INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team MACSI

Modeling, Analysis and Control of Industrial Systems

Lorraine

THEME NUM

Activity Report

2004

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1. Team

MACSI is a team of laboratoire de Recherche en Informatique et ses Applications (LORIA) in common with Centre National de Recherche Scientifique (CNRS), Institut National de recherche en Informatique et Automatique (INRIA), Université Henri POINCARÉ *(Nancy 1), Université Nancy 2 and Institut National Polytechnique de Lorraine (INPL).*

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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 design and/or control of Industrial Systems at different decision levels: stategic (organization and dimensioning of virtual enterprises or supply chains), tactical (planning, scheduling, maintenance, transport) and operational (control synthesis).

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 design and control of industrial systems. In consequence, the results of 2004 are split up into two parts:

- Modeling, specification, design and evaluation of industrial systems, 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 which may be divided among several enterprises or networks of enterprises;
- An enterprise;
- A plant;
- A production system;
- A workshop;
- A transport system.

The theoretical bases and tools are those of discrete event systems: DES simulation, Petri nets, time automata, discrete and continuous flow models, queueing systems, multi-agent systems, and discrete optimization: integer linear programming, meta-heuristics, hybrid approaches.

The aim of our research is resolutely two-fold, by developing on the one hand fundamental research, while being constantly dedicated to solving industrial applications.

Thus, MACSI considers specific problems of organization, of performance evaluation, of planning and scheduling including the 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

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

Participants: Zied Achour, Lyès Benyoucef, Hongwei Ding, Michael Fu, Sophie Hennequin, Thibaud Monteiro, Iyad Mourani, Nidhal Rezg, Daniel Roy, Alexandru Sava, François Vernadat, Xiaolan Xie.

MACSI activities within this topic are mainly dedicated to: modeling, specification, design and performance evaluation of industrial systems, using simulation (descriptive models) and/or optimization (analytical models). They include enterprise modeling (descriptive models), behavior modeling (analytical models), 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 [58]. In order to remain competitive in the global market, companies should be reactive to the rapidly changing demand and improve flexibility. Confronted with a highly competitive environment, supply chain management (SCM) is generally referred to as an effective means to help companies reduce costs, to 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 the 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 has to move smoothly between hierarchical levels, incrementally adding details; for instance, a multi-scale inventory system can be simulated by modeling the transportation delay with random variables. 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 [59][69][52]. Simulation has been identified as one of the best means to analyze and deal with presence of stochastic events 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 optimizing supply chains (IBM Supply Chain Analyzer, Autofat, Supply Chain Guru, Simflex, ...).

At the same time, thanks to several decades of theoretical and pratical 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 achievements 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 locally 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 on 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 attracted the increasing attention of many researchers and practitioners. Existing literature related to simulation-optimization methods can be classified under four major categories: gradient based search methods, stochastic optimization, response surface methodology and heuristic methods [54]. Heuristic methods are usually preferred over the other three, when dealing with qualitative decision variables.

MACSI's 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 [65], 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 [60]. To generate a better productivity, these companies need to coordinate the different actions which are distributed among autonomous partners [53][70][74][67]. 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 [71]. Moreover, the centralized philosophy is strongly opposed to the decisional autonomy of the supply-chain components (firms). This is why, the MACSI project proposes a more distributed approach in order to provide autonomy and to facilitate the management of a network of firms.

3.1.3. Control synthesis

Production systems are often complex making the realization of an effective and realistic control device more difficult. Several studies were dedicated to Discrete Event Systems (DES) control problems. The objective is to synthesize the suitable supervisor which will act in closed-loop with the process, in order to obtain the desired behavior. The proposed approach by Ramadge and Wonham deals with existence and synthesis of the most permissive supervisors of DES [73][77]. Indeed, this approach models industrial systems using automata and formal languages. However, the lack of these automata and formal languages limits 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 [68][66], in order to exploit the modeling power of PN and the rich mathematical results which characterize them. This allows us to have a qualitative analysis of the system (attainability, promptness, etc).

MACSI's goal 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

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

Participants: Henri Amet, Didier Anciaux, Lyès Benyoucef, 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, François Vernadat, Xiaolan Xie.

The organization and the control of any industrial system leads 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 [64][61][76]. 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 the presence of limited resources. A lot of the optimization activities within the MACSI project concern scheduling problems [75][55][57][62][72].

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 pertinent constraints 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, batching machines, resource blocking. We also consider various workshops: single and 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 exact approaches or approximation approaches in order to solve them in a reasonable computation time while obtaining near optimal solutions. We hybridize 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 efficient 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.

An example of concrete scheduling models concerns batching machines. In this context, the principal motivation to process jobs in batches is to reduce the time and the cost incurred by performing the jobs. For instance, 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 jobs that are scheduled continuously on a machine, we call such a machine, a sum-batch machine. 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 processes, 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.

Another example of concrete scheduling models concerns scheduling with minimal and maximal time lags. This arises as soon as the interval time between to consecutive operations is upper bounded (perishable or unstable products) or lower bounded (cooling or transportation). An important sub-family consists of considering no-wait scheduling problems in which a product must be moved on the following machine and the corresponding operation must begin as soon as the operation is finished on the first machine, with potential separate setup times (before arrival of the product) or removal times on the machine (after departure of the product).

Another important part of our research is linked to scheduling in the 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.

Another activity concerns Capacitated Arc Routing problems (CARP) in which client arcs in a network must be visited for pickup or delivery. 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 found in literature is not sophisticated enough to handle real-life applications. Our research proposes new problems which integrate more realistic constraints generalizing the CARP. MACSI's objective is to study the flexibility of the CARP in presence of disturbance and to deal with more generalisation including pertinent constraints. In this direction, we have a promising industrial application with BT Exact (British Telecom).

3.2.2. Planning inside enterprise network

The management of network of firms needs to integrate two decision levels: planning and control. At the planning level, a supply chain, coherent planning of all actors is needed [63][56]. 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.

The 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 mainly concern discrete production systems (mechanical production, assembly lines, semiconductors fabrication, etc.). Some studies also cover 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 performance 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 (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's 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. New Results

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

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

5.1.1. 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 competitive 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 [12]. Subsequently, it is applied to solve a supplier selection case study proposed by an industrial partner of project ONE [30] [31].

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 achieves a good trade-off between different optimization objectives. All the decision variables are incorporated into discrete-event simulation models for the estimation of their impacts on operational performances. The simulation models are extended from the supply chain modeling package [33] [32] 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 realistic 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 the demand fulfillment rate [34], [47].

5.1.2. *Verification of time discrete event systems (DES)*

Participants: Alexandru Sava, Xiaolan Xie.

The goal is to propose of formal tools and methods to model, analyze and verify DES systems in order to guarantee 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 uses Time Petri Net models (TPN) derived from autonomous Petri Net models by associating a firing interval to each transition. Consequently, synchronization, resource sharing and parallelism are inherited. But existing techniques for TPN analysis (i.e. the state class graph) are not suitable here. The approach we propose consists in two steps. The first step consists in modeling the exact behavior of the Time Petri Net by a state class graph, with 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 e volves 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.

5.1.3. *Petri nets synthesis / general stochastic Petri nets*

Participants: MuDer Jeng, Shen-Luen Chung, Xiaolan Xie.

The first objective is to develop a methodology for the systemic synthesis of models for large scale production systems. This research activity consists in modularly modelling production systems with degraded performances linked to machine breakdown and maintenance. The initially proposed models RCN-merged nets were extended to RCN*-merged nets in order to take into account assembly and disassembly routings. In order to get reversibility between the compressed and extended models, the importance of the siphons inside the Petri net are enlightened. This permits to model and analyse production systems with about a hundred machines and operations per job [15].

The second objective is to develop performance evaluation tools using general stochastic Petri nets. The result aimed at to derive the performances with respect to the time parameters of the transition. Simulation is used to get unbiased estimation. The number of needed simulations can hopefully be limited for some particular classes of Petri nets. An application to a plant manufacturing printed circuit boards is developed by crossing previous approaches and linear programming with Markovian hypothesis. This work has taken into account pertinent concrete constraints such as non pre-emptive operations and predictive maintenance [26], [36], [37].

5.1.4. *Supervisory control*

Participants: Zied Achour, Nidhal Rezg, Xiaolan Xie.

We propose a general approach for synthesizing a set of control places that optimally solve a forbidden state problem of any bounded Petri net (PN) when such PN controller exists [3], [4]. Indeed, it considers a general set of forbidden states in addition to liveness requirement and the presence of uncontrollable / unobservable transitions [5],[27],[28].

In [41], the control places problem for bounded Petri nets is considered. We discuss on the existence of PN controller. A control synthesis method based on the theory of regions which is a technique of Petri net synthesis from automata models. Plant models under consideration are generalized bounded Petri nets. The Petri net controller is optimal in the sense of maximum permissiveness under the restriction of the liveness of the controlled system. Supervisory control of partially observable Petri net plants has been addressed in (Moody and Antsaklis, 1999; Stremersch, 2000; Moody, et al., 1996) using linear algebra approaches which are extensions of the optimal place-invariant approach proposed in (Yamalidou, et al., 1996) for enforcing linear constraints for totally controllable and observable Petri net plants. The most serious drawback of these approaches is that the optimality of the control policy cannot be guaranteed. An exception is the linear algebra approach for enforcing linear constraints of firing count vector and/or markings of partially controllable and partially observable marked graphs. Note that the liveness of the controlled system cannot be enforced with these approaches. We follow, in this paper, the approach which addresses the forbidden state problems of generalized Petri net model with uncontrollable and unobservable transitions.

We propose a design methodology of Petri net controllers for the forbidden state-transition problem. To solve control temporal specifications, a global clock is introduced in the plant Petri net model. Forbidden state-transition are defined by some Time Floating General Mutual Exclusion Constraints. The proposed approach uses Ramadge-Wonham's control approach and the theory of regions. It uses a Ramadge-Wonham approach to determine desired behavior and then it uses the theory of regions to design a compiled Petri net controller that is a set of control places to add to the initial plant model.

5.1.5. *Performance evaluation using continuous flow models*

Participants: Michael Fu, Sophie Hennequin, Iyad Mourani, Xiaolan Xie.

In a first work, we considered a continuous manufacturing system with two machines under perturbations due to breakdown. The objective is to get the performance analysis and the gradients of the performance of this system. As the breakdown laws are general, there does not exist analytical solutions for this system. Under the hypothesis of time dependent failures (TDF), the system behavior is modeled with equations (min,+). This permits to obtain performance analysis and their gradients. These results were extended to a new model of stochastic Petri net called "continuous and stochastic event graphs". Under the hypothesis of operation dependent failures (ODF), the analysis is more delicate. In collaboration with Professor Michael Fu (University of Maryland), it was proved that the Infinitesimal Perturbation Analysis (IPA) cannot be used. A new methods have been elaborated called Smoothed Perturbation Analysis (SPA). It permits to get estimations of the gradients.

In a second work, transportation delays are considered in continuous manufacturing system composed of N machines and N-1 buffers. The machines could have operation dependent failures. We simulate the productivity of manufacturing system with transportation delays. The simulation is based on an original Petri net and shows that the productivity decreases as the delays increase.

We are now considering some extensions of this results. We consider transfer lines with N machines and N-1 buffers. The machines are subject to the both failure models : operation or time dependent failures.

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

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

5.2.1. *Stochastic optimization of inventory systems*

Participants: Jie Li, Alexandru Sava, Xiaolan Xie.

This research work deals with analysis and optimization of production-distribution systems systems. We are considering a production distribution system composed of one warehouse supplied by an upstream production plant. Customer orders arrive arrive randomly at the warehouse, with random order size and the production capacity is finite. The inventory at the warehouse is controlled by a base-stock policy. Therefore, the inventory system is characterized by batch orders with exponentially distributed size and batch delivery. Transportation time from the plant to the warehouse is constant. A method based on queuing theory was developed for estimating the end-customer service level, the fill rate and average inventory cost. This method needs only the first two moments of random variables of the system to evaluate the order-to-delivery lead-time of the warehouse, the total inventory on order and the inventory holding and backlogging cost. A gradient optimisation method is used to minimize the global inventory cost. Numerical comparisons with simulation show that the analytical approach is very efficient.Our further research direction deals with optimising the global inventory cost for a network on warehouses and production plants [38].

5.2.2. Optimisation of manufacturing systems

Participants: Iyad Mourani, Sophie Hennequin, Xiaolan Xie.

We considered a continuous-flow model of a single machine with delay. We assume that the machine failure and repair are subject to a general distribution and the demand is constant. The machine is subject to time-dependent failure. Material flows continuously from outside the system to the first machine, and then waits a period of time called delay t for material transfer, before arriving to the buffer. The goal of this work is to find, by using IPA technique, the optimal buffer level (Hedging point), which minimizes the long run average cost [40].

5.2.3. Maintenance policy of manufacturing systems

Participants: Anis Chelbi, S. Dellagi, Michael Fu, Mohamed Salah Ouali, Nidhal Rezg, Xiaolan Xie, X. Yao.

We established in this work a new preventive maintenance approach for manufacturing systems which inflated by the environment constraint. The manufacturing system under consideration is composed of a machine M1 which produces a single product [11], [29], [22]. To satisfy a constant demand d exceeding the capacity of M1, the system uses a subcontractor composed of a machine M2 which produces at a certain rate the same type of product. Both machines are subject to random failures. Machine M2, which constitutes the environment and outside the system, has a constant failure rate and its failures cannot be prevented by preventive maintenance. Machine M1 has a failure rate that is increasing with its age and its failures can be prevented by preventive maintenance actions. An age-limit policy is used for preventive maintenance planning and machine M1 stops for preventive maintenance when it reaches a given age m. In fact we noted by SMP a simple maintenance policy. In this policy we fixed a preventive maintenance age m which depends only on the history of machine M1. After that we established another policy notes IMP, the improved maintenance policy which depends on the history of machine M1 and the state of its environment the machine M2 [46]. Precisely when the preventive maintenance age m established in the first policy SMP coincide with a reparation period of the machine M2, we delay this age m to another age m+?m in order to decrease a demand loss. To justify this idea we compared the two policies in term of maintenance and demand loss cost, and we proved analytically that under some conditions related to the data of machines M1 and M2, the IMP policy is more economic then the SMP policy. More then the best choice of the delay period ?m can assure a best profit in using IMP policy. Numerical examples are used, to prove the impact of the IMP in terms of a performance measure and confirm its usefulness.

In another research work developed in collaboration with Michael Fu (University of Maryland), similar problems are modelled with Markovian Decision Process (MDP). Under restrictive technical conditions, some dominant properties were proved and used for a numerical resolution. The perturbation analysis technique was also applied to a production line under the hypothesis that the maintenance policy and the inventory policy are known. An approximation analytical approach using simulation was also developed. This method is good when the machine load is small but is deceiving when the machine load increases, while the perturbation based method gives optimal solution in a reasonable computation time.

5.2.4. Decision tools for predictive and corrective maintenance

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

Previous activities were concerned with decision making for industrial maintenance [42] [6]. Concerning the cost minimization of corrective maintenance tasks, new researches on their complexity have been developed [7].

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 proposed a set of methods for building optimal or near optimal maintenance trees.

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 made experiments to verify that this algorithm can allow us to solve medium size problems in reasonable time and with a reasonable approximation.

5.2.5. Predictive scheduling problems for manufacturing systems

Participants: Riad Aggoune, Mohamed Ali Aloulou, Henri Amet, Freddy Deppner, Julien Fondrevelle, Mikhail Kovalyov, Yazid Mati, Ammar Oulamara, Marie-Claude Portmann, Nidhal Rezg, Xiaolan Xie.

We consider manufacturing systems, in which several resources are needed such as material handling systems, tools and operators. The objective is to propose a methodology, which can manage with the variety of the needed resources. In the PhD thesis of Yazid Mati, a method was designed for job-shop with multi-resource and blocking problem [18], [23],. The two job problem was proved to be polynomial. An iterative method, based on the two-job polynomial algorithm, introduces the jobs successively in the current schedule. A taboo search is used to choose the best order of the jobs. The experiments illustrated the efficiency of this new approach. In parallel, the disjunctive graph paradigm was generalized and another taboo search approach based on critical path was developed, which avoids blocking situation.[14]

We study several permutation flowshop problems with unit time operations and minimal time lags [13]. Minimal time lag constraints indicate that for every couple of consecutive operations of a job, the second operation cannot start until a prescribed amount of time has elapsed after the completion of the first operation. These constraints can be used to model various industrial situations such as minimal waiting time in process (due to cooling for instance), transportation times from a machine to another, or communication delays between processors. we present the main results concerning flowshop scheduling problems with minimal time lags. We determine a general formula for the completion time of every job in a permutation flowshop with unit time operations and minimal time lags and we provide polynomial time algorithms that solve optimally some of these problems with several criteria [25],.

we study permutation flowshop problems with minimal and/or maximal time lags [35], where the time lags are defined between couples of successive operations of jobs. Such constraints may be used to model various industrial situations, for instance the production of perishable products. We present theoretical results concerning two-machine cases, we prove that the two-machine permutation flowshop with constant maximal time-lags is strongly NP-hard. We develop an optimal branch and bound procedure to solve the m-machine permutation flowshop problem with minimal and maximal time lags. We test several lower bounds and heuristics providing upper bounds on different classes of benchmarks, and we carry out a performance analysis [48].

We address the two-machine no-wait flowshop scheduling problem to minimize maximum lateness where setup and removal times are treated as separate from processing time [35]. We obtain optimal solutions for special cases. Moreover, we propose a branch-and-bound algorithm for the generic case. We conduct extensive experimentations to evaluate the performance of the proposed branch-and-bound algorithm. The computational analysis shows that the branch-and-bound algorithm is quite efficient, especially when the setup and removal times are not too large compared to the processing times. Moreover, in the absence of removal times, the dominance property proposed by Dileepan appears to perform very well.

We also study a problem of scheduling n jobs in a no-wait flow shop comprising of m batching machines [1]. All jobs visit the machines in the same order. A job completed on an upstream machine should immediately be transferred to the downstream machine. Batching machine can process several jobs simultaneously in a batch so that all jobs of the same batch start and complete together. The processing time of a batch is equal to the maximal processing time of the jobs in this batch. 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, that is the makespan, is minimized. For m=2, we prove that there exists an optimal schedule with at most two batches and construct such a schedule in O(nlogn) time. For m=3, we prove that the number of batches can be limited by 9 and give an example where all optimal schedules have 7 batches. Furthermore, we prove that the best schedules with at most one, two and three batches are 3-, 2- and 3/2-approximate solutions, respectively. It was proved that the first two bounds are tight for corresponding schedules [39]..

We study the problem of minimizing the makespan in a flow shop with two batch processing machines [20]. Batch processing machines execute groups of batches of tasks together. The so-called max-batch machines and sum-batch machines are considered. In the first case, a batch of tasks is processed simultaneously and the processing time of a batch is given by the longest processing time of the tasks in this batch. In the second case, the batch processing time is given by the sum of the processing times of the tasks assigned to it and a setup time is required before each execution of a batch. We study the mixed case where the flow shop consists of a max-batch and a sum-batch machine. For the restricted batch size of the first machine, we show that minimizing the makespan is NP-hard in the strong sense and we give some well solvable cases.

5.2.6. Decision tools for proactive-reactive schedules

Participants: Mohamed Ali Aloulou, Mikhail Kovalyov, Zerouk Mouloua, Ammar Oulamara, Marie-Claude Portmann, Wahiba Ramdane Cherif.

This research work was developed in parallel with the research works of the working group flexibility and robustness of the Gotha. 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 [16].

We addressed shop scheduling problems with the presence of perturbations. The tasks are characterized by due dates and some precedence constraints. In such a context, a good solution to this problem may rapidly become unfeasible. For this reason, it is more interesting to provide the decision maker with a set of solutions having an a priori known quality and offering some flexibility to adapt the scheduling in presence of perturbations [49].

We proposed an approach for building a two-level control architecture. In the first level, a proactive algorithm allows to build one or several flexible structures taking into account some initial data. A flexible structure is a set of schedules characterized by a type (semi-active, active or non delay) and a partial order of operations on each machine (our flexible structure is more general than the approach developed by the LAAS in Toulouse, which uses totally permutable subset of operations). In the second level, a reactive algorithm is used to guide the job execution and to react to the occurrence of perturbations by exploiting the flexibility of the considered structure. Further, we propose several measures to evaluate a priori the flexible structure quality in terms of performance and flexibility. The presence of flexibility implies the computation of the best case and the worst case performance of a structure. The worst case analysis of a structure performance led us to study new maximization problems never considered in the past. These problems consist in determining a semi-active, active or non delay schedule that maximizes a regular objective function subject to some precedence constraints [10],[8],[9].

An experimental 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 [43][44].

Before integrating MACSI team, Wahiba Ramdane-Cherif was working on Capacitated Arc Routing Problem routing (CARP). She investigated new problems integrating more realistic constraints generalizing the CARP. After his integration, she continue integrating more pertinent constraints in the CARP [17], [50]. In 2003-2004, we began to work on the flexibility of the CARP in presence of disturbance by using the approach developed in MACSI for proactive-reactive scheduling. In this field, we started a collaboration with BT Exact (Brititish Telecom) with a master training. We improved the current decision tools by introducing decomposition decision levels and better heuristics.

5.2.7. Supply chain and negociated coherent plans

Participants: Didier Anciaux, Latifa Ouzizi, Thibaud Monteiro, Daniel Roy, François Vernadat.

In the framework of the V-chain Groth European project, we proposed 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 level 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. 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 [21],[45],[24],[51],[19].

SMA architecture developed in MACSI team for reactive system control can be used as support for this approach.

5.2.8. A multi-objective simulation-optimization methodology for supply chain design and management

Participants: Lyes Benyoucef, Hongwei Ding, Guy Aimé Tanonkou, 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 developed a simulation-optimization methodology for supply chain design and management. Subsequently, it was applied to solve the supplier selection case study proposed by an industrial partner of project ONE.

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 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.

These approaches were validated on two applications: one for the design of a distribution net for the automative manufacturing and another for e-procurement for textile company.

6. Contracts and Grants with Industry

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

Participants: Zerouk Mouloua, Ammar Oulamara, Marie-Claude Portmann, Wahibal Ramdane Cherif.

This collaboration began with a master subject: scheduling and vehicle routing of the personnel of British Telecom. We first improved the current decision tools by introducing decomposition decision levels and better heuristics approaches. The main objective is to introduce flexibility inside the tools in order to react rapidly to perturbations. We will continue this work within the perspective of a ‘CIFRE’ allocation for a new PhD student or another type of industrial contract.

7. Other Grants and Activities

7.1. Regional activities

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

7.2. European projects

7.2.1. Project GROWTH ONE

Participants: Lyès Benyoucef, Hongwei Ding, Xiaolan Xie.

ONE is a European project (GROWTH program of the 5th FP), started in february, 2001, for 3 years and coordinated by CRF-FIAT, treated 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’s 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).

7.2.2. Thematic Network GROWTH-TNEE

Participants: Lyès Benyoucef, Xiaolan Xie.

TNEE (GROWTH program of the 5th FP), started in November, 2001 for 33 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. MACSI is 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 deened 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).

7.2.3. French-German project GRailChem

Participants: Lyès Benyoucef, Sophie Hennequin, Xiaolan Xie.

GRailChem is a french-german project, ‘Green Rail Freight Transport for Chemical Goods’, starting in november 2004.

The aim of this project is to improve the competitiveness and the attractiveness of railway freight transport and thereby resulting in a possible shift in freight transport from road to rail. On one hand the use of innovative information and communication technology solutions (ICT) will serve for this purpose, on the other hand the integration of the obtained information in the organisational process of consignors, transport service providers as well as in public administration and emergency and rescue organisations respectively, whilst developing new optimisation and improvement potentials simultaneously.

Partners: INRIA (F), Log-o-Rail (F), European Oxo GmbH (D), LII Europe (D), Nacco (F), ELTA (F), OHB (D), Timtec (D), BIBA (D)

7.2.4. Network of Excellence IPROMS

Participants: Zied Achour, Lyès Benyoucef, Sophie Hennequin, Jie Li, Iyad Mourani, Nidhal Rezg, Alexandru Sava, Guy-Aimé Tanonkou, Xiaolan Xie.

The Network of Excellence for Innovative Production Machines and Systems (IPROMS, starting in october 2004), funded by the EU’s FP6 Programme, will address the area of production research in an integrated manner in order to reshape the area and overcome its current fragmentation. I*PROMS will develop concepts, tools and techniques enabling the creation and operation of flexible, re-configurable, fault-tolerant and eco- and user-friendly production systems that can react to customer needs, environmental requirements, design inputs, and material / process / labor availability to manufacture high quality, cost-effective products. At present, I*PROMS comprises 30 member institutions representing 14 European countries. They will commit 139 research staff and 71 PhD students to prosecuting the joint programme of activities developed by the Network. I*PROMS is organized into five clusters: APM (Advanced Production Machines), PAC (Production Automation and Control), IDT (Innovative Design Technology), and POM (Production Organisation and Management). Our team participates to clusters PAC and POM.

7.3. Regional actions

7.3.1. QSL action: Software development for reliable control synthesis of Event Discrete Systems

Participants: Nidhal Rezg, Alexandru Sava, Xiaolan Xie.

The QSL (Qualité et Sureté Logicielle) project relates to the software development to integrate the various methods of synthesis in the control field developed by team MACSI of the INRIA Lorraine. The synthesis methods allow the determination of an optimal controller by taking into account uncontrollable and unobservable events of Discrete Events Systems (DES). An effort will be devoted in this project to the development of methods of synthesis integrating the temporal aspect and fault tolerance aspect in DES (sure controllers).

7.4. International activities

7.4.1. 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.

7.4.2. Collaboration with Canada

We collaborate with the Memorial University of Newfoundland, St John’s. Wieslaw Kubiak (Professor at Memorial University of Newfoundland), has been a professor invited by the Ecole des Mines de Nancy (since may to june). Themes: scheduling with minimal and maximal time lags, max and sum batch scheduling.

7.4.3. Collaboration with USA

Members of our team collaborate with Georgia Tech, Atlanta, on the problem of Optimization of Discrete Event Systems.

7.4.4. Collaboration with Belarus

More and more collaborations are developed with researchers from Belarus (Minsk). Themes: Scheduling, line balancing, corrective maintenance: optimization of test and repairing duration, design and scheduling for parallel and series structures.

New results were obtained in collaboration with Kovalyov (see sections 6.2.4, 6.2.5 and 6.2.6). Moreover, INTAS project is in preparation with Valery Gordon.

7.4.5. Collaboration with China

We collaborate with Shangai Jiao Tong University on scheduling and real time control of FMS using Petri nets (French-Chinese Avanced Project PRA submitted demand), with University of Sciences and Technology of Hongkong on the utilization of optimization-simulation approaches for design and optimization of supply chain (project PROCORE submitted demand) and with Hong kong Polytechnic University on batch Scheduling in supply chain (submission of a PROCORE project).

7.4.6. Collaboration with Taiwan

We collaborate with National Taiwan Ocean University on the theme of modeling and evaluation of VLSI manufacturing systems using Petri Net.

8. Dissemination

8.1. Scientific community animation

8.1.1. Action for the research community

The schedulers of MACSI have worked in collaboration with the teams TRIO and ALGORILLE of Loria and INRIA Lorraine. A seminary, where the three teams (MACSI, TRIO and ALGORILLE) met and invited other researchers of the scheduling community, has been held at least twice or third a year for the two last years. In this seminar talks concern scheduling problems arising in manufacturing, computer science and real time scheduling are proposed. One of these seminars were organized in the framework of the French scheduling groups BERMUDES and GOTHA [2]. A stronger collaboration between MACSI and ALGORILLE has been initiated this year on a particular token ring scheduling problem issued from ALGORILLE works. This problem has been modelled and will be solved by many different approaches coming from the different backgrounds (2D cutting or no-wait scheduling approaches as special case of schedules with minimal and maximal time lags).

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.

Many members of the team have participated in the "Club Génie Industriel". Many members of the team are members of the ROADEF (French Operations Research Society). Thibaud Monteiro is member of the board of directors and manages the pedagogical commission. Xiaolan Xie is member of the committee of the French Group of Petri Net. Many members of the team have participated to the GDR MACS pole STP. Mainly, in the following two groups: GT OGP (organization and production management) and GISEH (management and engineering of hospital systems). Nidhal Rezg is a co-animator of the group INCOS of the GDR MACS.

8.1.2. Member of organizing committees

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

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. This conference was held on April 26-28 2004 in Nancy. This conference was an opportunity for academicians and industrial with a broad range of interests in theory and application of project management and scheduling, to exchange experiences about recent developments and applications of these two areas. About 150 participants from 24 different countries participated to the conference and 112 papers was presented. A special issue of the European Journal of Operational Research dedicated to PMS 2004 will be published with A. Oulamara and M.-C. Portmann as guest editors.

Lyès Benyoucef and Xiaolan Xie organized the "Ecole thématique", of INRIA dedicated to supply chain management, in June 28, 29 2004.

Nidhal Rezg, Alexandru Sava and Xiaolan Xie have organised the QSL seminar of October 2004 on Control Synthesis of Discrete Event Systems.

8.1.3. Member of program committees of journals or conferences

Members of the team participated to the scientific committee of the following conferences:

- PMS'2004 Ninth International Workshop on Project Management and Scheduling, Nancy, France. (Marie-Claude Portmann)
- MOSIM2004, Nantes, France, 2004. (Marie-Claude Portmann, Xiaolan Xie)
- IMS'2004 (International Conference on Intelligent Maintenance Systems), France, 2004. (Xiaolan Xie)
- Intl Conf WODES'04, Reims, France, 2004. (Xiaolan Xie)
- IEEE Conf. on Systems, Man, and Cybernetic (SMC2004), Netherlands, 2004. (Xiaolan Xie)
- SAUM'04, Belgrade, Serbia, November 5-6, 2004 (Sophie Hennequin)
- MSR2005, Autrans, France, 2005. (Xiaolan Xie)
- PENTOM (Performances et Nouvelles Technologies en Maintenance), Maroc, 2005. (Xiaolan Xie)
- ROADEF'05 (Marie-Claude Portmann)

Members of the team were reviewers for the following journals: IEEE Transactions on Automatic Control, IEEE Transactions on Robotics and Automation, IEEE Systems, Man and Cybernetics, IJPR, JESA,DMTCS, EJOR, IJCIM, IJMA, IJPE, JDS, JIM, JIMAD, JORS, RIA, TSI.

Members of the team are editor of special issues of Journals:

- N. Rezg and X.-L. Xie for the special issue on modeling, analysis and control of reactive systems, International Journal of Production Research, to appear in April 2004.
- M.D. Jeng and X.L. Xie for the special issue on discrete event system techniques for CIM, International Journal of Production Research, to appear.

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

8.2. Teaching

The location of the teaching is linked to the bi-localization of the MACSI team. On one hand, teaching activities are located at the University of Metz (UFR MIM and UFR ESM) and in two independent Engineers schools : Ecole Nationale d'Ingénieurs de Metz (ENIM) and Ecole Nationale Supérieure d'Arts et Métiers de Metz (ENSAM).

On the other hand, teaching activities are located in Nancy, either at the Institut National Polytechnique de Lorraine (INPL), mostly at the Ecole des Mines de Nancy (ENSMN), Industrial Engineering department and at the University Henri Poincaré of Nancy, mostly at the UFR STMIA (Sciences Faculty) or at the Ecole Supérieur d'Informatique et d'Applications de Lorraine (ESIAL).

They are also involved in several professional and research masters. Henri Amet is responsible of the major of the Ecole des Mines de Nancy called "Decision and Production System Engineering".

Marie-Claude Portmann had been responsible of the Master Of Sciences in Industrial Engineering "Industrial Economy and International Management" of the Ecoles des Mines group. Marie-Claude Portmann had also been responsible of the Mastère "Recherche Opérationnelle et Stratégie de Décision" de la Conférence des Grandes Ecoles until septembre 2004. The new responsible is Ammar Oulamara. Marie-Claude Portmann becomes responsible of the Mastère "Management de la chaine logistique - Achats" ENSMN, ICN, ENSGSI and ESIDEC, which opened in October. 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.

Nidhal Rezg is responsible of the DESS Automatisation et Organisation Industrielles (University of Metz) and of the DESS GMP Conception des Systèmes Intégrés de Production (University of Metz).

Didier Anciaux is responsible of the Licence Professionnelle Gestion de la Production Industrielle (University of Metz).

Daniel Roy is responsible of the option Management de Projets Internationaux (ENIM).

Alexandru Sava is responsible of the Option Quality (ENIM).

Sophie Hennequin is co-responsible of the option Research and development (ENIM).

Thibaud Monteiro is the teaching person in charge of the Licence Professionnelle Gestion de la Production Industrielle (University of Metz).

MACSI belongs to the graduate school IEAM. Two members of MACSI give courses within the Master Conception, Industrialisation et Innovation of Metz (François Vernadat and Xiaolan Xie).

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