INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team MACSI

Modeling, Analysis and Control of Industrial Systems

Lorraine

THEME NUM

Activity Report

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1. Team

MACSI is a team of INRIA-Lorraine. The part of MACSI team located in Nancy belongs to 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). The part of MACSI team located in Metz belongs to Laboratoire de Génie Industriel et Production Mécanique (LGIPM) in common with ENIM, ENSAM and University of Metz.

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2. Overall Objectives

2.1. Overall Objectives

MACSI is an INRIA project-team since January 2000, after having been a preliminary-project (avant-projet) since January 1998. The objectives of MACSI are design and/or control of Industrial Systems at different decision levels: strategic (organization and dimensioning of virtual enterprises or supply chains), tactical (planning, scheduling, maintenance, transport) and operational (control synthesis).

The main activities of MACSI can be organized along two complementary axes:

- 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 or totally 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: complexity theory, design of exact efficient algorithms, integer linear programming, meta-heuristics, hybrid approaches integrating decomposition 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. As often as possible, generic solution approaches are proposed and validated by experiments or proof of analytical results.

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

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, Sophie Hennequin, Smaïl Khouider, Thibaud Monteiro, Iyad Mourani, Marie-Claude Portmann, Nidhal Rezg, Daniel Roy, Alexandru Sava.

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 [56]. 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 [66], [53]. 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 [62], 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 [57]. To generate a better productivity, these companies need to coordinate the different actions which are distributed among autonomous partners [67], [70], [64]. 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 [68]. Moreover, the centralized philosophy is strongly opposed to the decisional autonomy of the supply-chain components (firms). This is why, the MACSI project is working on a more distributed approach in order to provide autonomy and to facilitate the management of a network of firms, while considering a win-win global strategy.

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 [69]. 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 [65], 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*.

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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 [61], [72]. 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 have concerned scheduling problems [71], [58].

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 have considered 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 integrating negociations related to component arrivals and finished product deliveries. The considered problems are generally NP-hard; in consequence, depending on the problem sizes, 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 including product transportation. For any type of batch, the machine is set up for each family of jobs and subsets of products or batches are put on the machine and picked up jointly. It is a sum-batch, when each product is dealed successively by the machine and it is a max-batch, when all products are treated simultaneously by the machine and the batch processing time is equal to the greatest needed processing time. Good examples can be found in chemical processes and particularly in tyre plants.

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 to integrate more and more pertinent constraints. In this direction, we have a promising industrial application with BT Exact (British Telecom), including the tactical level.

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 [59], [55]. 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

4.1. 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 batched systems. Although the main results obtained in the project were studied within the framework of production of goods, most 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 flow and scheduling optimization with or without integration of optimized maintenance policy of the equipment;
4. definition and installation of workshop control systems which can react to the different operation risks at various decision levels;
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, tyre plants...

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. Performances optimization by using weighted marked graphs

Participants: Nathalie Sauer, Leila Toursi.

Marked graphs, as an elementary class of Petri nets (PN), provide a powerful tool not only for property analysis but also for performance evaluation of dynamic systems, like manufacturing systems. While being applied to model cyclic manufacturing systems, however, the analysis techniques developed for marked graphs become not appropriate if the model size is large. Considering of this, we bring in Weighted Marked Graphs (WMG) to model bulk production systems and to reduce the size of the model. An important step for designing these systems is to define the number of manufacturing resources such as transportation devices (conveyor, carriage, kanbans) with a promising productivity. These resources characterize the flexibility of the production system and are usually very expensive. Hence in the term of timed Petri nets, we define this kind of problems, consisting of reaching a given average cycle time while minimizing a linear combination of markings, as marking optimization problem. This work is mean to deal with the marking optimization problem of strongly connected Weighted Marked Graphs.

In this literature, we present the work for the marking optimization problem when the system is modelled by WMG. Firstly, properties of the optimal solution have been given and a branch and bound approach has been developed to obtain an optimal solution of this problem [51] while this method works well only on graphs with small size. Secondly, a metaheuristic based on simulated annealing algorithm and Branch and Bound approach has been developed to solve this problem [38]. This method has been adapted and applied to some examples of flexible manufacturing systems [37].

5.1.2. Supervisory control

Participants: Zied Achour, Nidhal Rezg, Alexandru Sava, Xiaolan Xie.

The complexity of discrete event systems (DES) makes more difficult the realization of an effective and realistic control device. Firstly the supervisory control of untimed Petri net is considered. Bounded Petri nets are used for modelling DES, hereafter also referred to as plants. For a discrete plant model and a set of specifications, the goal of control synthesis is to determine a supervisor represented by a given set of legal markings which guarantees the desired behaviour. Supervisory control allows the avoidance of a set of forbidden states defined by some General Mutual Exclusion Constraints (GMEC) by adding some control places. The controller design is subject to constraints including liveness requirement, maximally permissiveness with respect to given system specifications, and the presence of uncontrollable and/or unobservable transitions. The uncontrollable transitions represent events that cannot be prevented from occurring by a supervisor. Specifications that can be enforced by our approach are expressed as forbidden states (FSP) and/or Forbidden State-Transition Problems (FSTP). The proposed approach can be considered as a combination of the Ramadge-Wonham's approach [69] and the theory of regions. It first determines the automaton model of the closed loop system using a Ramadge-Wonham-like approach. It then uses the theory of regions to design the Petri net controller [60], which is a set of control places, whenever a Petri net controller exists. Control places may be with or without self-loops. They are called respectively pure and impure places. Necessary and sufficient conditions for the existence of such solution are established using the theory of regions for the DES totally and partially observable. It is shown through examples that there exist control problems that cannot be solved by adding pure control places. Indeed, impure control places have self-loops with controlled transitions which grant them with a higher power of control.

We propose than a design methodology for Petri net controllers for the forbidden state-transition problem by taking into account the time constraints. Consideration of time is crucial for realistic characterization of systems and hence leads to two types of concerns: the checking or validation of certain temporal specifications, and the control which requires temporal specifications. It is therefore important to integrate time in the specifications and synthesis. For this purpose, we introduce a new class of General Mutual Exclusion Constraints (GMEC) called Time Floating General Mutual Exclusion Constraints (TFGMEC), for which we propose a solution method inspired by a supervisor modelled by control places added to the initial Petri net model [14], [13].

Another interesting problem consist in taking into account time information associated to the occurrence of the events. This information involves increasing complexity of the control synthesis problem, but it allows generation more permissive control laws. Bounded Petri nets are used for modelling DES, hereafter also referred to as plants. Given the discrete model of a plant and a set of specifications, the goal of control synthesis is to determine a supervisor which guarantees the desired behaviour. Supervisory control allows the avoidance of a set of forbidden states defined by some General Mutual Exclusion Constraints (GMEC) by adding some control places. Consideration of time is crucial for realistic characterization of systems and hence leads to two types of concerns: the checking or validation of certain temporal specifications, and the control which requires temporal specifications. It is therefore important to integrate time in the specifications and synthesis. For this purpose, we introduce a new class of General Mutual Exclusion Constraints (GMEC) called Time Floating General Mutual Exclusion Constraints (TFGMEC), for which we propose a solution method inspired by a supervisor modelled by control places added to the initial Petri net model.

Furthermore, we consider the case where time is taken into account both in the plant discrete model. The dynamic of a TDES is driven by the occurrence of events within given time intervals. Two kinds of events are considered: controllable and uncontrollable. Our aim is to solve the forbidden state problem for this kind of systems. Our goal is to solve the forbidden state problem. The aim is to build a most permissive live controller which guarantees the respect of the given specifications. A supervisor is called most permissive if it has the ability to avoid only the forbidden states. A live controller has the ability to avoid deadlocks.

The approach that we propose considers that the evolution of time is discrete. Thus, the elapsing of time is modelled by a special event. As time cannot be stopped, this event cannot be forbidden or delayed by the controller. The modeling tool that we propose is the Time Control Petri Net. This tool is characterised by a firing condition associated with each transition made of a time constraint and a logic constraint. The time constraint is represented by a union of time intervals. The logic constraint is a control function. An enabled transition can be fired if both time constraint and logic constraint are satisfied. Consequently, the controller developped by the approach that we propose has the ability to 1) fix the arriving moment within the given time interval or 2) to forbid the occurrence of a controllable event. It can not act neither on uncontrollable events nor on time. The synthesis of the controller consists in building the state space generated by the evolution of the system and computing new time constraints and new logic constraints such that the forbidden states are no longer reachable and the controlled system is deadlock free [24]. A continuous time approch for control synthèsis of times discrete event systems is proposed in [12].

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. Performance evaluation and optimization of manufacturing systems

Participants: Liya Gu, Sophie Hennequin, Jie Li, Iyad Mourani, Alexandru Sava, Xiaolan Xie.

This work adresses both discrete-flow and continuous-flow manufacturing systems [3]. Moreover, Petri nets model is used for the simulation of the various manufacturing systems. The performance evaluation and especially the throughput rate of production system is studied and an analytical comparative study for discrete-flow model of the both existing failure models, namely operation-dependant failures end time-dependant failures is carried out [10]. For the continuous-flow model same results are obtained but not proved. The majority of the continuous-flow models do not take into account delays (production, lead-times and transportation) which have a great impact on performance measures and optimization. Hence, the modeling and the impact of these delays on the throughput rate are studied. The control of the production systems with delays is adressed and the Infinitesimal Perturbation Analysis technique is used to optimize our production system [28] and [29]. Various control policies are considered, namely Kanban policy [49], Echelon Bases Stock policy and CONWIP policy [30]. A simulation-based optimization is used to determine the optimal buffer level according to the given control policy [11].

Another research field concerns the stochastic optimization [2]. Our research work focuses on analysis and optimization of production-distribution systems. The system we consider is made up by an end-user warehouse supplied by a network of inventories and production facilities. Customer orders arrive randomly at the warehouse. The size of the client orders are random and the production capacity is finite. The inventory at the warehouse is controlled by a base-stock policy. The transportation time between a plant and the upstream warehouse is constant.

Firstly, we considered the case of a simple production-distribution system made of one warehoure supplied by a production plant. For this case we proposed an analytic approach to estimate the end-customer service level, the order-to-delivery lead time of the warehouse, the total inventory on order and the inventory holding and backlogging cost. This approach is based on queueing theory. The total inventory cost is optimised by a gradient method. Numerical experiments show the efficiency of the method.

Furthermore, this approach proved to be not addapted for production-distribution systems with several warehouses and production facilities. Therefore, in order to estimate the performances and optimize multi-echelon production-distribution systems, we provide a new Convergent Optimization via Most-Promising-Area Stochastic Search (COMPASS) algorithm called COMPASS*. This algorithm improves the original COMPASS proposed in [63]. This method is based on random search and on a new neighbourhood structure called most promising area. The performance measure is estimated via a stochastic, discrete-event simulation, and the decision variables are integer ordered.

We prove that the property of convergence to a set of local optimal solutions is satisfied for assumptions which are much more permissive that in the case of the original COMPASS. Thus, the COMPASS* algorithm is more computationally efficient and converges faster to a local optimum. The algorithm was tested and validated on the production-distribution system described above. Numerical results validate the COMPASS* method and show that it converge efficiently to a local optimal solution [25], [47] and [46]. We have also solved the case where the constraints imposed to the production-distribution system are estimated via simulation. These algorithms were extended usual inventory management policies such as base-stock policy, (R,nQ) and (s,S). Our further research directions concerns improving the computation efficiency of these algorithms and to extend this approach by taking into account machine failures and maintenance.

Another research field concerns a new methodology electromagnetism-like mechanism (EM). EM is used to solve the stochastic type II assembly line balancing problem. This NP-hard problem consists in assigning assembly activities to a given number of workstations of an assembly line in order to minimize the cycle time subject to precedence constraints. The operation times for each assembly activities are random. The solution methodology is a new EM algorithm which uses a random key to each activity and assigns them to workstations according to the random key and a heuristic EM outperforms simulated annealing (SA) for large scaled problems [19] [44].

5.2.2. Maintenance policy of manufacturing systems

Participants: Gabriel Arango, Anis Chelbi, Sofiene Dellagi, Michael Fu, Sophie Hennequin, Mohamed Salah Ouali, Nidhal Rezg, Xiaolan Xie.

Nowadays, the enterprises move under a hard competition. The satisfaction of the client in time became a difficult spot. Since that, the majority of the actual company call upon to the subcontractor in order to cover the client demand and to reduce the demand loss. In fact, it's time to expand new maintenance/production strategies by taking into account the context of subcontractor [1]. In this work we treat some maintenance policies integrated with production under the subcontractor constraint. The manufacturing system under consideration consists on a machine M1 which produces a single product. In order to satisfy a constant demand, the system called upon to subcontractor. The subcontractor is presented by another machine M2 which produces at a certain rate the same type of product as M1. Both machines are subject to random failures. An age-limit policy is used for preventive maintenance of machine M1. Point of view maintenance actions, the subcontractor is not controlled by us. We considered that the subcontractor imposes some unavailability periods. That's why we suppose that the failure rate of the subcontractor is constant. In this work we elaborated different strategies integrating maintenance and production. In these strategies we are taking in account the constraint of subcontractor. These strategies are optimised and its performances are compared to a simple maintenance policy SMP in which we don't taking in account the subcontractor. Finally, we classified all the strategies developed in this work according its performances orders compared to SMP and noted the performance constraints of theses policies [5], [4], [16] and [15].

In another research work, fuzzy logic is used to model the human behaviour in the preventive maintenance actions. Indeed, most preventive maintenance models assume that the system is restored to as good as new at each PM and consider the intervention time as negligible. However, for most repairable systems, the maintenance action is not necessarily the replacement of the whole system, but is used to slow the rate of system degradation and increase the lifetime. Hence, the system may not be restored to as good as new immediately after the completion of maintenance action. When a perfect maintenance model is used for maintenance policy, alternate tools of maintenance improvement as TPM (Total Productive Maintenance) or TQM (Total Quality Maintenance) have to be introduced to ensure that PM actions are perfect. However, the introduction of these kinds of programs requires great investments in human and informatics resources that not all enterprises are able to undertake. This is why consideration of maintenance imperfections and modeling of these imperfections is important for developing a more accurate maintenance program. Now, considering that PM is not always perfect (it may depend on the technician's experience, the level of complexity of the intervention, and the time to conduct PM actions), the above assumptions may be inaccurate. For this reason, fuzzy logic is used to model these imperfections, so that the system returns to an age between as good as new and as bad as old after maintenance actions. Fuzzy logic is preferred over an analytical method because it is relatively easy to implement in this situation considering that the human factor is hardly interpreted by analytical methods because of its unpredictable nature. This fuzzy model is then used to optimize the period for the PM which minimizes the expected cost rate per unit of time and the availability of the system composed by a single repairable machine as a system which undergoes preventive maintenance (PM) periodically and is completely repaired at each random failure [42] and [41].

5.2.3. Optimal Testing and Repairing a Failed Series System

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

We consider a situation where a *series* system consisting of n components fails without providing the cause of failure. This situation is typical for complex electronic, electric and wireless transmitting devices. We consider the problem of managing the diagnosis and repair of such a system with the aim to minimize the associated costs. We assume that exactly one component of the series system is responsible for the failure. As soon as the system has failed, it has to be repaired. There is a single operator that can sequentially perform testing and repairing operations over the components. Both testing and repairing operations are assumed to be perfect, that is, the result of testing a component is a true information that this component is failed or active (not failed), and the result of repairing is that the component becomes active. The system can be run to check whether all its components are active only after the testing-repairing procedure has been completed. The problem is to find a sequence of testing and repairing operations on the components such that the system is always repaired and the total expected cost of testing and repairing the components is minimized. The probability of each component to be responsible for the failure is given and each component can be tested and repaired at given costs. We showed that this problem is equivalent to minimizing a quadratic pseudo-boolean function. We identify solvable special cases of the latter problem and we present fully polynomial time approximation scheme (FPTAS) for the general case. We conduct computer experiments to demonstrate high efficiency of the proposed FPTAS. In particular, it is able to find a solution with relative error $\varepsilon = 0.1$ for problems with more than 4000 components within 5 minutes on a standard PC with 1.2 Mhz processor [8].

5.2.4. Maintenance planning and scheduling in manufacturing system

Participants: Aymen Mili, Ammar Oulamara, Marie-Claude Portmann.

Preventive maintenance planning and production scheduling are two inter-dependent activities, despite the different decisions are made independently and each activity ignores the constraints of the other. This problem have received a large consideration from both manufacturing industries and in the literature. We investigate the single machine total tardiness problem with availability constraints due to preventive maintenance operations. The objective is to propose an integrated model that simultaneously determines production scheduling and preventive maintenance planning so that the total tardiness of jobs and maintenance operations cost is minimized. We developped a new maintenance policy that consists of making a systematic preventive maintenance between a minimum and maximum load of work in order to ensure a minimum of reliability of the system. This policy is based on the load of machine instead of time. We consider two cases, the first when all jobs are available at the same time and the second case when jobs have arbitraty release dates. These scheduling problems are known NP-hard, so we developped for both cases integrated heuristics based on methods used for the case without availability constraints. These heuristics are compared with lower bounds developed for each case. We conduct an extensive computational experiments for each case [48].

5.2.5. Scheduling with time lags

Participants: Henri Amet, Freddy Deppner, Julien Fondrevelle, Ammar Oulamara, Marie-Claude Portmann.

We study permutation flowshop problems with minimal and/or maximal time lags, where the time lags are defined between couples of successive operations of jobs. Such constraints are used to model various industrial situations (food production, pharmaceutical, iron industries, etc.). We present theorical 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 [6]. We consider the two-machine no-wait flowshop scheduling problem with the objective of minimizing maximum lateness where set-up and removal times are considered as separate from processing times. We provide 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 set-up and removal times are not too large, compared to processing times. We also evaluate the performance of Dileepan's dominance property and show that it performs exceedingly well. For general shop problems including machine unavailability periods and release dates with general routes, we proposed a generalization of priority rules algorithms adapted to minimal and maximal time lags. In order to find a trade-off between the ability of building feasible solutions and the performance of the obtained feasible solutions, we designed two new approaches with increasing clusters beginning with simple clusters containing only one operation and ending, if necessary, with complete connected components. The approaches were verified on job shop problems and on a real chemical (freeze-drying) problem [17].

5.2.6. Scheduling of production systems with blocking constraints

Participants: Ali Gorine, Sophie Hennequin, Nathalie Sauer, Kun Yuan.

The research presented in this part concerns the scheduling of flexible systems (production or services) especially for Flow-Shop, two stages Hybrid Flow-Shop and Job-Shop scheduling problems without storage capacity and with a new blocking constraint encountered in many industrial processes. The lack of buffer space between machines implies that a machine which has completed the process of a given job, cannot release the job immediately. These situations are referred in the literature as blocking situations. In classical blocking situations, a machine remains blocked by a job until this job starts the operation on the next machine in the routing. For the particular type of blocking constraints considered in our work, the machine remains blocked by a job until its operation on the downstream machine is finished and it leaves (RC constraint).

In the flow-shop case with RCb constraint, we have obtained complexity results [9] and tested a few metaheuristics. This year, we have studied a new metaheuristic called electromagnetism-like optimisation heuristique (EM) to this kind of problems. The heuristic EM proposed by S.I. Birbil and S.-C. Fang simulates the electromagnetism theory by considering each solution as an electrical charge. Through the attraction-repulsion of the charges, solutions move to the optimality without being trapped into local optimal. This heuristic can obtain all the solution optimal for all those problems with no more than 10 jobs, and performs better than simulated annealing (SA) for those which have no more than 20 jobs. It is also proved that EM converges much quicker than SA especially for those large-sized problems with constraints [40] or not [52] .

With the team of X. Gandibleux (LINA Nantes) and S. Martinez (Institut de Technologie de Celaya, Mexique), we have studied the two-stages hybrid flow-shop with one machine at the first stage, RCb constraint and two objectifs. We have developed an exact method and MOSA (Multi Objectif simulated annealing) algorithm [18].

A new thesis, which has began this year, considers the job-shop scheduling problem with RCb constraint. A list of methods have been tested and a genetic algorithm is developed.

5.2.7. *Scheduling with deteriorating tasks*

Participants: Gerd Finke, Ammar Oulamara.

We consider the two-machine flowshop problem with *deteriorating tasks*. Such a problem consists of two machines that are continuously available and a set of tasks to be processed. Each task has two operations to be sequentially processed on the two machines. The tasks have deteriorating processing times, i.e. the processing time on the second machine is a continuous nondecreasing function of the waiting time between machines. Such deterioration appears, for instance, in the steel production where the material will cool during the waiting periods and has to be reheated for the subsequent process. A similar situation will also occur in scheduling maintenance tasks, where the maintenance time depends on the length of time elapsed since the last maintenance operation. We consider the restricted problem in which for a given sequence of tasks, one wants to find an optimal placement that minimizes the total completion time. This problem is trivial for classical two-machine flowshop problem; its suffices to schedule tasks as soon as possible. However finding an optimal sequence of tasks in order to minimize the total completion time is strongly NP-Hard. We suggest an optimal algorithm to solve the restricted problem based on shift operation within a certain block structure [50].

5.2.8. *Scheduling problem with batching machine and task compatibilities*

Participants: Adrien Bellanger, Gerd Finke, Aimé Kamgaing Kuiteing, Ammar Oulamara.

The motivation comes from processing products in tires manufacturing industry. The main part of production system (building and curing) can be modelled as a scheduling flowshop with two machines. The processing time on second machine is given by an interval. The first machine can process no more than one task at time. The second machine is a max-batch machine with capacity k. The tasks of the same batch have to be compatible. We show that the makespan minimization is NP-Hard in the strong sense and we present a heuristic approach [23].
We also consider the case of hybrid flowshop with two stages. At the first stage there are m_1 classical parallel machines and on the second stage there are m_2 parallel batching machines. We consider the objective of minimizing the makespan which is NP-Hard in the strong sense. We propose several aproximation algorithms with guaranteed performances. For the case with equal processing times of tasks on the first stage, we propose a polynomial time approximation scheme [43].

5.2.9. Cooperation in supply chain scheduling : minimizing the inventory holding cost and delivery cost

Participants: Zerouk Mouloua, Ammar Oulamara.

We consider a scheduling problem in a supply chain in which several suppliers are cooperating to ensure the production of one or several types of products in order to satisfy the needs of clients. Such a problem arises in different industry problems since the objective is to reduce the production cost and customer lead time by coordinating decisions between the suppliers. For example, we consider the case in which a company has two different plants, the two plants have to coordinate their decisions in order to mimize the overall costs and to reduce customer delivery time. The client asks for a fixed and well known quantity of each type of product needed. The plants are cooperating between them for making decisions that answer the following question : how much does each plant have to produce from each type ? they have to keep in mind that the client has to be delivered as quickly as possible with satisfying quantities. Copies of the same product are batched together for delivery to the costumer. The completion time of an item is equal to the completion time of the last item of its batch. The processing time of a batch depends on the number of items that it contains. An inventory holding cost is incurred for each item. The objective is to minimise the overall inventory holding costs. At first, we consider the problem of cooperation between suppliers for the production of a single product. An algorithm for dispatching the work between them is proposed. In the second part, we generalize for multiple products problem [26].

5.2.10. Cooperation in supply chain scheduling: minimizing the transport costs

Participants: Zerouk Mouloua, Marie-Claude Portmann.

We consider a basic supply chain composed of one or several suppliers that provide components needed by a manufacturer. The manufacturer has to deliver finished products to only one customer before given delivery dates. We first verify if the associated decision problem is feasible or not with unlimited transportation capacities. We further integrate progressively to the model more realistic transportation constraints and costs to be optimized : number of travels with unlimited number of trucks with unlimited capacity, number of travels with unlimited number of trucks with limited capacity and finally we consider limited number of physical trucks as a perspective. The simplest problems are polynomial and the last considered can be solved by using a pseudo-polynomial dynamic programming approach [27].

5.2.11. Negotiation in supply chain scheduling: new models

Participants: Smail Khouider, Mikhail Kovalyov, Thibaud Monteiro, Zerouk Mouloua, Ammar Oulamara, Marie-Claude Portmann.

Supply Chain Management implies a greater integration of model and decision tools. First transport models and production manufacturing models must be considered jointly and not separately. Second new Supply Chain structures, such as Extended Enterprises and Virtual Enterprises, induce negotiations concerning costs, delays and quality and exchange of knowledge and data, between various partners, who can have been in strong competition and want to keep some data quite secret while sharing other data with some partners of the Supply Chain. Some flow exchanges have been currently regulated by contracts with penalty systems; a more general control system needs to be designed. In consequence, new decision tools must be proposed at each level of the hierarchical decision structures: strategic, tactic and operational levels: In particular, new decision systems for the planning level including several partners of the Supply Chain and new scheduling tools generalizing classical scheduling models with new constraints and criteria linked to just-in-time strategies and to negotiation approaches [31].

We are now investigating new scheduling models including earliness and tardiness penalties associated both to release dates and to due dates of any job. An international group including researchers from Minsk, Paris, Tours and Nancy is preparing a very general survey on this family of scheduling problems in the framework of a GDR RO ORDO-SC project. Zerouk Mouloua is developing a hybrid approach crossing spatial decomposition, genetic algorithm and pseudo-polynomial PERT cost algorithm in order to get an efficient approximation algorithm for minimizing the sum of earliness and tardiness general penalties within a general shop constituted of several parallel flow shop completed by an assembly line.

We also proposed supplier research protocol and decision tools for supplier selection. The architecture of the negotiation and decision making is supported by a multi agent system and uses mixed integer programming models and solvers. The supply chain is composed by autonomous enterprises. Each enterprise must reach, in the same time, local and global goals. The research protocol is implemented in a virtual agent "Tier Negotiator Agent (TNA)" implanted in each tier of the supply chain, which provides human decision makers with data tables and suggests them to follow some directives. One TNA is activated each time a customer does not find sufficiently components for covering its needs and the protocol can activate TNA of upstream tiers [21], [22].

5.2.12. Flexible approaches for planning and scheduling in presence of disturbances

Participants: Christelle Bloch, Pascal Chatonnay, Mais Haj-Rachid, Zerouk Mouloua, Ammar Oulamara, Marie-Claude Portmann, Wahiba Ramdane Cherif.

Concerning flexibility in transportation problem. The objective is to propose a flexible solution for a basic model in routing problem and then to study how we can deal with more general models. We are currently working on decomposition flexible approach for routing problem with time windows that iterates between two steps. Classification step that construct a group of compatible clients and organisation step that built trips in each group. In this direction, we have a collaboration with the SET laboratory of UTBM and the LIFC laboratory of UFC, including the design of robust/flexible and operational solution for the planning and the control in real time of more general transportation problem. In preliminary study [32], we proposed a new and hard theoretical model in arc routing called the CARPTW (CARP with time windows) useful for waste collection, mail and newspaper delivery, or inspection of power lines. We proposed a memetic algorithm with new memetic operators able to tackle the time windows constraints in arc routing. Results showed the efficiency of the new crossover operator to tackle the time windows constraints.

5.2.13. Logistic platforms control

Participants: Renato Guimaraes, Henri Amet, Wahiba Ramdane Cherif, Marie-Claude Portmann.

We were contacted by several industrial partners, who need to improve the organization and the control of their logistic plate-forms. The main problem is to define layout and work organization in order to smooth the workload knowing that depending on our partners the load cycle can be one day, one week or six months. Nevertheless, each cycle contains a period of great activity and a period of low activity. If the activity of the plate-form follows exactly the customer demands, the inventories are minimized, but there is no possibility for good load balancing and the bottlenecks could be unacceptable.

In order to minimize the manpower costs while respecting the material resource capacity and satisfying as much as possible the customer requirements, any potentiality of flexibility must be explored. The improvement can come with organization changing (plate-form layout and activities), supplier negotiation (earliness or tardiness of delivery), customer behavior modification and decision tools for simulating and optimizing a given organization model. We are now studying new optimization models for plate-form load balancing and we are preparing a survey and classification of representative operations research models in plate-forms.

5.2.14. Branch on Price: A Fast Winner Determination Algorithm for Discount Auctions

Participants: Kameshwaran Sampath, Lyès Benyoucef.

Discount auction is a market mechanism for buying heterogeneous items in a single auction. The suppliers submit discount bids, which consist of two parts: the individual cost for each of the items and discounts based on the number of items procured. The winner determination problem faced by the buyer is to determine the winning suppliers and their corresponding winning items, such that the total cost of procurement is minimized. This problem is NP-hard and in this study we proposed a novel branch and bound algorithm called as *branch on price*, which uses a tight integer programming formulation with valid inequalities. Computational experiments showed that the proposed algorithm is many folds faster than the existing algorithm [20].

5.2.15. A Branch-and-Bound Framework for Interval Combinatorial Auctions

Participants: Kameshwaran Sampath, Lyès Benyoucef.

Combinatorial auctions, in which bidders submit bids for bundles or subsets of items, have been developed to optimize various e-commerce and supply chain business processes. In this study, we considered a special case of combinatorial auctions, which allows only interval bids, i.e. for a set of consecutive items. The winner determination problem for this bid structure with the *OR* bidding language (any number of winning bids for a bidder) is known to be solvable in polynomial time using dynamic programming. However, with the *XOR* bidding language (at most one winning bid for a bidder), the problem is *NP-hard*. We developed a novel branch-and-bound framework that uses the dynamic programming algorithm for the OR version as the bounding technique [7].

5.2.16. Discount Auctions for Procuring Heterogeneous Items

Participants: Kameshwaran Sampath, Lyès Benyoucef.

e-Procurement is an Internet based business process for sourcing direct or indirect materials. In this study we propose an auction mechanism called as discount auctions for procuring multiple items. The bid from a supplier consists of individual costs for each of the items and a discount function, which specifies the discount over the number of items. We show that such a bid is more meaningful and cost effective in terms of bid preparation and communication in common procurement scenarios. The bid evaluation problem is modeled as a mixed integer linear program and various structures in the problem that can be exploited for developing algorithms are explored. A heuristic based on linear programming relaxation is proposed to determine a feasible solution to the problem and its closeness to optimality is studied with computational experiments [45].

5.2.17. Integrated facility location and supplier selection decisions in a distribution network design

Participants: Guy-Aimé Tanonkou, Lyès Benyoucef, Xiaolan Xie.

This study deals with the integration of facility location and supplier selection decisions for the distribution network design problem. More specifically, the distribution network under consideration is composed of a set of suppliers serving a set of retailers through a set of Distribution Centers (DCs). To manage its inventory, the EOQ policy is used by each DC, and a safety stock level is maintained to ensure a given retailer service level. In this study, we assume that each retailer faces a random demand of a single product type, the supply lead-time from each supplier to each DC is *constant*, and no supply lead-time between DCs and retailers. The problem concerns the selection of suppliers, the location of DCs, the allocation of suppliers to DCs, and the allocation of retailers to DCs, where the goal is to minimize inventory and safety stock costs at the DCs, ordering costs and transportation costs across the network, and fixed DCs location costs. The introduction of inventory and safety stock costs leads to an NP-hard non-linear optimization problem. A Lagrangian relaxation approach is proposed to generate efficient solutions. Some numerical experiments are realized and analyzed showing the effectiveness of the proposed approach [35].

5.2.18. Distribution network design with random demand and unreliable suppliers

Participants: Guy-Aimé Tanonkou, Lyès Benyoucef, Xiaolan Xie.

This study addresses the location problem of distribution centers (DC) in a distribution network with unreliable suppliers and random demand. A two-period model is proposed in which selected suppliers are available in the first period and can fail in the second period. The facility location/supplier reliability problem is formulated as a stochastic programming problem for minimizing total fixed facility costs, transportation costs, DC replenishment costs, DC inventory and safety stock costs. Since the problem is NP-hard non linear stochastic optimization problem, we proposed a Monte Carlo optimization approach combining the sample average approximation (SAA) scheme and an efficient heuristic based on Lagrangian relaxation approach for solving the related sample optimization problem. Computational results are provided to assess the efficiency of the proposed method [34].

5.2.19. A two-period stochastic programming model for distribution network design

Participants: Guy-Aimé Tanonkou, Lyès Benyouef, Xiaolan Xie.

This study presents a facility location problem where decisions must be made in the presence of uncertainty. The distribution network is composed of a supplier serving a set of retailers through a set of distribution centers (DCs) to be located on the retailer's locations. The inventory at each DC is controlled with an EOQ policy and a safety stock is used to ensure a given service level. A two-period model is proposed in which opened DCs are available in the first period and can fail in the second period. The facility location problem is formulated as a stochastic programming problem for minimizing total fixed facility costs, transportation costs, DC replenishment costs, DC inventory and safety stock costs. We proposed a Monte Carlo optimization approach combining the sample average approximation (SAA) scheme and an efficient Lagrangian relaxation approach for solving the related sample optimization problem [33].

5.2.20. Joint Facility Location and Supplier Selection Decisions of Distribution Networks with Random Supply Lead-Time

Participants: Guy-Aimé Tanonkou, Lyès Benyoucef, Xaolan Xie.

Supplier selection and facility location problems are often considered separately. In this study, we *integrate* decisions that are usually made in three stages: the location of Distribution Centers (DCs), the allocation of suppliers to DCs, and the assignment of retailers to the located DCs. More specifically, the distribution network under consideration is composed of a set of potential suppliers serving a set of retailers through a set of DCs to locate. We assume that each retailer faces a random demand of a single product type, and the supply lead-time from each supplier to each DC is *random*. Economic Order Quantity policy is used by each DC to control its inventory, and a safety stock is kept to ensure a given retailer service level. The goal is to minimize total inventory and safety stock costs at the DCs, ordering and transportation costs across the network, and fixed DCs location costs. The resulting problem is a difficult non-linear combinatorial optimization problem. A Lagrangian relaxation approach is proposed to generate efficient solutions. Computational experiments are realized and analyzed proving the effectiveness of the proposed approach [36].

5.2.21. Identification of Software Specifications through Quality Function Deployment

Participants: R. C. Vlad, Lyès Benyoucef.

This study describes the procedure that has been used to determine the software specifications for a simulation component of an information platform. The procedure has been designed and implemented within the GRailChem project. The initiative was funded under a French-German scheme of cooperation and aimed to determine whether the intended information platform could actually improve the effectiveness and the efficiency of the freight transportation between Germany and France. The suggested procedure follows the general steps of the Quality Function Deployment to translate user requirements into system specifications, and later on, into simulation specifications. It also uses the Analytic Hierarchy Process to decrease the subjectivity of the decisions made during the systems analysis process [39].

5.3. European projects

5.3.1. Network of Excellence IPROMS

Participants: Lyès Benyoucef, Nidhal Rezg, 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 staffs 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.

6. Other Grants and Activities

6.1. National Actions

6.1.1. GdR MACS Project (submitted)

Participants: Marie-Claude Portmann, Wahiba Ramdane-Cherif.

Development of evolutionary distributed algorithms on peer to peer networks, integration into an existing "trade" platform and study of the extension to other application. The project brings together six university partners with complementary competences. This project is linked to the flexibile approaches for planning and scheduling in presence of disturbances.

6.1.2. GdR RO Project - ORDO-SC

Participants: Jean-Charles Billaut, Mikhail Kovalyov, Ammar Oulamara, Marie-Claude Portmann, Ameur Soukhal, Francis Sourd.

In classical scheduling models, just-in-time (or "zero inventory") principles turned into consideration of criteria involving both tardiness and earliness of completed jobs (finished products) with respect to their due dates. However, in logistics and supply chain scheduling, it is often important to observe not only the due date for completing a product but also the due date for starting its processing (which is called release date in scheduling literature). In this project we consider a soft and negociable release and due dates in supply chain scheduling that promising a new scheduling models in supply chain.

6.1.3. GdR RO Project - e-OCEA

Participants: Federico Della Croce, Marie-Claude Portmann, Wahiba Ramdane-Cherif, Vincent T'Kindt.

e-OCEA is web platform developped by by the LI lab of Tours. Several modules permit to user to aquiert knowledge on scheduling problems and to build a new branch and bound algorithms by using generic approach. The GDR RO - e-OCEA goal is to creat a new generic modules for building meta-heuristic algorithms for scheduling problems.

6.2. Regional actions

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

Participants: Zied Achour, 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).

6.3. International activities

6.3.1. 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.

6.3.2. Collaboration with USA

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

6.3.3. *Collaboration with Belarus*

More and more collaborations have been developed with researchers from Belarus (Minsk). The schedulers of MACSI are Foreign Collaborators of the ISTC Project B-986 "Models, methods and tools for decision support of designing and scheduling for the engineering systems with parallel and series structures". A new INTAS project as also been prepared in 2006, he is under examination. After several invitations of Belarus colleagues in Metz and Nancy during the last five years (Mikhail Kovalyov, Yuri Sotskov, Yakov Shafransky, Valery Gordon), a visit in Minsk in 2005. Marie-Claude Portmann met some of them in Poznan during the conference PMS in April 2006 and Mikhail Kovalyov spent two months in Nancy in 2006 as invited professor by the Ecole des Mines. The new subjects considered are linked to just in time in supply chain scheduling problems and are developed both in the framework of the ISTC and INTAS project and in the framework of a French GDR RO project.
Themes: Scheduling, line balancing, design and scheduling for parallel and series structures, negotiation and just in time scheduling in supply chains.

6.3.4. *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).

6.3.5. *Collaboration with Taiwan*

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

7. Dissemination

7.1. Scientific community animation

7.1.1. *Action for the research community*

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.

7.1.2. *Member of program committees of journals or conferences*

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

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, Journal of Scheduling, COR IJCIM, IJMA, IJPE, JDS, JIM, JIMAD, JORS, RIA, TSI, OMEGA.

7.2. Teaching

The location of the teaching is linked to the bi-localization of the MACSI team. On the one hand, teaching activities are located at the University of Metz (UFR MIM and UFR ESM) and in two independent Engineers schools : École Nationale d'Ingénieurs de Metz (ENIM) and École 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 École 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 École 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 École des Mines de Nancy called "Decision and Production System Engineering".

Ammar Oulamara is responsible of the Mastère "Génie Industriel: Aide à la décision pour les systèmes de production et de distribution". Marie-Claude Portmann is responsible of the Mastère "Management de la chaîne logistique - Achats" ENSMN, ICN, ENSGSI and ESIDEC.

Marie-Claude Portmann is member of the national committee CTI (Commission des Titres d'Ingénieur), who visits the French Engineer Schools and decides if they can continue to deliver the Engineer Diploma.

Nathalie Sauer is responsible of the Master X-AP (University of Metz) and is responsible of the Department of Industrial Engineering and maintenance (IUT Thionville).

Nidhal Rezg is responsible of the DESS Automatisation et Organisation Industrielle (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).

Alexandru Sava is responsible of the option Quality (ENIM) and co-responsible of the Master Logistique et Qualité (ENIM).

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

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

MACSI belongs to the graduate school IEAM. Many members of MACSI give courses within the Master Conception, Industrialisation et Innovation of Metz (Sophie Hennequin, Marie-Claude Portmann, Nidhal Rezg, Nathalie Sauer).

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