Information Technologies for Supporting Research of Complex Large-scale Resource-driven Discrete-event Systems Under Uncertainty

Evgeny Cherkashin[1], Qiumei Cong[2], Igor Bychkov[1], Nadezhda Nagul[1], Artem Davydov[1], Yue Wang[2], Shi Huiyuan[2]
[1] *Matrosov Institute for System Dynamics and Control Theory of SB RAS*, Irkutsk, Russia
eugeneai@icc.ru
[2] *Liaoning Shihua University, School of Information and Control Engineering,* Fushun, China
cong_0828@163.com

***Abstract*—The paper states basic ideas of an approach dealing with uncertainties in models of manufacturing process of an industrial scale. The models are a complex including discrete-event systems (DES) representing the manufacturing schedule and resource-driven game description of its behavior in a competitive multi-agent environment. The model object is a subject of control on various levels. Due to the large scale of the object, the control is synthesized as a result of a logical inference, either a theorem proving or forward-chaining modeling a computer simulation scenarios analysis. The uncertainties appear in the model due to activities of competitors or internal factors having probabilistic nature and represented as internal events or shortage of resources. The synthesized control should ensure that the system corresponds to a set of predefined constraints and/or maximizing/minimizing values of a set of characteristics.**

The aim of the research is to implement computer software platform for visual design of industrial manufacturing processes, defining their environments, internal uncertainties event generator rules, and constraints, realizing control syntheses, as well as model assessment criteria to compare the quality of various scenarios. The software could be applied to the wide range of domain problem solved in, *e.g.*, computer networks; resource allocation in computer cloud systems; automated manufacturing; air traffic control; robotic assembly lines; highly integrated command, control, communication, and information systems; control of formations of underwater unattended vehicles.

Introduction

Control of industrial processes is on the top of scientific interest since first automation was introduced to manufacturing goods or supply utilities. The evolution of automation in the last decades was an adoption of various technologies in industry to achieve (1980s) better production quality thanks to improved management, (1990s) better processes organization (reengineering of business processes), (2000s) collaborative manufacturing and management the process between counterparties. With the invention of computers, integrated circuits and communications, information and network communication technology are closely combined with industrial process. Individual manufacturing and network-computational systems now constitute industrial systems, which have improved overall operation efficiency and reduced consumption of raw materials. Due to the large scale of networked systems, it is difficult to realize the traditional centralized control. Therefore, the nowadays control structures of large-scale networked industrial processes is 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.

Representing industrial system as discrete-event system (DES), as some other technical and natural objects, we usually deal with consumption, production and concurrent temporal acquiring resources. Some examples of the similar kind are computer networks; resource allocation in computer cloud systems; automated manufacturing; air traffic control; robotic assembly lines; highly integrated command, control, communication, and information systems, *e.g.*, groups of underwater unattended vehicles. Uncertainties of the resource volume and the requirements are the parts of the discrete-event system model as its consumption/production cannot be modelled completely accounting all possible factors. In this case the model becomes too complex to evaluate and simulate. Decomposing the sources of uncertainties by the relevance to an industrial system, we resulted in two kinds: external and internal. External uncertainties are represented with game theory, as events of DES are generated by the environment of the industrial system. This representation will model the behavior of external agents (*e.g.* firms, teams, or individuals) having different competition and collaboration strategies.

The game theory has a direction which considers objects, which agents (players) have above mentioned properties of dealing with resources (consumption, production, locking, *etc.*). At each action, an agent in a general case consumes a resource (money, matter, energy, *etc.*), produces a resource (*e.g.*, commodities, energy, service). Action also can block activities of other agents, preventing a resource consumption/production, stealing a resource, *etc.* There are resources, which are accessible only by limited number of agents, *i.e.* a resource can be locked. These games are referred to as *resource-based games*. A good short introduction is published recently in [1].

Majority of the research considers the game model to be controlled supervisory ("from top"), *i.e.*, the competing opposites are supposed to be able to negotiate according to the previously synthesized Nash equilibrium. But in practice, it is not possible due to high risk of cheating and complexity arising in accounting all the players' requirements. In the distributed decentralized system, we have to consider the system as being influenced by competitors outside, generating events, and the system reacts on these events. The aim of control is to support systems sustainability (resilience), optimizing its output characteristics. Supervisor control shifts to the level of the agent from the level of the system of competing agents.

The research plan stated in this paper is aimed at investigation of the fundamental problem of development of methods for control synthesis for complex (large-scale) resource-driven discrete-event systems (DES) with uncertainties (RDDESU), which are generalizing various practical domains, including manufacturing process, *i.e.*, consisting of planning, scheduling (execution of a planned batch processing) and dynamic control of the schedule implementation. Manufacturing commodities and service quality is a basis of an enterprise existence, including its reputation and financial well-being. From the consumer point of view, the better manufacturing produces better commodities in time and in a sufficient amounts fulfilling demand.

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

1) new declarative means of complex DES description in aspects of: event occurrence, state change, resource consumption/production and acquiring, competitor behavior, functioning constraints, as well as computer simulation parameter definition;
2) devising approaches to visual definition of part of the declarative model with standard modelling notation, *e.g.*, UML, SysML, BPMN, CMMN;
3) development of methods for building modular supervisor controllers for RDDESU by means of logical inference, using its descriptive means and generally modified strategies;
4) adaptation of existing logical inference approaches to support resource-driven games and corresponding data structures and operations over them;
5) devising a software for DES description and its computer simulation, supporting generation and evaluation of various scenarios.
6) development of the technique for representing near-to-real manufacturing processes as RDDESU;
7) specialization and testing the methods and software under development in the field of manufacturing control.

The main advantage of our approach in comparison to the popular ones is that our method will try to synthesize a control structure (an algorithm or a list of concrete events in the worst case), which will react on occurring events bringing the system in a proper state, if possible, or give the set of additional conditions, fulfilling which the control synthesis could be possible. In the same time the practical requirements imposed us to develop means for complex DES representation, namely, data structures, visualization, automatic (unattended) intelligent methods and software of control synthesis.

I. A general idea

Resource based discrete-event systems with uncertainties (RDDESU) represent technical, natural and social objects (agents) in its environment of competitors, where competing all agents can consume/produce or acquire/release a resource at each externally or internally generated event changing system state, a *sociotechnological systems* (STS). The uncertainties appear in the system due to activities of competitors or internal factors having probabilistic nature and represented as internal events or shortage of resources. The synthesized control should ensure that the system corresponds to a set of predefined constraints and/or maximizing/minimizing values of system characteristics. From control theory point of view, the problem is so called poorly stated, as criteria of optimality cannot be defined (formalized).

Conflicts in STS can be analyzed by construction of a finite chain of sequentially made possible actions (mutual impacts) of opponents [1]. This formulation of the problem is the object of game theory (GT) of modern operational research, and the object is referred to as *resource-based conflict* (RBC), and the resources the agents own are their *resource bases* (RB). According to GT, we are to determine such sequence of actions (a strategy), which will lead to the end of the conflict (*i.e.* final state of RB of the players), which meets goals of both or at least one of the opponents, who is declared winner.

Despite widespread and commonly understood essence of the described RBC, GT state of the art is such, that available mathematical tools, used nowadays by GT developers, are not exactly suitable for completely adequate mathematical formalization of such conflicts, because application of these tools demands explicit representation of sets of possible implementations of conflicts in a form of trees, matrices or automata. By this dimensionality of practically interest representations of RBC are so large, and time, necessary for their construction, so long, that in most cases it is very hard or even impossible to apply known GT approaches to the adequate modelling of real RBC [1].

Alternative approach, which consideration in the context of RBC may have evident reasons, have raised from the artificial intelligence area. It differs from GT by basic representation of the potential activities of the opposing sides and possible ways of application of their capabilities during conflict. This approach is called "multi-agent", following that every STS is represented as a set of active entities, called agents, operating independently in accordance with their internal logics. Agents form multi-agent system (MAS). In comparison with modern GT models, MAS do not demand explicit representation of action of the opposing sides during conflict. It is sufficient to define implicit logics of action of all agents, comprising MAS, and to construct the initial state of the MAS, *i.e.* set of initial states of its agents. All further behavior of the modeled STS until some final state will be explicated by MAS itself [1].

Analysis of the manufacturing process modeling domain, the primary scientific interest of LNHU[1], showed that the object instances are represented as STS. The accuracy of the controlled processes represented as RDDESUs ensuring the prescribed parameters properties in the conflicting environment and internal properties causing uncertainties is the subject of their research. Internally uncertainties are mostly the shortage of resources, namely utilities, absence of staff due to illness, equipment fault. These problems are solved with reserving power, employees, rescheduling batch processing to the equipment used on less prioritized processes. The amount of the reservation and a set of other activities aimed at preventing occurring internal uncertainties and overcome them is figured out by computer simulation.

Thus, we propose to extend well-established approaches for industrial systems manufacturing processes modeling with game theory and DSS representation, the unknown parameters of the model is figured out in computer simulation based on control synthesis algorithms for DSS. The simulation processes are organized as theories of first-order logical language of Positively constructed formulas (PCFs) and its theorem proving techniques as the scales of the industrial systems require automating high-level activities of the object analysis process.

II. Related works

Currently, there are almost no publication on RDDESU due to the problem complexity related to the representation of the object (system) state, resource conversion and lock, uncertainties modeling. Some aspects of the stated problem, however, are in active research.

Modeling the competitive environment is relatively new in the field of research of industrial systems. The environment is described as set of possible events, which can occur, the possible actions are the way of reacting these events [2], [3]. In the paper, the solution is designed as set of rules for reacting to events. Reactions are constructed for both competitors and counterparties (suppliers, consumers). After that, the amount of additional resources to be spent to implement the reaction is accounted. The similar technique is used to assess possible risks in startups.

Most works do not cover the organization behavior in a perspective more than a couple of possible steps. This is probably due to the complexity of the theoretical representation of such approach. In the 2000s, a new direction of application of game theories (GT) with usage of classical control methods appears, namely, *mean field games* models (see a recent review is [4]). The theory started to attract scientific attention after publication of J. M. Lasry and P. L. Lions (2006), and, in the same time, of P. Caines, Minyi Huang and Roland Malhamé (2007). The theory allows one to apply regular approaches of continuous mathematic to figuring out a Nash equilibrium, resulting in less combinatorial and complex computation. But the problem state is based on the subsumption that there exists infinite number of rational opposing agents to the main player. In the environment, the activity influence of an agent to main player is infinitely small and, hence, the influence of the opposites are accounted aggregated and even one can use iterative techniques efficiently to figure out fixed point estimates. The main application areas are modeling crowd behavior, energy GRID modeling, market price formation.

Digitization of the business processes management supply chains, namely information technology support, resulted in preferable discrete representation of the manufacturing process. Discrete-event systems and their derivatives are the mathematical abstraction widely used in representation of the manufacturing processes of all types (continuous, discrete and batch). Most attention is paid to the local processes (within a company). The influence of the competing organizations in these models are presented as uncertainties and accounted by constructing a *predictive control*. Predictive control is a model-based optimization control approach. The system model is used to predict the future state of the system. One of the approaches that uses system state forecasting is the *receding horizon* optimization strategy improving the control inputs of the system. In the paper [5], the physical coupling among subsystems are considered, and the communication network is utilized to obtain Nash equilibrium solution for the optimization of each subsystem output through repeated iteration of coupling among subsystems, with the constraints being satisfied; in that case the system performance is optimized. Based on the previous paper [5] and paper [6], authors perform the nominal stability and performance analysis, and verify the distributed predictive control algorithm on a benchmark process (heavy oil fractionation process). The above method belongs to a class of non-cooperative distributed predictive control.

When the real process is strongly coupled, the stability and control performance of the system will be greatly affected by the local performance indexes obtained by the non-cooperative distributed predictive control. Therefore, researchers put forward the cooperative distributed predictive control method. Compared with non-cooperative distributed predictive control, the former takes the global performance index of the system as a function of each subsystem's performance index, which can ensure the optimal global performance index and improve the convergence speed while considering the subsystem's performance. Liu Yubo *et al.* [7] proposed a distributed predictive control method based on global coordination, the correlation of input and output of all associated subsystems are comprehensively considered, and verified it in Shell's heavy oil fractionator and other process. Venkat *et al.* [8] used game theory to study the optimality of a distributed predictive control, and concluded that the iterative solution has the global optimality, but the computation is complex.

Aiming at the predictive control method with limited resources, Asadi *et al.* [9] proposed the distributed coordinated predictive control method under the resource limitation, and

[1]Liaoning Shihua University

adopted the time-division and multiple-access technology to coordinate the sub-system. Zou *et al.* [10] proposed an event-driven distributed predictive control method, which implements an asynchronous coordination for each agent (subsystem) and reduced the computation and communication burden. Li *et al.* [11] adopted the non-zero-sum game reinforcement learning method to obtain the optimal solution of each agent iteratively and each subsystem is coordinated and controlled.

In the system with structural uncertainty and parameter uncertainty, Li *et al.* [12] proposed a time-varying multi-step control rate algorithm in the distributed predictive control method, in which a "multi-step control set" is designed, and the degree of freedom of the controller is increased. For the system with the bound change of the parameters, the performance of predictive control is further improved by combining the multi-step control method. For dealing with uncertainties of the resource allocation and the demand, all achievements focus on the production planning and scheduling stage and the existing distributed predictive control algorithm has not been involved.

III. The proposed approach

As stated in [13] the uncertainties is the main point of reduction of the model ability to make precise forecast and reveal real properties of the consumer products manufacturing and service provision. In order to minimize impact of the uncertainties model must account as much information as possible, as well as the object should have the ability to adopt itself to perturbation (a property of *resilience*). We divided the sources (see section I) of the uncertainties as external, a competitive multi-agent environment and internal, which arise at industry itself. In contrast to the nowadays fashionable approach of complex systems modeling based on machine learning techniques, we decided to use classical mathematical methods of control theory for discrete models, but with advantage of contemporary IT supporting automated research based on computer simulation, logical inference (automatic theorem proving), and application of physical and cyber-physical units. The control synthesis will be realized as a result of logical inference: back-propagation theorem proving and forward-chaining deduction. The first one is used to synthesize a modular supervisor control if the logical description formula has a proof, or show the system's properties preventing the synthesis. The second one is a computer simulation controlled by forward-chaining logical inference, where the control is synthesized as sequence of actions shifting system to a admissible state after an undesired event occurrence; the events occurrence are modeled with rules.

Computer simulation, control synthesis are based also on novel application of the authors' automatic theorem proving methods, previously used in construction of the complexes of models, their identification, and driving the computer simulation. The authors' positively-constructed formulae approach is to be extended with new techniques and modifiers of the default logical inference strategy supporting the implemented simulation techniques. So, the new calculi with special, including intuitionistic properties, will be devised. This should enrich existing techniques, which already support parallel processing; as compared to the Resolution method, the approach has less combinatorial inference search process, weak requirements of the formula structure, it is highly configurable and compatible with heuristics.

In ISDCT SB RAS, a number of techniques of its implementation is being developed. In comparison with Prolog and its constructive notation, PCFs have intuitionistic semantics in a wider range of rule representation, non-Horn ones. The PCF language expresses logical inference as a question-answering procedure, which looks like application rules in forward-chaining inferences (CLIPS, DROOLS), but supports disjunctive branching in the consequent part, which is naturally expresses variants of system evolution in a virtual future. The resulting inferences can have intuitionistic semantic if some general constraints on the whole formula are hold. These constraints are more general, than in Prolog-like systems. Another useful features of the PCFs inference is the ability to adjust to the properties of the domain. The default complete strategy is modified by means of constraints and guides (heuristics), which are just added to the default search strategy, this does not force the user to program new one.

The proposed research is based on the complex representation of a large-scale sociotechnical system as RDDESU, accounting more information for the object representation as compared to the approaches based on GT and DES, resulting in more adequate real technical systems modeling with its environment, usually competitive for resources. The competitive environment generating external uncertainties is represented with resource-driven games (RDG), namely, mathematical structures of multisets, operations over them, filter, and the rules of the behavior definitions. All these mathematical structures are compatible with DES representations. Development of data structures for representation of RDG as DES is a new problem in IT, as well as the amounts of structural and behavioral data of modelled object forces the research to use intelligent and visual technologies to represent the object and convert its representation into data to be processed with computer simulation and control synthesis software.

The research will deal mainly with the development of techniques for

1) definition the model structure of the RDDESU and their environments (further, just RDDESU),
2) adaptation of the standard visual notations for representation of the RDDESU,
3) construction of transformation software converting the visual representation of a RDDESU and other model aspects into a computer simulation object,
4) implementation of control of RDDESU,
5) development of new modifiers of the default inference engine to support computer simulation for RDDESU,
6) adaptation of three-level dynamic model of manufacturing as RDDESU,

7) implementation of scientific software for RDDESU research.

Consider methods and approaches main items of the list in details.

A. Resource-driven games representation of an industrial system

A resource-driven DES with uncertainties are represented as competing agents spending/producing or acquiring/releasing resources. In manufacturing industry, resources are raw materials, commodities, services and utilities (energy, gas). The competitive environment comprises such kind of agent, which activity always affect to other agents' resource production and consumption by eliminating an amount of resource or suppressing the activity altogether that is represented as zero productivity and consumption. The activity of an agent can also produce some amount of resource at competing agent side.

Mathematical representation of the resource-driven games is based on usage of multisets, where each item of a multiset is an amount of a resource representation (<resource-kind, amount>). A multiset represents the set of resources owned by an agent at a time moment. A number of operators (intersection, union, addition, subtraction, transformations *etc.*), filters and constraints are defined to express the resource possible ways of conversion within an action. The conversion is expressed, *e.g.*, with a grammar, where each of the grammar rule represents a conversion act. All the possible grammar inferences results in multisets of various consequences. Over these sets, similarly, operations, filters and constraints can be also defined. Filtering the resulting multisets produces various model forecasting or property evaluations [1].

The approach that uses simpler multi-agent model was applied in distribution of the load in a heterogeneous distributed computing environment [14]. A computational process is descried as an abstract program implementing within a problem-solving scheme. The scheme represents the applied modules to be run and their relationships. A multi-agent algorithm for distribution of the modules between environment nodes realizing a possible computation instance of the scheme has been developed. The resource reallocation is started as soon as an existing computation process fails. The instance plan is generated as a result of tender of jobs, allocation of a core class to the instance costs a resource. The bidding data are collected in the run time accounting various kind of failures. In comparison to the known algorithms, the proposed one implements an adaptive multi-scenario solving this issue and therefore increases a degree of computational process fault-tolerance. The further direction of the study is related to using this algorithm in complex technical systems with decentralized group control of problem-solving processes in the conditions of conflict and cooperation.

B. System modeling

DES aspect of a RDDESU is represented with usual means, such as, like automaton, system of state conversion defined as function. Uncertainties are expressed as possible competing agent actions and probabilistic events occurring internally in the system. Real-world problems (RWP) usually have large scale as compared to theoretical testing examples. The structures of the RWP representation are complex and comprises various aspects (projections). A popular way of overcoming the complexity of object representation is usage of visual models, where various aspects are represented with corresponding visual images. In the IT field standard ways of the representation are UML, SysML, BPMN and other notations. These notations can be used for RDDESU representation, especially SysML, which domains are description of complex systems, including software, organizations, processes etc. For each of the model notation a visual editors and export/import formats (such as XMI), usage techniques were designed. In our project we will use visual notations and their tools, with conversion of the models into internal representation.

In order to proceed with computer simulation and other object synthesis, the model of RDDESU must be represented as internal objects, which is essentially a PCF formula defining RDDESU. This object is constructed from the set of visual models using SysML diagrams (State diagrams, Parametric diagram, Requirement diagram, *etc.*) by models' transformation. These models in form of XNI-files are loaded in an object-logical environment constructed as network of objects of the Logtalk logical Prolog based language.

Transformation software is constructed as logical objects [15]. The standard XMI representation of the visual models is transformed into set of triples `<subject, predicate, object>` as an internal representation of input models [16]. This representation provides uniform access to all model structures of all models simultaneously. Logtalk objects analyze structure of models and other objects generating intermediate structures representing the structure of modules to be generated as source code. The transformation obeys a scenario of IS construction in the image and likeness of Model Driven Architecture paradigm. Usage of such kind of transformation approach allows us to develop software system carcasses on the level of abstract models, involve various sources of model data in the transformation, define and structuring conversion knowledge as objects.

The approach was tested in representation of 144 Mothur modules (an applied package for genetic sequencing analysis) as dataflow block of Rapidminer studio, allowing natural scientists to operate the process of genetic investigations themselves. The technique will be used to construct transformation of SysML representation of RDDESU into an internal representation. The usage of the logic object-oriented language Logtalk in the model transformation instead of standard ATL, QVT approaches allows one to use both power of logical inference and the expressiveness of object-oriented programming systems, as well as the integration with existing libraries in within the same programming system. For example, inheritance in a prototype hierarchy allows programmer to change rule sets, encapsulation allows simplification of access to input data, recognizing patterns in input data on-the-fly.

C. Control synthesis

Control for RDDESU is synthesized either as supervisor, preventing occurrence of events, or as a set of trajectories of system's evolution constrained with a time interval (set of ordered time moments), where each time moment corresponds to an admissible state of the system.

For most common and convenient way to represent a DES, finite state automata, results of P. Ramage and W. Wonham [17] are applied. The main approach to decentralized control synthesis on the basis of the theory of supervisory control is the conjunctive architecture of local supervisors when global permitted events are the only ones which were allowed by each of the local supervisors. Most of the results of decentralized control are associated with this approach [17]. Subsequently, a generalized approach, so-called general architecture of a decentralized supervisor [17].

According to the synthesized control, some events of automata-based DES are supposed to be prohibited from occurring to restrict system behavior within constraints given by some specification. The means of such control is the supervisor. The problem of designing a proper supervisor for fully or partially observed DES is the main problem of supervisory control theory (SCT). Controllability of a specification is a crucial property which must be verified to start building a supervisor. It may be compared to the safety property of the controlled system: no uncontrolled event which is not allowed by specification may occur. In the case when the input RDDESU specification is not controllable, controllable sublanguage (subautomaton) of this specification is to be found as a new admissible specification. In the case of manufacturing modelling the sublanguage denote a set of events, which appearance can be controlled.

Modular supervisors for DSS have been constructed for control of on a top level and AUV (autonomous underwater vehicles) group with automatic theorem proving on the bases of PCFs. An inference result of theorems represented with PCFs with subformulas corresponding to the controlled system and the requirements, which are to be hold, a conclusion is being drawn on the possibility to construct a corresponding supervisor control, or, in case of the impossibility of inference construction, a set of the system parameters are given, which prevent the inference. The obtained data is useful as heuristic for reduction of the number subsystem combinations needed in the modular supervisor synthesis [18], [19].

Discrete-event systems (DES) is a wide class of behavior representation of a dynamical systems changing state at a discrete time moments thanks to event occurring. In this direction, last decade we obtained results on decentralized hierarchical control synthesis for groups of autonomous underwater vehicles [20]. The number of the trajectories can be constructed, e.g., movement of the group in a conserved formation along a prescribed trajectory, patrolling a water area with gateways. The control is synthesized accounting the uncertainties of the environment, non-ideal functioning the communication and measurement equipment, discretization of the measurement (sampling) and constraints imposed to control resources.

In RSF Project 16-11-00053 a logical programming like language grammar for PCFs was developed to describe team missions of robots [21] and synthesize a control to achieve the mission goals. For the purpose, a PCFs language has been developed containing special system predicates and so-called computational function (functions, which are substituted as its calculated value instead its expression), allowing one to control default inference strategy and construct resulting terms. The forward-chaining inference of the PCFs calculus is being adapted to real time computational systems. The system constructs the inference till dead time is reached. If the inference corresponds a set of criteria, it is considered as successful. If a set of inferences are obtained, they are analyzed and the better is chosen. Other original features of PCFs are investigated and adapted in solutions of the technical problems. The real time mode is harder to implement than the receding horizon predictive approach.

An opposite approach is the compensation of the event appearance consequences, forcing the system in an admissible state with spending a reserved resource. This can be achieved with a set of rules recognizing the unsatisfactory state, analyze its properties, and add new actions to the schedule to move the system to admissible states. In a general case the admissible state is defined as a set of constraints. It is very hard to construct a complete set of rules for recognition and a transition synthesis for the domain, which is under investigation. In this case, a set of actions are performed in the same time moment splitting the current scenario to a set of subscenarios (alternative virtual futures) for each possible action. After each splitting and transition set of constraints are checked. The scenarios, which do not comply the constraints are rejected. The trajectory, which reaches the modeling horizon corresponds to the synthesized control driving the system in an intermediate, but admissible state. When a bunch of alternative admissible futures were synthesized, the choice of the better one is carried on with assessing criteria, *e.g.*, minimizing additional resource consumption. Thus, the control is synthesized by means of logic controlled computer simulation, and respects some ideas presented in section II.

In order to implement the computer simulation on PCFs representation of RDDESU, data structures for multisets and a default strategy modification are to be designed, and operations within construction of logical inferences are to be implemented. The latest version of our automatic theorem proving (ATP) software (provers) have RAM (Random Allocated Memory) allocation engines efficiently implementing indexing over the sets of terms. Filter operations for multisets are the similar structures. Items of the multisets are similar to term and atom in sense of data representation. Special subroutines will be programmed to account specific properties of multisets, their elements and relations, making multiset manipulations memory and time efficient.

The inference engine is to be adjusted with new modifiers and guides to support time and RAM efficient application of operations, filters and constraints as well as representation of grammars over the multisets. The default strategy can be modified with adding each rule (a question) a priority, arranging the rules in an order of application, restricting application of a rule when a pattern is recognized, backtracking the inference in case if criteria have not met within a time interval or a number of the inference rule application, checking constraints to the indexed subsets on the stage of substitution figuring out.

IV. Discussion

Expected results and their practical values are expected to be as follows:

1) A technique for representation of various aspects of resource-driven Discrete-event system with uncertainties as a complex of models will be developed, data structures for representation of the complex will be proposed.
2) For a visual representation of the aspects, a corresponding standard visual representation (*e.g.* within UML, SysML *etc.* paradigms) and its editing software will be adopted, and a usage technique will be proposed.
3) A software for (a) transformation of the visual models to the internal representation will be realized as structured logical objects, encapsulating transformational knowledge and algorithms; (b) methods of building supervisors for the DES will be developed based on the use of means of automatic proof of theorems in PCF-calculus (calculus of positively-constructed formulas).
4) The authors' technique of constructive inferences constructions on the base of positively-constructed formulas (PCFs) will be improved to support data object structures (multisets) and operations over them as first class objects, being subject of the inference, as well as new modifications of the default strategy of the inference search will be obtained, making the inference be more productive; a parallel versions of new strategy will be devised for cluster computing systems.
5) Methods, developed in the project will be organized as a modular software for carrying on scientific research (scenario generation, computer simulation and criteria assessment) in the field of DES of the above mentioned type, intelligent user interfaces for process control will be devised, as well as various means of the result representations.
6) For application aspect of the research, techniques of the near-to-real manufacturing process formulation as complex of visual models will be developed, examples of the formulation will be presented and their control synthesized.
7) An extensive testing of the synthesized control on testing and near-to-real examples will be carried out to assess the performance and other characteristics with the competing approaches.

In parallel the following investigations will be carried on in LNHU. The work is related to the adaptation the RDDESU approach to the real-world classes of manufacturing process. The colleagues will perform the following activities to obtain corresponding results.

1) Research of resource-driven multi-objective optimization method based on the resource-driven game model, a new efficient method for obtaining the optimal set point (the optimal solution) and the coordinating multi-objective strategy will be developed.
2) Research of distributed predictive control for resource-driven discrete-event systems under uncertainty with regards of industrial scale and complexity.
3) The establishment of visualization model of typical industrial process of ethylene and polypropylene production.
4) Application of the proposed control algorithm of resource-driven discrete-event system to typical petrochemical processes accounting the uncertainties.

The expected results discover new opportunities for rising level of commodities batch manufacturing control, as well as service. The project expands the theoretical knowledge in DES, game theory, automatic theorem proving, constraint programming, which are the fields of artificial intelligence, as well as manufacturing modeling. The produced software could be used to construct CAE/CAM (Computer-aided engineering/Computer-aided manufacturing) systems for concrete enterprises.

Conclusion

The problem of construction of an automated research software for investigating properties and control synthesis for a complex large-scale industrial dynamical system is considered in the paper. The control must hold the system within prescribe set of constraints describing admissible states, while the system is affected by uncertainties of various kind. The system model general design is proposed, where the uncertainties are divided on external, caused by competitors and counterparties, and internal occurring at place being result of utility shortage, equipment failure, staff absence. The theories of Discrete-event systems and Resource-based games are used in the representation of the industrial system batch manufacturing processes, which are considered to be a general most complex case.

The following results are to be obtained. (1) A resource-driven game based model of a manufacturing process accounting competitive environment of an enterprise will be developed, as well as (2) techniques of control synthesizing minimizing deviations of the process execution due to perturbation, (3) new strategies of inference search for positively constructed formulae, (4) new formalized knowledge for model conversion and interpretation represented as objects, (5) computer simulation and visualization system implementing the above mentioned methods and techniques. The scientific novelty is justified the usage of data close to real, application of the transformational technologies in software that allow one to deal with more complex models and account more data. The theoretical results could be used to construct decision support systems for engineering manufacturing processes, assessment of the robustness of the synthesized control.

Chinese colleagues already have certain foundation on the control synthesis, modeling and optimization of production scheduling and planning, description and management method for uncertainties occurring in production process. For a concrete manufacturing process, techniques for formulation of the production scheduling model, and deal with the internal uncertain factors of manufacturing process based on the chance constraint programming and fuzzy theory [13] have been developed. For the typical concrete manufacturing process with multivariate, strong coupling, large time delay and multi-time scale, a set of systematic and practical optimization and control scheme is proposed by the two-layer way, in which the upper layer adopts the set-point optimization method with the slow sampling time and the down layer adopts the distributed predictive control with the fast sampling time. In view of this, some factors such as the change of the raw material, the life and drop of the total load, external environment and the associated coupling among the sub-systems that influence the control quality of the system in industrial control can be overcomed, the control performance can be improved, the product quality and economic benefit can be increased.

The enrichment of the two-level standardized model of manufacturing process with resource-driven representation and parts simulating internal disturbances will add a third level of execution dynamics under a control. The manufacturing process naturally is being under impact of various uncertainties (perturbations) such as delay of resource supply, the equipment breakdown, temporal lack of labor, sudden production need, requiring equipment occupation on the urgent tasks, *etc*. These uncertainties are modeled either "in overage", *e.g.*, as probability to finish production in time, or an average resource loss (see section II). We suggest rectify these approaches with synthesis (on the third level) of an optimal control supervisor automata preventing some events to happen, or as a result of computer simulation in discrete time with introduction various disturbances according to a predefined policy. The control is synthesized as a sequence of actions of a trajectory holding imposed constraints in virtual timescale during a significant time period.

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