INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team macsi

Modeling, Analysis and Control of Industrial Systems

Lorraine

THEME 4A

Activity Report

2003

Table of contents

1. Team

MACSI is a project-team of INRIA-Lorraine. This team belongs also to LORIA (UMR 7503), which is a research laboratory common to CNRS, University of Henri POINCARÉ *(Nancy 1), University of Nancy 2 and National Polytechnic Institute of Lorraine.*

MACSI members, located in Metz, are also members of the LGIPM, laboratory of Industrial Engineering and Mechanical Production common to ENIM, ENSAM - CER of Metz and University of Metz.

MACSI members, located in Nancy, are also members of LORIA UMR 7503 of CNRS, University Henri POINCARÉ *(Nancy 1), University of Nancy 2 and INPL.*

Head of project-team

Marie-Claude Portmann [Professor at Ecole des Mines de Nancy (INPL)]

Vice-head of project team

Xiaolan Xie [Senior Research Scientist at INRIA-Lorraine]

Administrative assistant

Françoise Laurent [Ecole des Mines de Nancy (INPL)]
Christel Wiemert [INRIA]

Staff member INRIA

Lyès Benyoucef [Junior Research Scientist, INRIA]
Xiaolan Xie [Senior Research Scientist, INRIA]

Staff member UNSA

Henri Amet [Associate professor at Ecole des Mines de Nancy (INPL)]
Mohamed Ali Aloulou [ATER at UHP until August 30th, 2003, since 1st September 2003 ATER at Paris 10 University]
Didier Anciaux [Associate professor at University of Metz]
Sophie Hennequin [Associate professor at Ecole Nationale d'Ingénieurs de Metz]
Asma Ghaffari [ATER at Ecole des Mines de Nancy (INPL) until August 30th, 2003, since 1st september 2003 Associate professor at Ecole Centrale de Paris]
Thibaud Monteiro [Associate professor at University of Metz]
Ammar Oulamara [Associate professor at Ecole des Mines de Nancy (INPL)]
Marie-Claude Portmann [Professor at Ecole des Mines de Nancy (INPL)]
Wahiba Ramdane-Cherif [Associate professor at Ecole des Mines de Nancy (INPL), since September 1st, 2003]
Nidhal Rezg [Associate professor at University of Metz]
Daniel Roy [Associate professor at Ecole Nationale d'Ingénieurs de Metz]
Alexandru Sava [Associate professor at Ecole Nationale d'Ingénieurs de Metz]
Antony Vignier [Associate professor at ESIAL, UHP-Nancy I, until August 30th, employed for one year in the society IDENTIFIA (Sign Craft)]

External collaborator

François Vernadat [Professor at the University of Metz, working now for the EU community]

Ph.D. student

Zied Achour [defence in 2005]
Freddy Deppner [defence in 2004]
Hongwei Ding [defence in 2004]
Julien Fondrevelle [defence in 2005]
Jie LI [since mars 1st 2003]
Iyad Mourani [defence in 2005]
Latifa Ouzizi [co-supervised with Morocco University (defence in 2004)]
Guillaume Thisselin [MENJR until June 30th]

Student intern

Isil Osmanlioglu [Master internship, March-June 2003]
Salem Maloum [Master internship, February-September 2003]
Faouzi Amier [Master internship, March-June 2003]

Invited Professor

Mikhail Kovalyov [Professor, Economical Faculty of the Belarus State University in Minsk, since May 13th until July 13th, two months]

2. Overall Objectives

MACSI is an INRIA project-team since January 2000, after having been preliminary-project (avant-projet) since January 1998. The objectives of MACSI are Modeling, Analysis and Control of Industrial Systems. The application fields concern mainly discrete production systems, but do not exclude unit, continuous or series production systems.

At the origin, MACSI research activities were organized along three complementary axes:

- Modeling and specification of industrial systems including enterprise modeling (descriptive models), behavior modeling (analytical models) and control synthesis;
- Performance evaluation and regulation of systems using stochastic discrete event systems. This axis concerns both analytical methods (for particular systems) and generic optimization methods for generic systems;
- Organization and production control. This axis mainly covers the following topics: predictive and reactive scheduling, on line production control, layout and research of good maintenance policies for production workshops.

The main activities of MACSI are now clearly identified within the framework of the design and control of industrial systems. In consequence, the results of 2003 will be spllited up into two parts:

- Modeling, specification, design and evaluation of industrial system, using simulation (descriptive models) and performance evaluation (analytical models) of industrial systems including enterprise modeling (descriptive models), behavior modeling (analytical models), control synthesis and production system design;
- Modeling, simulation, optimization and decision making tools applied to off line and on line control of industrial systems including planning, predictive, proactive and reactive scheduling, on line production control and research of good maintenance policies.

The ”Industrial Systems” we consider can be:

- A network of enterprises (with centralized or partially decentralized command);
- A supply chain eventually divided between several enterprises or network of enterprises;
- An enterprise;
- A plant;
- A production system;
- A workshop;
- A transport system.

The theoretical bases are those of discrete event systems and discrete optimization. The aim of our research is resolutely two-fold, by developing on the one hand fundamental research, while having on the other hand constantly the concern of industrial applications.

Thus, MACSI considers specific problems of organization, of performance evaluation, of planning and scheduling including search for efficient maintenance policies.

A complementary objective is to contribute to the development of a systematic method and associated tools dedicated to the design and analysis of production systems, based on modeling and formal specification of the structure and its control, following what is done already in software engineering for example.

3. Scientific Foundations

3.1. Specification, control synthesis, design and evaluation of industrial systems

Key words: *Analytical models*, *control synthesis*, *design*, *extended enterprise*, *virtual entreprise*, *modeling*, *network*, *specification*, *optimization*, *performance evaluation*, *simulation*, *supply chain*.

Participants: Ziad Achour, Lyès Benyoucef, Hongwei Ding, Thibaud Monteiro, Nidhal Rezg, Daniel Roy, Alexandru Sava, François Vernadat, Xiaolan Xie.

MACSI activities within this topic are mainly dedicate to: modeling, specification, design and performances evaluation of industrial systems, using simulation (descriptive models) and/or optimization (analytical models). They include enterprise modeling (descriptive models), behavior modeling (analytical models) and control synthesis and production system design.

3.1.1. Supply chain management

Global economy not only offers new business opportunities for companies but also challenges the companies to optimize their business processes to remain competitive. Competition is not between individual organizations but between competing supply chains [43]. In order to retain the competence in the global market, companies should be reactive to the rapidly changing demand and improve the flexibility. Confronted with a highly competitive circumstance, supply chain management (SCM) is generally referred as an effective means to help companies reduce costs, be reactive and so on. Supply chain management is a way to supervise the flow of products and information as they move along the supply chain. The goal is to optimize the supply chain, which can not only reduce inventories, but may also create a higher profit margin for finished goods by giving customers exactly what they want. Apart from its effectiveness, SCM is a complex process because of the stochastic nature and ever-increasing complexity of the supply chain/networks. Hence, there is no generally accepted method by researchers and practitioners for designing and operating a supply chain.

The design and management of supply chains/networks are complicated by the great variety of available policies for each of decision problems (purchasing, production, warehousing, transportation,...), by the need to assess complex trade-offs between conflicting objectives, and by the requirement of testing the dynamic behavior of the overall system within an environment affected by uncertainty. Furthermore, one have to move smoothly between hierarchical levels, adding details incrementally; for instance, a multi-echelon inventory system can be simulated by modeling the transportation delay with random variable, or, alternatively, the lead time can be determined by solving a vehicle routing problem (VRP) and explicitly simulating the transportation sub-system.

Lots of deterministic and stochastic supply chain optimization models have been developed in the literature [44][56][37]. Simulation has been identified as one of the best means to analyze and to deal with stochastic natures existing in supply chain. Its capability of capturing uncertainty, complex system dynamics and large scale systems makes it attractive for supply chain study. It can help in the optimization process by evaluating the impact of alternative decision policies. Therefore, many simulation models have been built to facilitate the use of simulation in designing, evaluating, and optimising supply chains (IBM Supply Chain Analyzer, Autofat, Supply Chain Guru, Simflex,...).

At the same time, thanks to several decades of theoretical and tool developments, state-of-the-art optimization engines such as ILOG-CPLEX and DASH-XPRESS have proven to be able to solve real large size decision making problems of millions of variables and millions of constraints. These optimization engines are now used to power advanced Supply Chain Management tools (I2, Manugistics, Peoplesoft, SAP,...) for solving complex supply chain planning/scheduling problems. Impressive cost reduction and customer satisfaction achievement are frequently reported and success stories are frequently reported by optimization engine providers or by SCM tool providers. The strength of SCM tools resides in their ability to efficiently coordinate activities through the whole supply chain: from demand planning, to procurement, to manufacturing, to inventory control and to distribution. These activities that were optimized local in the past are now optimized globally through the use of SCM tools. The **weakness of these optimization tools** is the impossibility to take into account random events. All optimization tools are based deterministic optimization models and the quality of the results strongly depends on the quality of the estimated data such as demand forecasts and the variability of the random quantities.

Simulation-optimization is a subject that has increasingly attracted the attention of many researchers and practitioners. Existing literatures related to simulation-optimization methods can be classified under four major categories: gradient based search methods, stochastic optimization, response surface methodology and heuristic methods [39]. Heuristic methods are usually preferred over the other three, when dealing with qualitative decision variables.

MACSI objective is to develop a simulation-optimization methodology for supply chain design problems that selects the strategic decisions (opening and/or closing decisions for network configurations) based on their impact on both qualitative and quantitative supply chain performances. The methodology is composed of three basic modules: a genetic algorithm (GA) optimizer for strategic decision selection, a discrete-event simulation environment (DES) for operational performance evaluation and a supply chain modeling package. The GA optimizer guides the search direction to the near-optimal solution systematically considering the feedback from simulation evaluation. All the candidate network configurations, proposed by the GA optimizer, are evaluated by corresponding simulation models. The simulation models are extended from the supply chain modeling package via object-oriented technology. Appropriate estimation of key performance indicators (KPI) of the supply chain are provided as feedback for guiding the genetic search. Moreover, uncertainties related to demand, production and distribution are taken into account by decision-makers through simulations.

3.1.2. Network of firms

To achieve the expected goals in terms of minimizing the delay of deliveries, the holding costs and the transportation costs, it is imperative that enterprises work together. New forms of organizations have emerged, the so-called extended enterprises and virtual enterprises (Hardwick and Bolton [51]), in which partners must demonstrate strong co-ordination and commitment capabilities to achieve the desired goals. A virtual enterprise (VE) could be a single enterprise or a grouping of similar companies (i.e. similar goods).

Today, in a network of firms, manufacturers no longer produce complete products in isolated facilities. They operate as nodes (i.e. single or virtual enterprise) in a network of suppliers, customers, warehouses and other specialized service functions (Davidow and Malone [45]). To generate a better productivity, these companies need to coordinate the different actions which are distributed among autonomous partners (Axelrod [38], Malone and Crowston [57], Rota [67], Kjenstad [54]). Due to the high complexity of a whole network of firms, a centralized decisional system seems not be able to manage easily all the necessary information and actions (Monteiro and Ladet [58]). Moreover, the centralized philosophy is strongly opposed to the decisional autonomy of the supply-chain components (firms). This is why, MACSI project proposes a more distributed approach in order to adhere to nodes autonomy and to facilitate the management of a network of firms.

3.1.3. Control synthesis

Production systems are often complex making more difficult the realization of an effective and realistic control device. Several studies were dedicated to solve the Discrete Event Systems (DES) control problems. For proposed discrete models, of respectively the process and specifications of the wished behavior, the objective is to synthesize the suitable supervisor who will act in closed-loop with the process, in the goal to obtain the desired behavior. The proposed approach by Ramadge and Wonham deals with existence and synthesis of the most permissive supervisors of DES [65][72]. Indeed, this approach models industrial systems using automats and formal languages. However, the lack of these automats and formal languages limit the possibilities of developing effective algorithms to analyze and synthesis the systems. To mitigate these disadvantages, several control synthesis methods based on Petri nets (PN) were proposed [55][53], in order to exploit the modeling power of PN and the rich mathematical results which characterize them. This allow to have a qualitative analysis of the system like attainability, promptness, etc.

MACSI objective is to propose a new approach for control synthesis of discrete event systems based on marked graphs. This approach allows to solve the forbidden state problems characterized by a set of General Mutual Exclusion Constraints (GMEC) in presence of unobservable transitions.

3.2. Simulation, optimization and decision making tools applied to industrial system control

Key words: *Discrete optimization*, *network of firms*, *on line control*, *production manufacturing*, *planning*, *predictive/proactive/reactive scheduling*.

Participants: Riad Aggoune, Mohamed Ali Aloulou, Henri Amet, Didier Anciaux, Lyès Benyoucef, Freddy Deppner, Hongwei Ding, Julien Fondrevelle, Sophie Hennequin, Mikhail Kovalyov, Jie Li, Thibaud Monteiro, Iyad Mourani, Ammar Oulamara, Latifa Ouzizi, Marie-Claude Portmann, Wahiba Ramdane Cherif, Nidhal Rezg, Daniel Roy, Alexandru Sava, Guillaume Thisselin, François Vernadat, Xiaolan Xie.

The organization and the control of any industrial system lead to various optimization problems such as: forecasting, raw material and component supplying, inventory management, planning, scheduling, quality control of the products and the production systems, maintenance policies, etc. [48][46][69]

The MACSI project focuses on decision making for production systems. Some activities are linked to planning, such as the search for coherent plans within a virtual enterprise or more classical planning research in presence of limited resources. Some of the optimization activities of the MACSI project concern scheduling problems [68][40][42][50][62].

3.2.1. Scheduling

Most of the scheduling publications work on very simplified problems very far from the reality of the workshop. We progressively integrate more and more constraints pertinent for concrete applications in our models. In particular, we consider simultaneously or separately: calendars on the machine, minimal and maximal time lags between the operations, sum-batch and max-batch, resource blocking and various workshops: single machine, parallel machine, flow-shop, hybrid flow-shop, job-shop and even assembly shop with synchronization between the products. Our orientation towards supply chain control provides us also with new models of planning and scheduling. The considered problems are generally NP-hard; in consequence, we use either branch and bound approaches or approximation approaches in order to solve them in a reasonable computation time while obtaining near optimal solutions. We hybrid different approaches in order to be as efficient as possible: construction approaches, meta-heuristic such as simulated annealing or genetic algorithm and decomposition approaches. A main difficulty consists in building very good lower and upper bounds in order to improve the methods and/or to evaluate the quality of the proposed methods. Other important research activities consist in getting new complexity results or new dominant properties.

There is an extensive literature on models that integrate scheduling with batching decisions. In this context, the motivation for batching jobs is a gain in efficiency: it may be cheaper or faster to process jobs in a batch than to process them individually. A situation example where a batching occurs when machines require set-ups if they are to process jobs with different characteristics. For example, in family scheduling model, jobs are partitioned into families according to their similarity. In this case, a set-up is required when the machine switches from processing job in one family to jobs in another family. In this model, batch is a maximal set of job that are scheduled contiguously on a machine, we call such machine as sum-batch machine. There are two variants of the family scheduling model depending on when the jobs become available. Under batch availability, a job becomes available when the complete batch, to which it belongs, has been processed. Other situation is job availability, in which a job becomes available immediately after its processing is completed.

Another situation where batching may result in improved efficiency occurs when a batching machine is able to process several jobs simultaneously. An example is given by chemical process, which are performed in tanks. In these cases, a batching machine processes a batch of jobs at the same time and there is sometimes an upper bound on the batch size. A review of models which combine scheduling with batching can be found in Potts and Van Wassenhove [64], Webster and Baker [71], Potts and Kovalyov [63], more details about batch scheduling problems in Oulamara [61].

An important part of our research is linked to scheduling in presence of disturbances. We have been working for several years on this subject and we are members of research groups working on creating robustness, stability and/or flexibility in the scheduling process (off line and on line control). Our main approach consists in defining new structures, by proposing to the workshop a family of schedules instead of a single schedule. The family is built by an interactive multi-criteria proactive procedure. The flexibility introduced in the family is then used by the reactive on line procedure, which makes standard decision in absence of disturbances and reacts to small and medium disturbances; it orders a re-scheduling when the pro-active schedule can no more be followed without an important performance decrease.

We integrate a new activity concerning Capacitated Arc Routing Problem (CARP). It was the subject of the PhD thesis of Ramdane-Cherif [66] (MACSI member since September 1st, 2003). Contrary to the well-known Vehicle Routing Problem (VRP), in which client nodes in a network must be visited for pickup or delivery, the CARP consists of processing a subset of arcs. Compared to node routing problems, the CARP has been neglected for a long time by researchers. Fortunately, it has raised a growing interest in the two last decades, mainly because of its important applications like urban waste collection, winter gritting and inspection of power lines. However, the CARP of the literature is not sophisticated enough to handle real-life applications. The researches in [66] propose new problems which integrate more realistic constraints generalizing the CARP.

For MACSI, the objectives will be to investigate new directions related to CARP and this including more pertinent constraints. Indeed, using the developed MACSI approach for proactive-reactive scheduling, we intend to study the flexibility of the CARP in presence of disturbance. In this direction, we have a promising industrial application with BT Exact (British Telecom).

3.2.2. Planning inside enterprise network

Network of firms management needs to integrate two decision levels: planning and control. In planning level, a supply chain, coherent planning of all actors is needed (Gavirneni, Kapuscinski and Tayur [47], Cachon and Lariviere [41]). This integration not only applies to the material flows from raw material suppliers to finished product delivery, but also to the financial flows and information flows from the market (i.e. the anonymous consumers) back to the supply-chain partners. This planning function lies at the tactical level of the network of firms. Control function has a shorter run decision and a smaller focus than planning. Its objectives are restricted on one single or virtual enterprise. It lies at the operational level.

MACSI project tries to propose a new approach, for the network of firms and the supply chain management, based on the virtual enterprise paradigm and the use of multi-agent concept. The virtual enterprise is defined as a grouping of nodes (or entities) which are linked together with information and material flows. Of course, each node could be itself a virtual or simple enterprise. This work integrated a part of the work made during the V-CHAIN project.

4. Application Domains

The application areas of MACSI concern mainly discrete production systems (mechanical production, assembly lines, semiconductors fabrication, etc.). Some studies cover also continuous production systems (in particular iron and steel industry), unit or by batches systems. Although, the main results obtained in the project were studied within the framework of production of goods, certain results can be applied to the service industry (enterprise modeling, performance evaluation, scheduling). The competences of MACSI members cover primarily:

1. production systems design going from the formalized requirements, functional, structural and informational aspects, resources and system layout identification and selection, management policy selection, until the simulation and prediction of the system performances;
2. reorganization of existing systems and their performances evaluation;
3. workshop physical flows optimization and identification of scheduling policy, possibly taking into account an optimized maintenance policy of the equipment;
4. definition and installation of workshop control systems which can react to the different operation risks;
5. production systems integration using integration platforms.

The industrial sectors in which MACSI members are solicited or for which they develop their research concern:

- car industry (Renault-France, FIAT-Italy and Ford-Spain),
- textile industry (HiTec Italy),
- mechanical fabrication (in particular, car equipments manufactures),
- assembly lines scheduling and load balancing (Aprilia-Italy),
- semiconductors manufacture,
- iron and steel industry,
- pharmaceutical and agro-alimentary industries (customer of INCOTEC).

MACSI industrial activities are increasingly related to the design and management of supply chain. They consist in proposing models covering information, material and decision flows respectively, and including several companies working in collaboration to realize some products.

5. Software

Some software were developed within the framework of Ph.D thesis and an industrial contract. They are prototypes intended to validate the ideas. MACSI is only the ideas owner used in the software development for:

1. European project V-CHAIN, in particular, the scheduling of assembly lines in the Aprilia company,
2. European project ONE
   - modeling and simulation of production and distribution network, in particular, PUNTO-FIAT distribution network in Germany,
   - development of a simulation-optimization approach for strategic outsourcing, in particular for supplies selection of HiTec, an Italian textile company,
3. Development of a decisions tool (using Delph 7.0) dedicated to the production planning generation for short and medium terms of the RENAULT assembly lines.

6. New Results

6.1. Specification, control synthesis, design and evaluation of industrial systems

Key words: *Supply chain*, *simulation*, *optimization*, *multiobjective*, *genetic algorithm*, *dynamic*, *stochastic*.

6.1.1. A multiobjective simulation-optimization methodology for supply chain design and management

Participants: Lyès Benyoucef, Hongwei Ding, Xiaolan Xie.

Supply chain design and management usually involve multiple conflicting optimization objectives, such as low costs, high quality, short lead-time and high demand fill-rate. Traditionally, the total cost of all supply chain activities is used as the only key performance indicator (KPI) for supply chain optimization. However, in the current competition environment, it is not always desirable to reduce costs if this results in degraded customer service level. Trade-off between these conflicting performance indicators should be made by decision makers. Motivated by these facts, we have developed a simulation-optimization methodology for supply chain design and management [8]. Subsequently, it is applied to solve the supplier selection case study proposed by an industrial partner of project ONE [26] [27].

The methodology is composed of three basic modules: a multiobjective genetic algorithm (MOGA) optimizer for strategic decision-making, a discrete-event simulation model for operational performance evaluation and a supply chain modeling package. More specifically, the multiobjective GA is developed to perform stochastic search of best-compromised solutions, which achieve trade-off between different optimization objectives. All the decision variables are incorporated into discrete-event simulation models for estimation of their impacts on operational performances. The simulation models are extended from the supply chain modeling package [28] [7] via object-oriented technology. Appropriate estimation of key performance indicators of the supply chain are provided as feedback for guiding the genetic search. Moreover, uncertainties related to demand, production and distribution are taken into account by decision-makers through simulations. The uniqueness of the proposed method is that it not only makes decision at the strategic level, but more importantly it addresses the operational aspects of each solution through simulation. In summary, the characteristics of this method are three-fold:

1. GA's evolutionary nature enables identification of promising search directions of both sourcing and inventory decision variables thanks to the performance knowledge learned from simulation.
2. Simulation allows faithful evaluation of strategic decisions, i.e. supplier portfolio, and the impacts of uncertainties and risks on supply chain operational performances, which is usually difficult for traditional analytical optimization methods.
3. Multiobjective optimization enables practitioners simultaneously to handle both costs and other non-financial performance indicators, such as demand fulfillment [29].

6.1.2. Supervisory control with unobservable events

Participants: Ziad Achour, Nidhal Rezg, Xiaolan Xie.

In the field of the supervisory control, we follow the approach of Holloway and *al.* [52] and Ghaffari and *al.* [9] to address the forbidden state problems of general live marked graphs with uncontrollable and unobservable transitions. General Mutual Exclusion Constraints (GMEC) defined on some so-called critical places are used to express the control requirement and to define the set of forbidden markings.

The main contributions of our work can be summarized as follows. Supervisory control of partially controllable and partially observable Petri nets has been addressed in [59][60][70][49]. Compare to [59][60][70], where complicated algebra approaches are presented without granting the optimality, we propose a new polynomial optimal approach. This approach, contrary to [49], where the authors consider the case with unknown initial marking but without unobservable transitions, concerns the supervisory control of Petri nets with known initial marking and unobservable transitions. Furthermore, compared with [6], it provides simple analytical results based on the concept of observer instead of the algebra analysis.

Our approach significantly extends the analytical results of Ghaffari and *al.* [9] to partially observable case and provides simple analytical results for non-trivial cases of the GMEC specifications. More specifically, contributions and motivations of this work with regard to Ghaffari and *al.* [9] include two results:

- It proves that the supervision problems in the presence of unobservable events can be decomposed into two sub-problems; observability problem and control problem.
- It significantly extends analytical results of Ghaffari and *al.* [9] to general live marked graphs with unobservable transitions for GMEC specifications by using new observability results.

6.1.3. Verification of time discrete event systems (DES)

Participants: Alexandru Sava, Xiaolan Xie.

Recently, the technological progress together with the increasing demands of quality and productivity have determined the development of complex manufacturing and communication systems. Due to economical considerations, it has become crucial to dispose of formal tools and methods to model, analyze and verify these systems in order to guaranty a priori that the specifications are respected.

Our research work deals with evaluation of end-to end delays such as tasks execution time, the time needed to produce a product or the time elapsed between different production stages. The method we proposed to solve this problem is based on the Time Petri Net model (TPN). This tool is derived from autonomous Petri Net model by associating a firing interval to each transition. Consequently, it inherits the Petri Net based models capacity to represent naturally important DES behaviors such as synchronization, resource sharing and parallelism. Moreover, it offers the possibility to model most of the time constraints intervening in a TDES behavior. However, the existing technique for TPN analysis (i.e. the state class graph) is not suitable for time properties verification. This technique does not allow computing end-to-end delays in task execution, which is an important issue for time critical systems.

The approach we propose consists in two steps. The first step of our method consists in modeling the exact behavior of the Time Petri Net by a state class graph. We proposed a new definition of the state classes in order to represent the exact state space reachable during the TPN evolution. Then, we use a global clock to measure the time elapsed while the system evolves between two given state classes.

Our future work deals with controlling the evolution of the manufacturing system in order to guarantee that time specifications are satisfied.

6.2. Simulation, optimization and decision making tools applied to industrial system control

Key words: *Discrete and continuous flow models*, *distributed control*, *coordination*, *maintenance*, *manufacturing systems*, *multi-agent system*, *negotiation*, *network architecture*, *optimal control*, *planning*, *scheduling*, *virtual enterprise*.

6.2.1. optimization of manufacturing systems via simulation

Participants: Iyad Mourani, Sophie Hennequin, Xiaolan Xie.

Nowadays, manufacturing systems become more and more complex with an increasing number of parameters. That is the reason why simulation is often the only method used to analyze and study manufacturing systems. Unfortunately, because of the real complexity of manufacturing systems, simulation needs an important processing time and looks like an incontrollable "black box". It seems to be important to define and construct new methodologies to simulate and to insure a good optimization of such type of systems.

Manufacturing systems can be represented by a discrete or continuous flow of the parts. In the first case, the more realistic, the modeling is based on the flow of the different parts on the machines and in the second case a continuous approximation of the discrete flow is realized which allows to simplify the model and to obtain differential equations.

The behavior of a manufacturing system is harmfully affected by machine failures. Machine failures may be either operation dependent (ODF) or time dependent (TDF). Operation dependant failures can only occur while a machine is processing a part, while time dependant failures can occur even if it is forced down.

The purpose of our work is to realize the optimization of automated manufacturing systems, such as transfer lines with ODF and TDF machines, via simulation based on discrete and continuous flow models. Firstly, the optimal control for a simple manufacturing system (one machine, one buffer and a demand) in the discrete flow case is studied. We point out and prove that in this case the hedging point control is the optimal control [32]. Secondly, the comparison between ODF and TDF of the machine's throughput for transfer lines is studied. It has been proved that the productivity of an ODF machine is better than the productivity of a TDF machine.

6.2.2. Stochastic optimization of inventory systems

Participants: Jie LI, Alexandru Sava, Xiaolan Xie.

This research work deals with analysis and optimization of inventory systems. We are considering an inventory system composed of one store, with base stock control policy. The demand arriving time is a Poisson process. The number of products ordered at each client arrival is also a stochastic variable. Therefore, the inventory system is characterized by batch orders with exponentially distributed size and batch delivery. A method based on queuing theory is about to be developed for estimating the end-customer service level, the fill rate and average inventory cost. Furthermore, we are interested in estimating the inventory level in order to minimize the inventory cost and meet the end-customer service levels.

6.2.3. Maintenance policy of manufacturing systems

Participants: Nidhal Rezg, Xiaolan Xie.

In the field of maintenance and control policy, we consider a repairable production unit subject to random failures, which supplies input to a subsequent assembly line. The production unit is submitted to a maintenance action as soon as it reaches a certain age 'T' or at failure whichever occurs first. A buffer stock 'h' is built up in order to guarantee a continuous supply of the assembly line at a constant rate during repair and preventive maintenance actions whose respective durations are random. This production unit operating strategy is investigated taking into account a minimum required stationary availability level 'A'. We found the optimal operating characteristics (h^* and T^*) which minimize the total average cost per time unit and satisfy the availability constraint.

Another point we took into account for the joint of Preventive Maintenance and inventory control is the integration of a new decision variable called the inventory build-up start time (noted A) for the inventory control. This decision variable allows the minimization of the inventory cost, and consequently the average total cost per time unit. We will prove the difficulty of solving this problem analytically when the constraints proposed in [11] and [12] are taken into account. An experimental design approach based on the simulation model is developed to solve this problem and constitutes the major contribution.

6.2.4. Supply chain and negotiated coherent plans

Participants: Didier Anciaux, Thibaud Monteiro, Latifa Ouzizi, Marie-Claude Portmann, François Vernadat.

In the framework of the V-chain Groth European project, we propose a semi-decentralized architecture for building coherent plans in a network of enterprises. We consider a virtual enterprise (VE) as defined in the V-chain project. The partners of the VE, referred to as nodes of the VE (NEV), use negotiation and mediation principles to collaboratively elaborate consistent production plans. The proposed architecture of the VE is a set of levels corresponding to production cycles of products to be delivered by the VE to the customers. A multi-agent system is used to model the behavior of the VE. For each level, a negotiator agent negotiates with NEV's of the same level. Each NEV is able to elaborate direct and backward planning, taking into account variation of demands and forecasts to guarantee a global benefit of the virtual enterprise [33] [22] [23]. The development of decision tools for helping the negotiator agent of each level generates interesting problems.

These new optimization problems have now to be solved either by using integer linear programming solver (for problem of small and medium size) or by developing new specific approximation algorithms.

6.2.5. Decision tools for predictive and corrective maintenance

Participants: Riad Aggoune, Mikhail Kovalyov, Ammar Oulamara, Marie-Claude Portmann.

Two activities are concerned with decision making for industrial maintenance. They were the subject of the PhD thesis of Riad Aggoune (presented in December 2002) and of Guillaume Thisselin (from September 2002 to June 2003). New researches on their complexity are currently developed.

The first activity is linked with scheduling in parallel the production tasks and the predictive maintenance tasks. Both approximation [19] for industrial problems and exact methods for problems of small size were proposed for various hypotheses (mainly flow shop and job shop production systems).

The second activity is linked to cost minimization of corrective maintenance tasks. We consider a complex production system, which was working and suddenly fails. The system is said to be in a "critical fail state" and the goal is to make it work as rapidly as possible without knowing what are the non working components. We have to minimize the average cost of testing and repairing operations under the assumption that tests and repairs are perfect. We propose a set of methods for building optimal or near optimal maintenance trees. In [35], we propose exact methods for solving problems containing no more than 14 components. We use more or less memory space and computation of more or less tight bounds in order to get the most efficient solution algorithms. On one hand, a dynamic programming approach is the most efficient but is limited by the necessary memory space (exponential in function of the number of components), on the other hand, a pure branch and bound approach without memory takes a very long computation times. Some hybrid approaches using partial memory and tight bounds provided us with interesting results. In [34], we truncated our exact methods by limiting the depth of some tree explorations in order to be able to solve approximately problems of larger size.

For linear systems, the problem without repairing costs is polynomial, while for linear systems with testing and repairing costs, the complexity of the problem is open. We have worked recently on the complexity of this problem. Until now, we do not get the exact complexity of this problem, but we were able to build an "epsilon" polynomial approximation scheme for solving it. We are making experiments to verify if this algorithm can allow us to solve medium size problems in reasonable time and with a reasonable approximation.

6.2.6. Decision tools for proactive-reactive scheduling

Participants: Mohamed Ali Aloulou, Mikhail Kovalyov, Marie-Claude Portmann.

For several years, we are interested by the activity of shop scheduling in presence of disturbances. For execution in the shop, we do not propose a single predictive schedule, which will become rapidly impossible to apply, but a family of schedules, which contains flexibility to be used on line to control the shop by a reactive specific schedule. With this approach, the number of re-scheduling can be decreased, while the performance can be better than using only a pure reactive schedule process without any global forecast schedule.

There exist different levels of flexibility: time flexibility (with the presence of idle time between operations), order flexibility (with the possibility to permute the order of operations on a resource) and resource flexibility (with the possibility to change the resource, which will perform an operation). We use the two first type of flexibility: time flexibility and order flexibility. Our approach is different from other approaches mainly developed at the LAAS in Toulouse or by persons trained by the LAAS and pursuing their careers in another University. They use mainly permutable operation groups and more recently pyramidal groups defined by interval relative position. A predictive schedule is given by a total order, which gives precisely the order of the operations on each resource. Our proactive schedule is partially defined by a partial order, which gives only a partial transitive order between the operations and which contains as a particular case the permutable operation groups. The definition of a proactive schedule is completed by the type of used schedule: semi-active or left-shifted schedules; active schedules, in which an operation cannot be placed sooner without delaying another operation; non delay schedules, in which a machine does not remain inactive, if an operation is available to be performed on it.

A set of procedures [20] have been developed to build proactive schedules, which are good compromise between the performance guarantees and the contained flexibility. A comparison has been made between a traditional predictive-reactive approach and our proactive-reactive approach. The shop model was an assembly shop included in a virtual enterprise or in a supply chain, linked to our activities in the V-chain Groth European project.

In order to compute the worst performances linked to a partial order and a type of schedule, we have to solve new problems of maximization, which allows us to get new complexity results and new polynomial algorithms [2] [21].

6.2.7. No-Wait batch scheduling problems

Participants: Freddy Deppner, Julien Fondrevelle, Mikhail Kovalyov, Ammar Oulamara.

This year, in collaboration with Professor Kovalyov, during his visit of MACSI team in May and June, we worked together on problem of scheduling a no-wait flow-shop with unbounded batching machines. We studied a problem of scheduling n jobs in a no-wait flow-shop consisting of m batching machines. Each job has to be processed by all machines. There is no intermediate buffer between any pair of machine. Batching machines can process several job simultaneously. We assume that the capacity of any batch is unbounded. The problem is to find an optimal batch schedule such that the maximal job completion time is minimized. For $m = 2$, we proved that there exists an optimal schedule with at most two batches and construct such a schedule in $O(nlgn)$ time. For $m = 3$, we proved that the number of batches can be limited by 9 and we presented an example where all optimal schedules have 7 batches. We prove that the best schedule with at most one, two and three batches are 3, 2, and 3/2 approximate solutions respectively. A paper of this work is submitted to IIE Transactions on scheduling and logistics. We continue to work on batch scheduling problem and for a near future, we will integrate the batch scheduling in supply chains problems.

6.2.8. Scheduling problems involving minimal and maximal time lags

Participants: Freddy Deppner, Julien Fondrevelle, Mikhail Kovalyov, Ammar Oulamara, Marie-Claude Portmann.

A large part of the current research works in scheduling is interested in integrating new constraints in the classical models, in order to describe realistic industrial situations. Our study comes within this framework: we consider flow-shop scheduling problems, where minimal and/or maximal time lags are defined. These temporal constraints impose that the waiting time between two operations must be not less (resp. no more) than a specified value. First, we restricted the study to the case where the time lags are only defined between consecutive operations of a job. A branch-and-bound that solves to optimality the m-machine permutation flow-shop problem with maximal time lags was proposed [31] and several heuristics were tested to provide upper bounds. We also put a lot of care into generating interesting benchmarks by taking several parameters into account in order to deal with realistic problems. These resolution methods were extended in the case where minimal time lag constraints are added. Besides, we investigated the scheduling problems with time lags from a theoretical point of view [71] and [31]) where various results concerning dominance properties and complexity results were proved. Other approximation approaches were developed for more general constraints and more general shops: there exists release dates, the constraints are not only between two consecutive operations and job-shop are considered as well as flow-shop. Some construction methods were proposed to get feasible schedules, some convergence theorems were proved and some genetic algorithms were built and improved to try to optimize the makespan criterion [25].

7. Contracts and Grants with Industry

7.1. Production planning generation for short and medium terms of RENAULT assembly lines

Participants: Lyès Benyoucef, Nidhal Rezg, Xiaolan Xie.

Started in April, 2002, for one year, with RENAULT, this contract focuses on the production planning of car assembly plants for the medium term (2 years). This plan is reviewed monthly in order to meet the customer demand forecast. The main motivation of RENAULT is the development of a decision tool which is able to:

- Propose a production planning for the different assembly lines:
  - Take into account the industrial constraints;
  - Take into account the social constraints;
- Feasibility check of the 2 years sales forecasting,
- Summary, per day, per month and per line of the previous decisions.

Two types of assembly lines were considered in this study: dedicated lines and mixed lines. By dedicated line, we assume that the line assemblies only one model of cars, contrary to the mixed lines where different types of cars can be assembled.

As a first step of the study, we focused on the dedicated line case. A backward mathematical formulation of the problem was proposed and the necessary computational algorithms implemented using Delphi 7.0. The necessary input data and the results are respectively:

Input data:

1. 2 years demand forecast for each car model,
2. List of assembly lines where the model can be assembled,
3. Production capacity (cars/hour), for each assembly line,
4. For each assembly line and for each month: 1) nominal assembly capacity in 2 or 3 shifts and 2) additional working hours taking into account the fixed flexibility,
5. Data related to the social constraints: overtime limitation, duration and existing or not of third shift, etc.

Results:

1. Feasible 2 years production planning (quantity to produce, per month and per line),
2. Configuration of each assembly line (2 shifts of 3 shifts),
3. Number of overtimes (per line and per month),
4. Number of opening days (per line and per month),
5. Confirmed a short term (3 months) production planning for each assembly line.

The model and tool are under validation and test by RENAULT. As perspectives, we intend to solve 'mixed line' case and propose different assembly plans with different objectives functions including logistic costs.

8. Other Grants and Activities

8.1. Regional activities

Our research work concerning flexibility and scheduling is developed in the framework of a PPF "Process of flexible production". They are also part of the regional theme QSL.

8.2. European projects

8.2.1. Project GROWTH ONE

Participants: Lyès Benyoucef, Hongwei Ding, Xiaolan Xie.

ONE is a European project (GROWTH program of the 5th PCRD), started in February, 2001, for 3 years and coordinated by CRF-FIAT, treats the development of optimization Methodology for Networked Enterprises. Its principal objective is to develop realistic models for supply chain design and management, with taking into account different costs, lead-times and social and environmental impacts. MACSI contributions are mainly the evaluation of different KPI (Key Performance Indicator) and the optimization of stochastic supply chain. The first year was dedicated to the study of the academic and industrial State-of-the-art and to the definition of case studies in automobile and textile sectors. The second and the third years were devoted to the development of simulation and optimization models for supply chain management. Some numerical results were obtained for the two cases studies proposed by FIAT (production and distribution network design) and HiTec (supplier selection problems) respectively.

Partners: FIAT (Italy), RENAULT(France), HiTec (Italy), LSE (UK), CNRS-I2S (France), BIBA (Germany), INRIA (France) and INTRACOM (GR).

8.2.2. *Project GROWTH V-chain*

Participants: M.A. Aloulou, Didier Anciaux, Thibaud Monteiro, Ammar Oulamara, Latifa Ouzizi, Marie-Claude Portmann, Daniel Roy, François Vernadat.

V-chain is a European project (GROWTH program of the 5th PCRD), coordinated by DMR Consulting, started in March 2001 for 30 months. The project ended at the end of August 2003. V-Chain objectives are mainly the definition and management of logistic chains of manufacturing sectors within the framework of virtual enterprise, i.e. a network of suppliers and clients sharing both risks and profits of production. The applicability relates to car industry (Ford, Spain) and motor cycles manufacturing (Aprilia, Italy).

For this year, our main result is the proposition of the architecture modeling of different logistic chains and their key components in order to propose a method, for the design and control of virtual chains. These developments are carried out within the framework of WP5-Virtual Enterprise Framework - for which MACSI is the coordinator. This project is partly the subject of Mrs. Latifa OUZIZI Ph.D. thesis. Development were also carried out, in collaboration with university of Udine, for the planning and scheduling of motor-bike assembly for an italian company.

Partners: Ford (Spain), Aprilia (Italy), DMR Consulting (Spain), Johnson Controls (Spain), Exel (Spain), Dynamit Nobel (Spain), Grupo F. Segura (Spain), Vitria (UK), Innova (Italia), University of Valencia (Spain), University of Udine (Italy), INRIA (France).

8.2.3. *Thematic Network GROWTH-TNEE*

Participants: Lyès Benyoucef, Xiaolan Xie.

TNEE, started in November, 2001 for 30 months and coordinated by CRF-FIAT, is a thematic network with the objective to federate many European projects working on extended enterprises. It gathers the European leaders of various industrial sectors including manufacturing industry, the industry of service and the great European research centers specialized in manufacturing and service industries. The principal actions are: (i) information exchange, (ii) definition of benchmarks and better practices, (iii) coordination of efforts, (iv) disseminations. Partner in the two European projects (ONE and V-Chain), MACSI is a member of TNEE, responsible of the working group "logistics". A first meeting of the working group was organized by INRIA (Paris, April 08-09, 2002). This meeting was regarded as a success and the results were used as a basis to structure the work of the network in different themes. Also, we took part in several meetings on manufacturing and extended enterprises and the redaction of the "TNEE White Book".

Partners : CRF-FIAT (Italy), CNR-ITIA (Italy), MCC (Spain), UPMAD (Spain), ZEM (Germany), INRIA (France), University of Warwick (UK), BASF (Germany), FHD.IFF (Germany), IAI (Israel), BIBA (Germany), IVL(Sweden).

8.3. International activities

8.3.1. NSF-INRIA

The collaboration project NSF-INRIA (10/2000 -09/2003) is between the University of Maryland (Prof. Fu) and MACSI (DR. Xie). For 2 weeks (from November, 23rd to December 6th, 2003), Xiaolan Xie was visiting the University of Maryland.

8.3.2. RM ”Reliability and Maintenance” Network

Partners of the RM network, the University of Laval (Canada), the Polytechnic School of Montreal (Canada), the Higher School of Science and Technology of Tunis (Tunisia) and MACSI, exchange their industrial and scientific experiences and results on reliability and maintenance of production systems.

8.3.3. Collaboration with Minsk

More and more collaborations are developed with researchers from Bielorussia (Minsk): Mikhail Kovalyov (2000, 2001 and 2003), Yakov Shafransky (2002) and Yuri Sotskov (2002). New results were obtained in collaboration with Kovalyov (see section results). Moreover, INTAS project is in preparation with Valery Gordon.

8.3.4. Invited persons

Mikhail Kovalyov, professor at the Economical Faculty of the Belarus State University in Minsk, stayed at the Ecole des Mines de Nancy as invited professor since May 13th until July 13th.

9. Dissemination

9.1. Scientific community animation

9.1.1. Action for the research community

New collaborations linked to scheduling researches have been developed this year. They are between three INRIA teams (MACSI, Algorille and TRIO) and for which several meetings were organized.

A seminar opened to the computer science master students was organized in December 2003 by the three teams. New subjects were presented commonly such as no wait job-shop with members of Algorille.

In the framework of the GRD MACS MACSI members participate more or less regularly to working groups called Bermudes (scheduling) and Vendôme (ERP). The working group Bermudes, which is interested in scheduling complex shops (hoist scheduling, flexible manufacturing systems and hybrid flow-shop), is now a part of the GDR MACS. The working group GOThA, which is interested in theory and practice of scheduling, nearer from Computer Science activities, is now a part of the GDR Alp. We are particularly active in the working group of the GOTHA interested by flexibility, robustness and stability of schedules. In the framework of the CNRS, it corresponds to a specific action called FRO (Flexibilité et Robustesse en Ordonnancement). Last year a collective paper was published in the ROADEF bulletin; this year, a book with 14 chapters is in preparation for publication by Hermes, we are authors of one of the chapters.

MACSI members take part in the activities and meetings of the GRD-MACS pole STP. Mainly, in the following two groups: GT OGP (organization and production management) and GISEH (management and engineering of hospital systems).

The industrial engineering club has vocation to federate the community of the researchers in industrial engineering, by extremely interdisciplinary nature. Frequently, MACSI members take part in the activities and meetings of the club. Thibaud Monteiro is member of the board of directors and manages the pedagogical commission.

Xiaolan Xie is member of the steering committee of the Petri nets network.

9.1.2. Member of organizing committees

MACSI members were involved in many scientific and organizing conferences committees.

MACSI was the organizer, in collaboration with TRIO and MOSEL project-team of INRIA-Lorraine and the CRAN, of the workshop MSR2003 (Modélisation des Systèmes Réactifs), October 06-08, 2003, Metz. Xiaolan Xie and Nidhal Rezg were respectively the co-president of the program committee and the president of the organizing committee.

Marie-Claude Portmann is president of the PMS'2004 conference (the 9th International Conference of the Euro Working Group Project Management and Scheduling), chairing both the organizing and the program committee, 8 other members of the team are members of the organizing committee. This conference will be held April 26-28 2004 in Nancy.

9.1.3. Member of program committees of journals or conferences

Marie-Claude Portmann was member of the program committee of ROADEF'2003 in Avignon (France), IEPM'2003 in Porto (Portugal), MOSIM'2003 in Toulouse (France) and Génie Industriel 2003 in Québec (Canada).

Xiaolan Xie is associate editor for IEEE Transactions on Robotics and Automation.

9.1.4. Members of PhD and Habilitation defences

Marie-Claude Portmann was member of the PhD or Habilitation defences of: André Rossi (PhD, INP Grenoble, October, referee), Fabrice Jumel (PhD, INP Lorraine, November, referee), Carl Esswein (PhD, University François Rabelais of Tours, December, referee).

9.2. Teaching

The MACSI team consists in two researchers and 12 professors and associate professors. Their teaching activities are assumed in numerous Universities and Engineer Schools, either as their duties linking to their situation or as overtime teaching hours. In particular, they are teaching at the Engineer School ENIM and at the University of Metz (Sciences Faculty), at the Engineer Schools ESIAL, ESSTIN, ENSEM and Ecole des Mines in Nancy, but also at the University of Nancy 1 Henri Poincaré (Sciences Faculty), at the University of Nancy 2 (IUT) and at the University Louis Pasteur in Strasbourg. They are also involved in several professional and research masters. Marie-Claude Portmann is responsible of a professional international master entitled "Industrial Economy and International Management" (the courses of the first semester are made in English) and of a master of the CGE entitled "Operations Research and Decision Strategies". Henri Amet is responsible of the major of the Ecole des Mines de Nancy called "Decision and Production System Engineering".

Marie-Claude Portmann is member of the committee of the UMR LORIA, of the Administrative committee of the Ecole des Mines de Nancy and for the sixth year president of the INPL Specialists committee, who recruits the new professors and associate professors in computer sciences at the INPL.

Marie-Claude Portmann is member of the national committee CTI (Commission des Titres d'Ingénieurs), who visits the French Engineer Schools and decides if they can continue to deliver the Engineer Diploma, verifying the material conditions, the management of the schools, the contacts with enterprises, the international activities and the contents of the courses.

Didier Anciaux is the jury president of the License Pro on 'Industrial Production Management' at the University of Metz. Thibaud Monteiro is the teaching responsible of the License Pro 'Industrial Production Management' at the University of Metz. Daniel Roy is the scientific program responsible of the 'management of international projects' option between ENIM/ University of Luxemburg

MACSI belongs to the graduate school IEAM. Two members of MACSI give courses within the DEA Production Automatisée (PA) of Nancy-Cachan (François Vernadat and Xiaolan Xie).

10. Bibliography

Articles in referred journals and book chapters

[1] Z. ACHOUR, N. REZG, X. XIE. *Commande par supervision des systèmes à événements discrets basée sur l'utilisation du GRAFCET et la théorie des régions.* in « Journal Européen des systèmes Automatisés », 2003, to appear.

[2] M. A. ALOULOU, M. Y. KOVALYOV, M.-C. PORTMANN. *Maximization Problems in Single Machine Scheduling.* in « Annals of Operations Research », 2003, 17 p..

[3] C. BLOCH, M. PORTMANN, A. VIGNIER. *Application des algorithmes génétiques à l'ordonnancement de la production.* M. PIRLOT, J. TEGHEM, editors, in « Résolution de problèmes de RO par les métaheuristiques », Hermès, Lavoisier, 2003, chapter 6.

[4] D. CHEN, F. VERNADAT. *Enterprise interoperability: A standardisation view.* K. KOSANKE, R. JOCHEM, J. NELL, A. O. BAS, editors, in « Enterprise Inter- and Intra-Organizational Integration: Building International Consensus », Kluwer Academic Press, 2003, pages 273-282.

[5] D. CHEN, F. VERNADAT. *Standards on Enterprise Integration and Engineering - A state of the art.* in « International Journal of Computer Integrated Manufacturing », volume 16, 2003.

[6] P. DARONDEAU, X. XIE. *Linear Control of Live Marked Graphs.* in « Automatica », number 3, volume 39, March, 2003, pages 429-440.

[7] H. DING, L. BENYOUCEF, X. XIE. *A Modeling and Simulation Framework for Supply Chain Network Design.* in « Supply Chain Management », Kluwer Academic Publisher, 2003.

[8] H. DING, L. BENYOUCEF, X. XIE. *A Simulation Optimization Methodology for Supplier Selection Problem.* in « International Journal of Computer Integrated Manufacturing », 2003, to appear.

[9] A. GHAFFARI, N. REZG, X. XIE. *Feedback control logic for forbidden state problem of marked graphs: Application to a real manufacturing system.* in « IEEE Transactions on Automatic Control », number 1, volume 48, 2003, pages 18-29.

[10] T. MONTEIRO, P. LADET, H. BOUYCHRIHA. *Multi-criteria negotiation for a distributed control of a client/provider relationship.* in « Journal of Decision System », to appear.

[11] M. S. OUALI, N. REZG, X. XIE. *Maintenance préventive et optimisation des flux d'un système de production.* in « Journal Européen des systèmes Automatisés », volume N 1, 2002.

[12] N. REZG, X. XIE, Y. MATI. *Joint Optimization of Preventive Maintenance and Flow Control in Production Line Using Simulation.* in « IJPR », 2003, to appear.

[13] D. ROY, D. ANCIAUX, T. MONTEIRO, L. OUZIZI. *Multi-agent architecture for supply-chain management.* in « International Journal of Manufacturing Technology Management », to appear.

[14] F. VERNADAT. *Enterprise Modelling and Integration: From fact modelling to Enterprise Interoperability.* K. KOSANKE, R. JOCHEM, J. NELL, A. O. BAS, editors, in « Enterprise Inter- and Intra-Organizational Integration: Building International Consensus », Kluwer Academic Press, 2003, pages 25-33.

[15] F. VERNADAT. *Internet-Based Enterprise Architectures.* M. SINGH, editor, in « Practical Handbook of Internet Computing », SRC Press, USA, 2003.

[16] F. VERNADAT. *Open Systems Architectures: From monolithic approaches to service-based architectures.* J. C. R. JARDIM-GONÇALVEZ, A. B. A. STEIGER-GARÇAO, editors, in « Concurrent Engineering: Enhanced Interoperable Systems », Lisse, The Netherlands, 2003, pages 823-829.

Publications in Conferences and Workshops

[17] A. ABDMOULEH, M. SPADONI, F. VERNADAT. *Distributed client/server architecture for implementing a meta-model CIMOSA-based.* in « Proc. Multi-conference on Computational Engineering in Systems Applications (CESA'03) », Lille, France, July, 2003.

[18] Z. ACHOUR, N. REZG, X. XIE. *Commande des systèmes partiellement observables basée sur les graphes d'événements.* in « MSR'03 », Metz, France, October, 2003.

[19] R. AGGOUNE, M.-C. PORTMANN. *Flow Shop Scheduling Problem with Limited Machine Availability: A Heuristic Approach.* in « International Conference on Industrial Engineering and Production Management - IEPM'2003 », volume 1, pages 140-149, Porto, Portugal, 2003.

[20] M. A. ALOULOU, M.-C. PORTMANN. *An efficient proactive reactive scheduling approach to hedge against shop floor disturbances.* in « Multidisciplinary International Conference on Scheduling : Theory and Applications - MISTA'2003 », volume 1, pages 337-362, Nottingham, United Kingdom, 2003.

[21] M. A. ALOULOU, M.-C. PORTMANN, M. Y. KOVALYOV. *Worst case performance evaluation of flexible solutions in single machine scheduling.* in « Computing Engineering in Systems Applications - CESA'2003 », Lille, France, 2003, 7 p..

[22] D. ANCIAUX, L. OUZIZI, M.-C. PORTMANN. *Planification d'une chaine logistique par négociation.* in « 5ème Congrès International de Génie Industriel (CIGI'03) », Québec, Canada, October, 2003.

[23] D. ANCIAUX, L. OUZIZI, M.-C. PORTMANN, F. VERNADAT. *A model for co-operative planning within a virtual enterprise.* in « International Conference on Industrial Engineering and Production Management - IEPM'2003 », volume 3, pages 209-220, Porto, Portugal, 2003.

[24] L. CUENCA, A. ORTIZ BAS, F. VERNADAT. *From DFD modelling to CIMOSA partial models and enterprise components.* in « International Conference on Industrial Engineering and Production Management - IEPM'2003 », Porto, Portugal, 2003.

[25] F. DEPPNER. *Ordonnancement d'atelier avec contraintes d'écart minimal et maximal entre opérations.* in « 4e Conférence Francophone de MOdélisation et SIMulation - MOSIM'03 », pages 430-436, Toulouse, France, 2003.

[26] H. DING, L. BENYOUCEF, X. XIE. *A Simulation-Optimization Approach Using Genetic Search for Supplier Selection.* in « 2003 Winter Simulation Conference », New Orleans, U.S.A., December, 2003.

[27] H. DING, L. BENYOUCEF, X. XIE. *Simulation and optimisation for supply chain network design - Case studies of automotive and textile industries.* in « European Summer School on Supply chain », LAG, Grenoble, France, September, 2003.

[28] H. DING, L. BENYOUCEF, X. XIE. *Simulation Model of a Mixed Make-to-Order and Make-to-Stock Distribution Network.* in « 6th International Conference on Industrial Engineering and Production Management », Porto, Portugal, May, 2003.

[29] H. DING, L. BENYOUCEF, X. XIE. *A Multiobjective Optimization Method for Strategic Sourcing and Inventory Replenishment* . in « IEEE International Conference on Robotics and Automation (ICRA04) », April, 2004.

[30] A. EL MHAMEDI, F. VERNADAT. *Techniques d'analyse d'activités non structurées pour la méthodologie PETRA.* in « 5ème Congrès International de Génie Industriel (CIGI'03) », Québec, Canada, October, 2003.

[31] J. FONDREVELLE. *Résolution exacte d'un problème d'ordonnancement de produits périssables : cas du flow-shop de permutation.* in « Quatrième conférence francophone de Modélisation et Simulation - MOSIM'03 », Toulouse, France, 2003.

[32] I. MOURANI, S. HENNEQUIN, X. XIE. *Optimal discrete flow control of failure prone manufacturing systems* . in « CDC'03 conference, USA », IEEE, editor, December, 2003.

[33] L. OUZIZI, D. ANCIAUX, M. PORTMANN, F. VERNADAT. *Formalisation de la négociation pour la planification d'une entreprise virtuelle.* in « Proc. Integrated Design and Production / Conception et Production Intégrées (CPI'2003) », Meknès, Morocco, October, 2003.

[34] G. THISSELIN, M.-C. PORTMANN. *Méthode approchée pour le test et la réparation au moindre coût d'un système complexe en panne.* in « Cinquième congrès internatinal de Génie Industriel - CIGI'2003 », Québec, Canada, 2003, vol CD Rom, 10 p..

[35] M.-C. THISSELIN. *Exact Methods for Testing and Repairing a Failed Complex System with a Minimal Average Cost.* in « International Conference on Industrial Engineering and Production Management - IEPM'2003 », volume 3, pages 492-501, Porto, Portugal, 2003.

[36] F. VERNADAT. *Une approche d'amélioration des processus dans un organisme statistique international.* in « 5ème Congrès International de Génie Industriel (CIGI'03) », Québec, Canada, October, 2003.

Bibliography in notes

[37] B. ARNTZEN, G. BROWN, T. HARRISON, L. TRAFTON. *Global supply chain management at Digital Equipment Corporation.* in « Interface », volume 25, 1995, pages 69-93.

[38] R. AXELROD. *Donnant, donnant : une théorie du comportement coopératif.* Odile Jacob, 1992.

[39] F. AZADIVAR. *Simulation optimization methodologies.* in « Proc. 1999 Winter Simulation Conference », pages 93-100, 1999.

[40] J. BLAZEWICZ, K. ECKER, E. PESCH, G. SCHMIDT, J. WEGLARZ. *Scheduling Computer and Manufacturing Processes.* Springer Verlag, Berlin, 1996.

[41] G. CACHON, M. LARIVIERE. *Contracting to assure supply: how to share demand forecasts in a supply chain.* in « Management Science », number 5, volume 47, 2001, pages 629-647.

[42] J. CARLIER, P. CRETIENNE. *Problèmes d'Ordonnancement.* Masson, Paris, France, 1988.

[43] M. CHRISTOPHER. *Logistics and supply chain management: Strategies for reducing costs and improving services.* in « Financial Times », Pitman Publishing, London, UK, 1992.

[44] M. COHEN, S. MOON. *Impact of production scale economics, manufacturing complexity, and transportation costs on supply chain facility networks.* in « Journal of Manufacturing and Operations Management », volume 3, 1990, pages 269-292.

[45] W. DAVIDOW, M. MALONE. *L'entreprise à l'âge du Virtuel.* in « MAXIMA, Paris », Institut du Management d'EDF et de GDF, 1995.

[46] L. DUPONT. *La Gestion Industrielle.* Hermès, Paris, 1998.

[47] S. GAVIRNENI, S. KAPUSCINSKI, S. TAYUR. *Value of information in capacitated supply chains.* in « Management Science », number 11, volume 45, 1999, pages 16-24.

[48] V. GIARD. *Gestion de la Production et des flux.* edition 3ème édition, Economica, Paris, France, 2003.

[49] A. GIUA, C. SEATZU. *Observability of Place/Transition Nets.* in « IEEE Trans. Automatic Control », number 9, volume 47, 2002, pages 1424-1437.

[50] GOTHA. *Les problèmes d'ordonnancement.* in « Recherche Opérationnelle/Operations Research », number 1, volume 27, 1993, pages 77-150.

[51] M. HARDWICK, R. BOLTON. *The industrial virtual enterprise.* in « Communications of the ACM », number 9, volume 40, 1997, pages 59-60.

[52] L. HOLLOWAY, B. KROGH. *Synthesis of feedback control logic for a class of controlled Petri nets.* in « IEEE Trans. Automatic Control », number 5, volume 35, 1990, pages 514-523.

[53] A. ISHIKAWA, K. HIRAISHI. *Analysis and control of discrete event systems represented by Petri nets.* in « Discrete Event Systems », 1987, pages 115-134.

[54] D. KJENSTAD. *Coordinated supply chain scheduling.* Ph. D. Thesis, Department of Production and quality engineering, Norwegian university of science and technology, 1998.

[55] B. H. KROGH. *Controlled Petri nets and maximally permissive feedback logic.* in « 25th Annual Allerton Conference », pages 317-326, Urbana, IL, 1987.

[56] H. LEE, C. BILLINGTON. *Material management in decentralized supply chain.* in « Operations Research », volume 41, 1993, pages 835-847.

[57] T. W. MALONE, K. CROWSTON. *The interdisciplinary study of coordination.* in « ACM Computing Survey », number 1, volume 26, 1994.

[58] T. MONTEIRO, P. LADET. *Formalisation de la coopération dans le pilotage distribué des flux interentreprises: Application à une entreprise de production de biens.* in « JESA (Numéro spécial - pilotage distribué) », number 7-8, volume 35, 2001, pages 963-989.

[59] J. MOODAY, M. LEMMON, P. ANTSAKLIS. *Supervisory control of Petri nets with uncontrollable/unobservable transitions.* in « 35th IEEE CDC », Kobe, Japan, 1996.

[60] J. MOODY, P. ANTSAKLIS. *Petri Net Supervisors for DES with Uncontrollable and Unobservable Transitions.* research report isis-99-004, February, 1999.

[61] A. OULAMARA. *Flowshops avec détérioration des tâches et groupement des tâches.* Ph. D. Thesis, UGF de Grenoble, France, 2001.

[62] M. PINEDO. *Scheduling.* in « Handbook of Industrial Engineering », John Wiley, New York, NY, 1992, pages 2131-2153.

[63] C. POTTS, M. KOVALYOV. *Scheduling with Batching: a review.* in « European Journal of Operational Research », volume 120, 2000, pages 228-249.

[64] C. POTTS, L. VAN WASSENHOVE. *Integrating scheduling with batching and lot-sizing: a review of algorithms and complexity.* in « Journal of the Operational Research Society », volume 43, 1992, pages 395-406.

[65] P. RAMADGE, W. WONHAM. *Supervisory control of a class of discrete-event processes.* in « SIAM J. Contr. Optimiz. », number 3, volume 25, 1987, pages 206-230.

[66] W. RAMDANE-CHERIF. *Problèmes d'optimisation en tournée sur arcs.* Ph. D. Thesis, Laboratoire d'Optimisation des Systèmes Industriels, Université de Technologie de Troyes, France, 2002.

[67] K. ROTA. *Coordination temporelle de centres gérant de façon autonome des ressources - Application aux chaînes logistiques intégrées en aéronautique.* Ph. D. Thesis, Université Paul Sabatier de Toulouse et de l'ONERA, 1998.

[68] F. ROUBELLAT, P. LOPEZ. *Ordonnancement de la production.* Hermès, Paris, 2001.

[69] G. SALVENDY. *Handbook of Industrial Engineering.* John Wiley, New York, 1992.

[70] G. STREMERSCH. *Linear Algebraic Design of Supervisors for Partially Observed Petri Nets.* in « Proc. IFAC Conf. on Control Systems Design (CSD'2000) », pages 281-286, Bratislava, Slovak Republic, 2000.

[71] S. WEBSTER, K. BAKER. *Scheduling groups of jobs on a single machine.* in « Operations Research », volume 43, 1995, pages 692-703.

[72] W. WONHAM, P. RAMADGE. *On the Supremal Controllable Sublanguage of a Given Language.* in « SIAM Journal on Control and Optimization », number 3, volume 25, 1987, pages 637-659.