication, and information systems, *e.g.*, groups of underwater unattended vehicles.

Uncertainties are classified in external and internal, event-based and resource-based. Uncertainties, as events of DES generated by the environment of the industrial system, can be represented with game theory. This representation will model the behaviors of external agents (*e.g.* firms, teams, or individuals) under different competition and collaboration strategies. Resource-based uncertainties represent usually crshortage of resources (utilities).

Existing approaches

Aim of control is to retain IS near a **set point** or correspond to a **set of constraints**.

- Environment generates events, industry reacts. A set of reacting rules must be synthesized.
- Mean field games. Number of agents are infinite, continuous mathematic methods are applied.
- Predictive control, a model-based optimization. Model predicts the future states with receding horizon strategy.
  - Distributed cooperative control of relatively independent subsystems. Lowering computational complexity.
  - with limited resources and asynchronous coordination.
  - with structural uncertainties (equipment failure, illness of staff). Resource reserves are accounted.
- Fuzzy and neural network methods (blackbox).

We propose to represent IS with its environment as DES, which behavior described by resource-based games. In this case we could apply methods of supervisor control synthesis in addition to the predictive techniques.

Aim of the research

The aim is the development of new methods of intelligent control synthesis for resource-driven DES with uncertainties is based on

1. new declarative means in aspects of: event occurrence, state change, resource consumption/production and acquiring, competitor behavior, *etc.*;
2. devising approaches to visual definition of the model with UML, SysML, BPMN, CMMN;
3. development modular supervisors by means of logical inference;
4. adaptation of existing logical inference approaches to support resource-driven games;
5. devising a software for DES description and its computer simulation.
6. represent near-to-real manufacturing processes as RDDESU;
7. testing the methods and software in manufacturing control.

Using automation is due to the complexity and scale of the problem.

Resource-based games

$S = \langle v_0, R, F \rangle$, where v_0 is a multiset, $v_0 = \{4 \cdot (a, A), 8 \cdot (b, A), 9 \cdot (c, A),$
$6 \cdot (a, B), 10 \cdot (b, B), 3 \cdot (c, B), 12 \cdot (d, B), 1 \cdot A\}$.

Rules, defining agents' behavior:

$(r_1^A) : \{1 \cdot A, 2 \cdot (a, A), 1 \cdot (b, A)\} \to \{-1 \cdot (a, B), -1 \cdot (d, B), 1 \cdot B\},$
$(r_2^A) : \{1 \cdot A, 1 \cdot (a, A), 3 \cdot (b, A)\} \to \{-2 \cdot (a, B), 1 \cdot B\},$
$(r_3^A) : \{1 \cdot A, 1 \cdot (a, A), 2 \cdot (b, A), 3 \cdot (c, A)\} \to \{-1 \cdot (b, B), -4 \cdot (d, B), 1 \cdot B\},$
$(r_1^B) : \{1 \cdot B, 3 \cdot (a, B), 2 \cdot (b, B)\} \to \{-2 \cdot (a, A), -1 \cdot (b, A), 1 \cdot A\},$
$(r_2^B) : \{1 \cdot B, 3 \cdot (a, B), 2 \cdot (b, B)\} \to \{-4 \cdot (c, A), 1 \cdot A\}.$

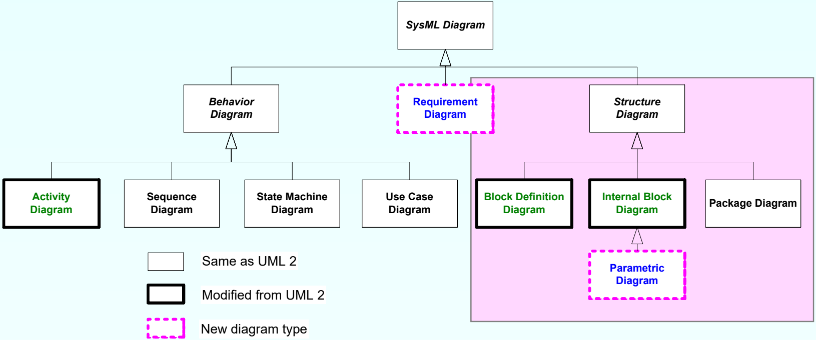
Filter conditions:

$(C_1^A) : (a, A) \geq 2,$
$(C_2^A) : (b, A) \geq 4,$
$(C_3^A) : (c, A) \to max,$
$(C_4^A) : (d, B) \to min,$
$(C5A) : (b, B) \leq 2,$
$F_A = \{C_1^A, \dots, C_5^A\}$ is A-**goal**.

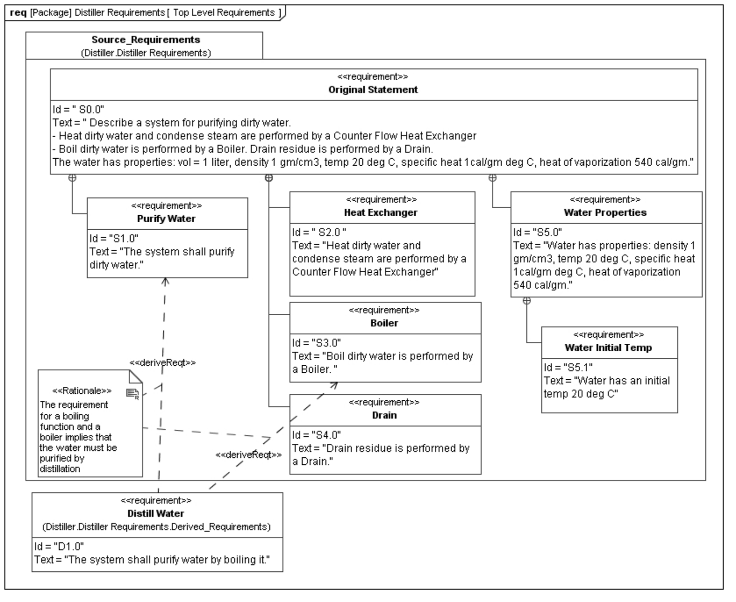
$(C_1^B) : (a, B) \geq 3,$
$(C_2^B) : (b, B) \geq 5,$
$(C_3^B) : (c, A) \to min,$
$(C_4^B) : (b, A) \leq 3,$
$F_A = \{C_1^B, \dots, C_4^B\}$ is B-**goal.**

The example is taken from Igor Sherement's ICCS-DE 2020 paper `http://ceur-ws.org/Vol-2638/paper22.pdf`.

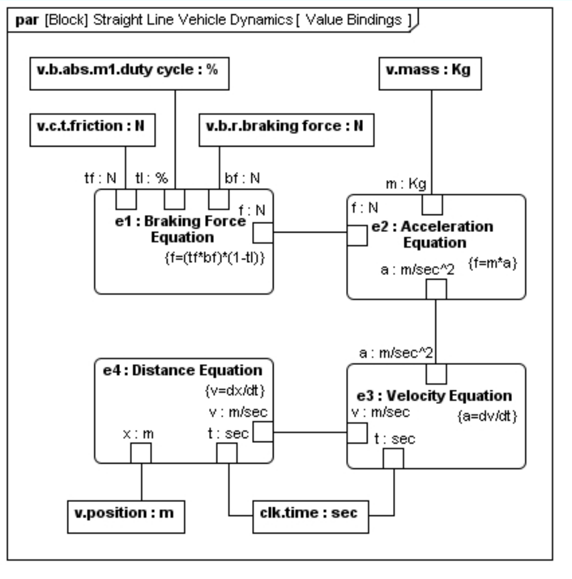
System modeling. SysML



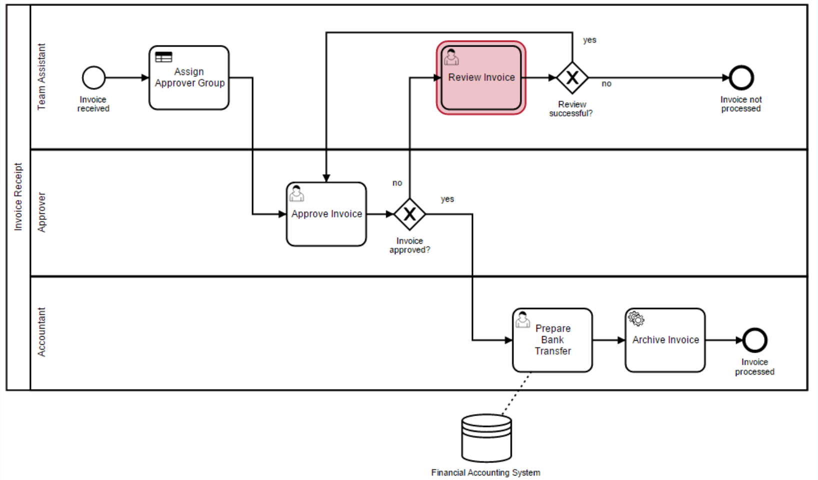
System modeling. Requirements Diagram



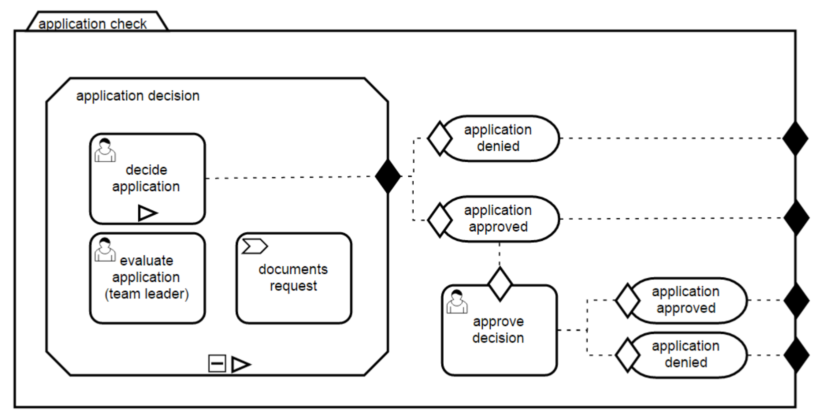
System modeling. Parametric Diagram



BPMN – Business process modeling notation



CMMN – Case management model and notation



Control synthesis

1. DES control is synthesized algorithmically by analysis the controlled automaton. The synthesized control (subautomaton) prevents occurring events shifting system out of admissible state set.
2. Modifiers of inference rule the default strategy of PCFs were designed for that purpose. The control is synthesized while making proofs.
3. If the synthesis is not possible, it shows structural elements, preventing the synthesis.
4. The same was done for language representation of the DSS.
5. Decentralized control tested on controlling formations of UAVs.

Another way is use of forward-chaining inference like receding horizon in RTS mode, where inference stops as soon as time is up. At each step set of constraint are tested, the admissible states form resulting trajectories and control.

Discussion: Expected results

1. A technique for representation complex of models, data structures.
2. Adaptation of standard visual notations (UML, SysML, ...).
3. Transformation of the visual models to the internal representation.
4. Methods of synthesizing supervisors for the DES on the base of automatic theorem proving in PCFs.
5. Device new techniques of constructive inferences constructions adopted to the subject of research.
6. Modular automated research software on the base of computer simulation of predictive control with our extensions.

LNHU will perform the following activities:

1. Research of resource-driven multi-objective optimization: optimal set point and the coordinating multi-objective strategy.
2. Research of distributed predictive control for RDDESU systems with regards of industrial scale and complexity.
3. The establishment of visualization model of ethylene and polypropylene production.
4. Application of the proposed control techniques in petrochemical processes accounting the uncertainties.

The software aimed at CAE/CAM systems development for IS.

Conclusion

The talk was devoted to assess the applicability of existing methods, algorithms and software for construction of **automated research** software for synthesis of control for three-layer advanced industrial process control models.

- Planning, a composition of the bach processing line.
- Scheduling, execution of the plan, utilizing and producing resources.
- Control of dynamic of the scheduling with synthesis of DES control supervisors and admissible trajectories in the predictive control mode.

The enrichment of the convenient standardized two-level model with resource-based game theory enables us to decompose the sources of uncertainties ain a image and likeliness of industry modeling subunits as agents of multi-agent systems.

Thank You for attention!