• HEC Montréal •
• École Polytechnique de Montréal •
• Université McGill •
• Université du Québec à Montréal •

Newsletter

Groupe d'études et de recherche en analyse des décisions

GERAD

One of ours is the world's TOP!

According to a review by Pao-Nuan Hsieh and Pao-Long Chang, published in August 2009 in the *International Journal of Production Economics*, Gilbert Laporte, one of GERAD's founding members, is one of the world's most productive researchers (and for some criteria, the first) in the area of production and operations management. We are very proud of this accomplishment by one of our members. Congratulations Gilbert!

We also heard excellent news in the renewal of the GERAD grant by the Fonds québécois de la recherche sur la nature et les technologies (FQRNT), in the "Strategic clusters" program. GERAD will receive $2.34 million during the next six years. This support by FQRNT is an endorsement of our Centre and a motivation for us to continue our quest for excellence in research and training.

This issue presents the outlines of thirteen research projects that were reported-on in first-class journals. The selection shows the diversity of tools (mathematical programming, stochastic processes, statistics, game theory, and other operations research methods) and of application areas (scheduling, financial engineering, marketing, vehicle routing, energy, and health) in research projects undertaken at GERAD.

Enjoy the newsletter,
Georges Zaccour

bulletin@gerad.ca

SUMMARY

Volume 6 • Numbers 1 & 2
December 2009

In this issue ... articles in first-class journals ...

December 9, 2008: **Marc Fredette**, Assistant Professor at the Department of Management Sciences at HEC Montréal, received the Award for teaching excellence for an assistant professor, in HEC Montréal. This award recognizes the teaching contribution by an assistant professor.

February 26, 2009: **Olivier Bahn** was appointed Pedagogical Director "Energy Asia" at HEC Montréal. He is in charge of the graduate diploma (DESS) in energy management in China as well as various training programs in energy management for managers and executives in Asia.

March 4, 2009: A team of three HEC Montréal professors, of which two members of the GERAD, **Jean François Cordeau**, Canada Research Chair in Logistics and Transportation, and **Gilbert Laporte**, Canada Research Chair in Distribution Management, as well as a CIRRELT analyst, **Serge Bisaillon**, won the 2009 ROADEF Challenge among 29 teams from 15 countries.

April 16, 2009: **Gilbert Laporte**, holder of the Canada Research Chair in Distribution Management at HEC Montréal, received the 2009 Gérard-Parizeau prize. The $30,000 award pays a tribute to a prominent person in the fields of history, economics or management.

June 1st, 2009: **Marc Fredette** was promoted Associate Professor, Department of Management Sciences, HEC Montréal.

June 1st, 2009: **Roland Malhamé** sees his mandate as the director of GERAD extended from June 1st, 2009 till May 31st, 2011.

June 1st, 2009: **François Watier** was appointed Director of the Graduate Studies Programs of the Department of Mathematics, Université du Québec à Montréal.

June 1st, 2009: **Michel Gamache** was promoted Full Professor, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal.

June 3rd, 2009: **Ramzi Ben-Abdallah**, a Ph.D student co-directed by Professors Michèle Breton and Hatem Ben-Ameur of the Department of Management Sciences, has received the Mercure award for the best doctoral thesis in 2008, entitled "Essays on the Valuation of Derivatives on Long Maturity Treasury Bonds" along with a cash prize of $3,000. His thesis was chosen from the 17 theses eligible for the award in 2008.

June 18, 2009: Major subsidy from the Canada Foundation for Innovation (CFI), under the Foundation's Leading Edge Fund for the School's Calculation and Data Mining Laboratory. The project has been handled by Full Professor **Michèle Breton**.

June 18, 2009: **Gilbert Laporte**, holder of the Canada Research Chair in Distribution Management, has been made an honorary member of the Omega Rho Honor Society, of the Institute for Operations Research and the Management Sciences (INFORMS). This distinction recognizes the importance of his research in distribution management and its applicability in industry.

October 12, 2009: **Gilbert Laporte** has received the "Robert Herman Lifetime Achievement Award in Transportation Science", of the Transportation Science & Logistics Society of INFORMS. This award is presented every two years by the Science & Logistics Society of INFORMS. Gilbert Laporte is the 8th recipient of this prize.

September 1st, 2009: **Michèle Breton** is nominated scientific director of the Institut de finance mathématique de Montréal (IFM2).

November 2nd, 2009: **Michèle Breton** is elected to the Royal Society of Canada.

PAST ACTIVITIES

December 4-5, 2008: Workshop on Dynamic Games in Economics, Italy

May 4-6, 2009: 2009 Optimization Days

May 14-15, 2009: Third Workshop on Game Theory in Marketing

June 14-17, 2009: 26th International Conference on Machine Learning (ICML 2009)

June 18-19, 2009: Multidisciplinary Symposium on Reinforcements Learning (MSRL 2009)

June 19-21, 2009: 25th Conference on Uncertainty in Artificial Intelligence (UAI 2009)

June 19-21, 2009: 22nd Annual Conference on Learning Theory (Colt 2009)

June 28-30, 2009: Second Workshop on Dynamic Games in Management Science, Valladolid, Spain

June 19-July 3, 2009: 1st Montreal Workshop on Idempotent and Tropical Mathematics

July 1-3, 2009: Seventh International ISDG Workshop, Djerba, Tunisia

August 17-21, 2009: Third Montreal Industrial Problem Solving Workshop

November 6-7, 2009: Workshop on Game Theory in Marketing Channels

2009-2010 COLLOQUIUMS AND WORKSHOPS

December 10-11, 2009: 3rd Workshop on Game Theory in Energy, Resources and Environment

May 12-14, 2010: Spring School on Supply Chain and Transportation Network Design

June 19-24, 2010: 14th International Symposium on Dynamic Games and Applications, Banff, Alberta

NEW MEMBERS

Mehmet Gumus, McGill University

Raf Jans, HEC Montréal

Fabrice Larribe, Université du Québec à Montréal

Adrian Vetta, McGill University

NEW ASSOCIATE-MEMBER

Monia Rekik, Université Laval

Ortho-MADS: A Deterministic MADS Instance with Orthogonal Directions

Mark A. Abramson, Charles Audet, John E. Dennis Jr. and Sébastien Le Digabel

It introduces the Ortho-MADS algorithm developed in the PhD thesis of S. Le Digabel under the supervision of Professor C. Audet from École Polytechnique and GERAD.

The article describes a new implementation of the Mesh Adaptive Direct Search (MADS) class of algorithms, introduced by Audet and Dennis in SIOPT (2006). MADS targets the optimization of functions typically represented by black-boxes without any usable properties. These functions can be expensive, noisy, fallible, and are often defined through computer simulations. Such problems are encountered in many fields such as engineering and finance.

The use of derivatives or their approximation is excluded for such problems, and therefore a method using only function evaluations is indicated. In the 2006 article, MADS is written as a generic family of algorithms, and a practical implementation is proposed. This implementation is called LT-MADS and is based on random triangular matrices. These matrices are used to generate the search directions of the algorithm, which, when normalized, form a dense set on the unit sphere. The demonstration of this last result requires a probabilistic argument.

Ortho-MADS is an alternative to LT-MADS. It also generates dense directions, but the analysis holds without any probabilistic argument. To do so, the method does not build the research directions randomly, but uses the quasi-random Halton sequence. Thus, the method is not random, but deterministic, and allows the reproducibility of experiments, which was impossible with LT-MADS. The use of a parameter related to the Halton sequence can vary the experimental results to the manner of a random seed. A second advantage of Ortho-MADS over LT-MADS is that the research directions are orthogonal to each other thereby maximizing some coverage measure of the search directions at each iteration.

In the paper, Ortho-MADS is shown to be a valid implementation of MADS, which allows the method to inherit all the convergence properties of MADS based on the Clarke nonsmooth calculus. Furthermore, extensive tests are performed on a set of 45 problems from either the literature or real applications. These tests show the dominance of Ortho-MADS over LT-MADS or a single execution of the method on a given problem. In the context of multiple executions by varying the random seed of LT-MADS or the Halton seed mentioned earlier for Ortho-MADS, LT-MADS retains a small advantage. However, given that the optimization of black-boxes can be very costly, the context of a single execution is the most relevant and therefore Ortho-MADS is considered dominant. This is why Ortho-MADS is now the default implementation of MADS in both our recent articles and in the NOMAD software freely available on internet (http://www.gerad.ca/nomad).

Our industry partners financing our research include the Air Force Office of Scientific Research, the Boeing Company, the Consortium for Research and Innovation in Aerospace in Québec, ExxonMobil, the Research Institute of Hydro-Québec, the Sandia National Laboratories and the Pacific Marine Environmental Laboratory. The applications of this work include wing shape optimization in aeronautics, buoys placement for tsunamis detection, placement of sensors for snow level measurement in hydrology, optimization of aircraft trajectories, spent potliner treatment process, and surgical planning in paediatric cardiology.

(*SIAM Journal on Optimization*, 20(2), 948-966, 2009)

***Mark A. Abramson**, Boeing, USA*

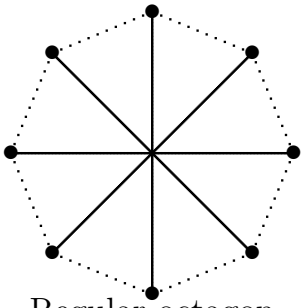
***Charles Audet**, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal and GERAD*

***John E. Dennis Jr.**, Rice University, USA*

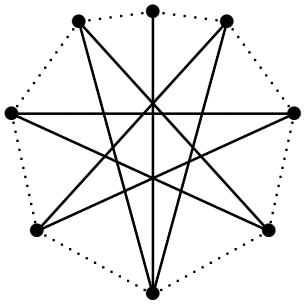
***Sébastien Le Digabel**, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal and GERAD*

The Saga of the Three Little **Octagons**

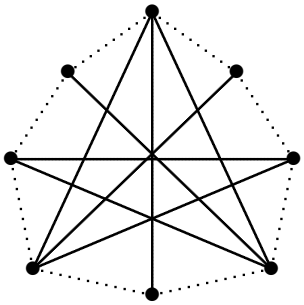
Charles Audet, Pierre Hansen
and Frédéric Messine



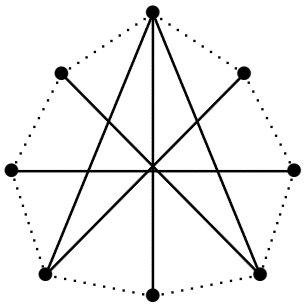
Regular octagon
Area ≈ 0.7071
Perimeter ≈ 3.0615



Maximal area octagon
Area ≈ 0.7269



Maximal perimeter octagon
Perimeter ≈ 3.1211



Maximal perimeter
equilateral octagon
Perimeter ≈ 3.0956

Pour la science is a monthly scientific reference journal. It offers in-depth articles on current scientific subjects of interest, as well as short notes on entertaining, controversial or more encyclopaedic themes. The journal is accessible to readers interested in science who wish to understand recent developments and their implications, Pour la Science is also a leading magazine for teachers, students, researchers, doctors and engineers. (Paragraph translated from the website Pour la Science: http://www.pourlascience.fr/ewb_pages/g/groupe-pour-la-science.php). It is the French version of the journal *Scientific American*.

In the paper *La saga des trois petits octogones* the authors summarize their work over the last ten years concerning the joint use of geometric reasoning and global optimization methods.

The paper examines *small polygons* with n vertices and sides, i.e., convex polygons whose longest diagonal's length equals 1. The article addresses the following three questions.

1. What is the small polygon of maximum area?
2. What is the small polygon of maximum perimeter?
3. What is the small equilateral polygon of maximum perimeter?

The optimal solutions are not always carried out by regular polygons. The small equilateral polygon of maximum area is regular, and is not studied in this paper.

This research began in 1922 with the work of Karl Reinhardt, University of Frankfurt am Main, continued in 1950 thanks to the octagon proposed by the mysterious wife of Stephen Vincze (from the University of Budapest), revived in 1975 when Ron Graham, AT & T Bell Labs, discovered the small hexagon with largest area, and finally, the research continued recently by combining geometrical methods and global optimization algorithms.

At the time the authors focused on these problems, the smallest polygons for which these questions remained open were the octagons. The article gives the optimal solutions to these three problems.

(*Pour la Science*, 380, June 2009)

***Charles Audet**, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal and GERAD*

***Pierre Hansen**, Department of Management Sciences, HEC Montréal and GERAD*

***Frédéric Messine**, École Nationale Supérieure d'Électrotechnique, d'Électronique, d'Informatique, d'Hydraulique et des Télécommunications, France*

Information Acquisition for Capacity Planning via Pricing and Advance Selling: When to Stop and Act?

Tamer Boyaci and Özalp Özer

Strategic capacity investments require significant, irreversible capital outlays and have to be taken well before revenues are realized. In an environment driven by demand uncertainty, the typical "build it and they will come strategy" forces the capacity provider to bear considerable risk in making the expensive capacity investment. In this paper, we propose an alternative strategy, namely the "let them come and build it later strategy". A manufacturer can pursue this strategy by advance selling its products and thereby inducing some customers to commit to buying prior to the start of the sales period and before the capacity is made. By doing so, the manufacturer can capture some of the market demand in advance, and can thereby moderate the overall demand uncertainty. Furthermore, the advance sales information obtained from the purchase commitments can provide the manufacturer with information about the market potential of the product and enable her to plan capacity according to more accurate demand information. On the downside, however, postponing the capacity investment to acquire advance sales information may force the manufacturer to face a tighter deadline for building capacity, and may result in higher costs. Customers can also benefit from committing early since they secure their products and are not vulnerable to potential shortages. They may also garner discounts. In the presence of such trade-offs, the critical issue for the manufacturer is to decide on how much to sell in advance, and given the advance sales information obtained, how much capacity to build. Our paper makes a first attempt to address these issues.

Our modeling framework consists of a single manufacturer who decides on the level of capacity to build for a product that faces price-sensitive uncertain demand. The manufacturer has one opportunity to invest in capacity before the sales season starts, the amount of which defines the upper bound on how much the manufacturer can produce and sell during the sales season. The manufacturer has the option acquire information by offering advance selling prior to the selling season. This advance sales information contains the cumulative commitments and possibly other information such as past prices, and has predictive value about the product's remaining demand. We capture this relationship in a rather general form, which includes various known demand learning constructs as a special case. At any point in time, the manufacturer has the option to stop advance selling and decide on the capacity level. Once this decision is taken, the remaining customers in the market are served during the regular season. We also consider the manufacturer's pricing problem. We study the case in which the manufacturer determines advance sales and sales season prices optimally, as well as the case in which the price schedule is fixed. For both scenarios, we formulate the manufacturer's decision problem as a dynamic program with an embedded optimal stopping problem. Analyzing this problem, we establish the optimality of control band policies that prescribe the optimal time to stop collecting advance sales information. Under this policy, the manufacturer monitors the prevailing advance sales information including the total number of commitments to date, and if this quantity falls within the control band, it is optimal to stop advance selling and to decide on the capacity. Otherwise, the manufacturer continues advance selling.

Our study generates managerial insights as to when advance selling and "let them come and build it later" is a profitable strategy. We show that the profit gains could be significant especially when (i) demand uncertainty is high, (ii) more customers anticipate capacity shortages in the market; (iii) building capacity is expensive, but timing is not a major concern; (iv) commitments have moderate

Please see ***Information Acquisition*** *on page 16 . . .*

Option Pricing under **GARCH** Processes by PDE Methods

Michèle Breton and Javier de Frutos

An option is a financial instrument whose value depends on the value of another underlying asset, giving the holder the right, but not the obligation, to trade the underlying asset at some pre-specified dates in the future, at a previously agreed price, until maturity. The value of an option depends essentially on the underlying asset's volatility, which affects the magnitude of possible future gains in case the option is exercised. The well-known Black and Scholes formula computes the value of an option that can only be exercised at maturity, when the volatility of the underlying asset is assumed constant over time.

However, it is well known that financial series models using constant, or even deterministic, volatility do not fit empirical observations very well. Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models, where the conditional volatility of a time series is updated at discrete times from observed realizations, were shown to be much better predictors of the evolution of financial asset prices over time. However, even in the simplest case, the valuation of options written on underlying assets following a GARCH-type process raises substantial theoretical and numerical issues.

In this paper, we propose a valuation approach based on the numerical solution of a partial differential equation describing the evolution over time of the option's value. Under the option pricing model, volatility is constant between two GARCH time steps, and jump conditions are imposed each time the volatility estimation is updated. In this case, an explicit solution by Fourier series exists between updates, and the option value can be represented by several functions of time and asset price, parametrized by volatility and by the price of the underlying asset at the last volatility update time.

Our algorithm is based on a spectral approximation of the partial differential equation describing the evolution of the option's value along with the jump conditions, and on a Fourier-Chebyshev interpolation of the function describing the option's value. The key idea is to exploit the properties of Fourier series representation of periodic solutions of partial differential equations. Thus, we use an even periodic extension of the option value, as a function of time and asset price, sufficiently smooth to allow for high precision using a relatively small number of Fourier coefficients. A spectral interpolation using Chebyshev polynomials is then used to approximate the option value as a function of volatility and of the asset price at the last update time. As a result, the option value (a function of four variables) is represented by its Fourier and Chebyshev coefficients.

Our method is very general and can be applied to any of the numerous GARCH specifications used in practice. We reach high precision in a few seconds of computing time, and exponential convergence with respect to the number of discretization points.

(*Operations Research*, to appear)

***Michèle Breton**, Department of Management Sciences, HEC Montréal and GERAD*

***Javier de Frutos**, Universidad de Valladolid, Spain and GERAD*

Scheduling Technicians and Tasks in a Telecommunications Company

Jean-François Cordeau, Gilbert Laporte, Federico Pasin and Stefan Ropke

In partnership with various public and private organizations, the French Operational Research and Decision Analysis Society (ROADEF) periodically organizes competitions (challenges) to stimulate the development of optimization tools to solve industrial problems. In the course of these competitions, which are open to all, registered teams are required to submit the method they have developed to solve the proposed problem in the form of a software program. These programs are then tested and compared on real data provided by the sponsoring organization. In July 2006, a competition was launched by ROADEF and France Télécom on the optimization of the work schedules for technicians assigned to network maintenance tasks. Overall, 31 teams registered for the competition and 11 were invited to present their work at the ROADEF annual meeting held in Grenoble in March 2007. According to the final ranking announced during this meeting, our team tied for second place.

Work schedules for technicians are usually planned day by day, each group of technicians having a supervisor responsible for deciding which technicians should be assigned to each specific task. This assignment must take into account several aspects such as the type of task to be performed, the skills of each technician, day offs, etc. A group of technicians normally comprises between 20 and 60 technicians. There exists a large array of possible tasks, each requiring different skills. To perform a task, the supervisor must dispatch a team comprising a sufficient number of technicians qualified to meet the requirements of the task. An important constraint of the problem is that teams are formed for a whole day and cannot be changed between tasks. Teams are, however, changed on a daily basis to adapt them to the tasks to be performed and to take days off into account.

The problem addressed in our study consists in assigning tasks to days of the planning horizon, scheduling tasks within each day, creating teams for each day, and assigning tasks to each team. Obviously, all these decisions are closely intertwined and it is impossible to achieve a good planning by separating the four types of decisions. We thus had to develop a method to make all types of decisions in an integrated fashion. The objective sought in this decision making is to minimize the total time needed to complete all tasks.

To address the problem globally, we have developed an Adaptive Large Neighbourhood Search (ALNS) heuristic. The central idea of ALNS is to use multiple heuristics to destroy and repair solutions. In our context, a destroy heuristic removes tasks from the schedule, while a repair heuristic reinserts these tasks differently in the destroyed solution and updates teams accordingly. The method alternates between destroying and repairing the solution. After each iteration, a new feasible solution is obtained. If this new solution improves upon the previous one, it is automatically accepted and becomes the new incumbent. Otherwise, the new solution is accepted with a probability that depends on solution quality and the amount of computing time remaining. This diversification mechanism allows escaping from local minima by introducing some randomness in the search.

The method we have developed is simple, fast and effective. It has allowed us to obtain high quality solutions on industrial size instances within reasonable computing times not exceeding 20 minutes.

(*Journal of Scheduling*, to appear)

***Jean-François Cordeau**, Department of Logistics and Operations Management, HEC Montréal and GERAD*

***Gilbert Laporte**, Department of Management Sciences, HEC Montréal and GERAD*

***Federico Pasin**, Department of Logistics and Operations Management, HEC Montréal*

***Stefan Ropke**, Technical University of Denmark, Denmark*

Complementarity of **Hydro and Wind** Power: Improving the Risk Profile of Energy Inflows

Michel Denault, Debbie Dupuis and Sébastien Couture-Cardinal

Quebec enjoys an enviable energy situation due to its hydroelectric resources. The quality of this energy comes not only from its renewable abundance (190 TWh on average annually), but also from the great temporal flexibility of reservoir hydroelectricity. Firstly, a hydroelectric plant can change its level of production in a few minutes; secondly, the reservoirs allow for vast quantities of potential energy to be stored for long periods and at low cost. No other type of power production offers these characteristics of temporal flexibility to such an extent. We also note that while the most profitable hydro sites in the province are already developed, many valuable ones still remain.

On the other hand, Quebec also has an enormous, virtually untapped, wind potential. Wind power, while (potentially) abundant, is however at the other end of the spectrum when it comes to flexibility. The generated power changes at each moment, in ways that one does not control nor easily predict, and storage is not economically feasible.

One is then faced with the following question regarding the choice of developing more hydroelectric sites or a complementary wind component: which comparative advantage can wind power have over hydroelectricity? Its comparative disadvantages are already well studied, primarily in terms of the need for hydroelectricity to complete the voids caused by wind intermittence. In fact, except ecological considerations, the principal defect of hydroelectricity comes from its input: water. More precisely, the constancy of the water inflows matter: two or three years drier than usual, the reservoirs empty and little can be done about it.

At the start, the idea of the article was thus to check the assumption that one can attenuate the risk of an energy deficit on a rather long horizon, one year for example, by a diversification of the energy inputs. Is a 'hydro+wind' production system more stable in time than a purely hydroelectric system?

To answer this question, we jointly modeled the annual water and wind inflows over the period of 1958 to 2003. We then simulated system production under various proportions of hydroelectic and wind production.

A first statistical result is that the water and wind inflows followed two long cycles of approximately twenty years during which the annual inflows were almost always above the general average, then below the average. A second result is that the cycles in question are almost identical for water and wind, i.e. a long wet and windy period, then a drier and calmer period, the tendency reversing itself towards 1983.

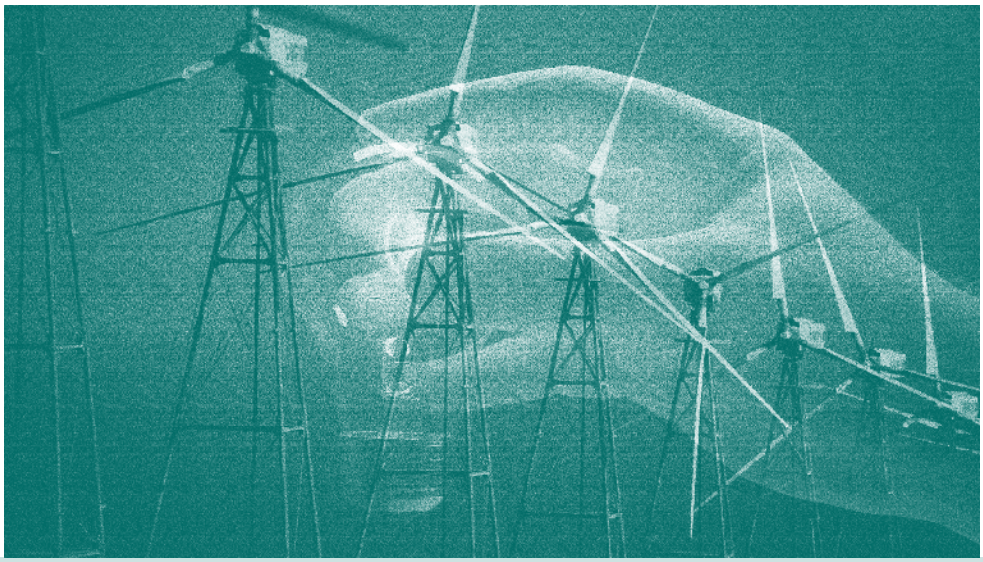
As for the question of the energy risk, the diversification of the inflows brings a positive, although small, reduction. When considering all the data (1958-2003), to include a wind proportion of 12% in the system of production decreases the risk of energy deficit slightly, with a 2% quantile of the order of 2 TWh.

(*Energy Policy*, 37, 5376-5384, 2009)

***Michel Denault**, Department of Management Sciences, HEC Montréal and GERAD*

***Debbie Dupuis**, Department of Management Sciences, HEC Montréal and GERAD*

***Sébastien Couture-Cardinal**, Risk Management, National Bank of Canada*



Branch-and-Price-and-Cut for the Split Delivery Vehicle **Routing Problem** with Time Windows

Guy Desaulniers

Vehicle routing problems are faced almost every day by companies distributing or collecting goods. These problems consist of determining least-cost vehicle routes to service a set of customers while satisfying operational constraints such as vehicle capacity and time windows restricting the time of visit at each customer. In most problem variants, a customer must be visited by a single vehicle. However, when customer demands are relatively large compared to vehicle capacity, allowing several visits to a customer can yield substantial savings. Split delivery vehicle routing deals with this relaxation.

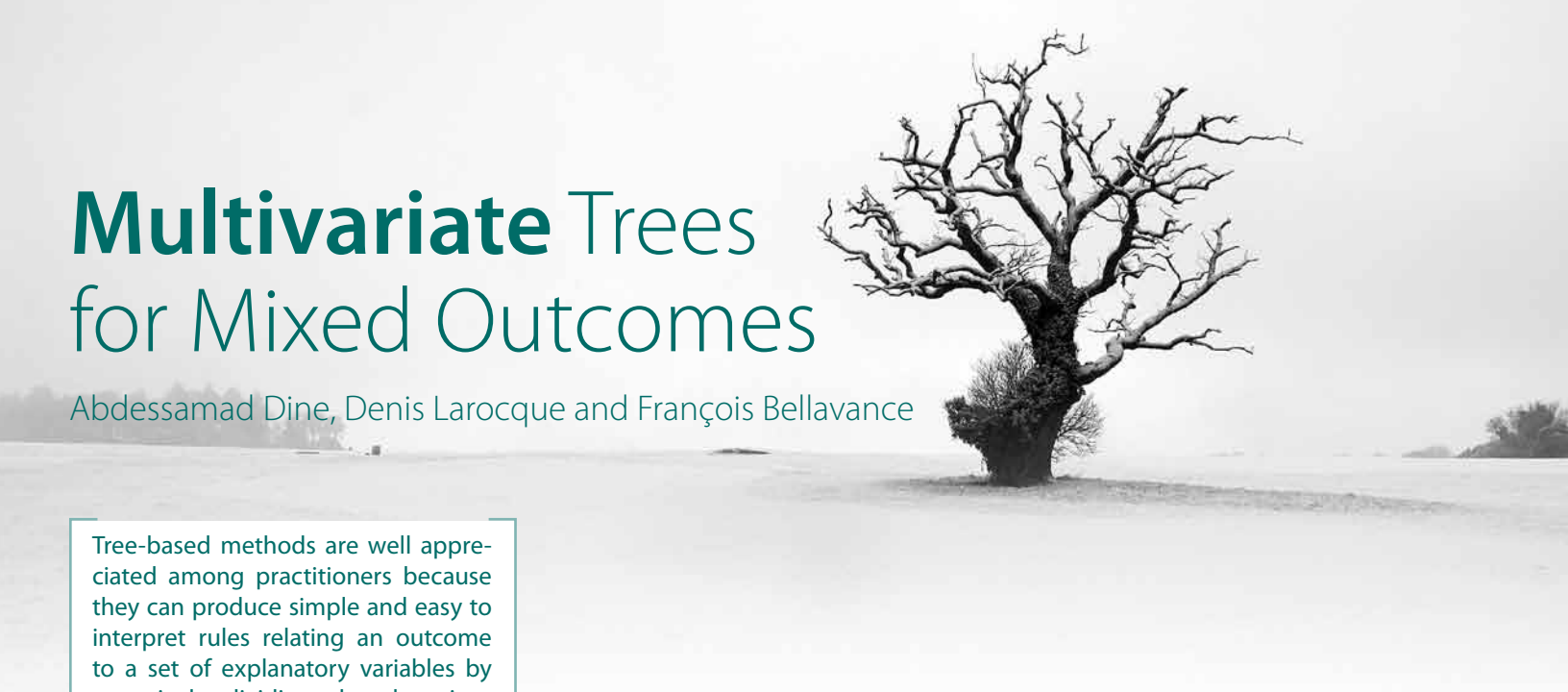
The split delivery vehicle routing problem with time windows has not been studied much in the literature: prior to this work, only two heuristics and one exact branch-and-price method have been proposed. Currently, branch-and-price is the leading methodology for solving various types of vehicle routing and crew scheduling problems with resource constraints such as time windows. It consists of a branch-and-bound method where the lower bounds are computed by column generation. A column generation method decomposes the problem into a linear master problem and one subproblem, and iterates between the solution of these two problems. To obtain low computational times, it must use an efficient algorithm for solving the subproblem. In the existing branch-and-price method, the subproblem is a resource-constrained elementary shortest path problem that determines vehicle routes. The quantity to deliver to each customer visited along those routes are decided in the master problem, using an exponential number of constraints.

In this paper, we propose a novel decomposition of the problem, yielding a different subproblem that determines routes and delivered quantities. This subproblem combines a resource-constrained elementary shortest path problem with the linear relaxation of a bounded knapsack problem. Hence, a column generated by the subproblem corresponds to a route and a delivery pattern where some customers receive a full delivery (equal to the customer's demand), at most one customer receives a partial delivery (positive, but less than its demand), and others receive a null delivery. This delivery pattern structure ensues from the solution of the linear relaxation of a bounded knapsack problem. Exploiting this structure, the author develops an ad hoc label-setting algorithm for solving such a subproblem. As clearly highlighted by the decomposition process, the integrality requirements are not imposed on the generated variables, but rather on convex combinations of these variables. These convex combinations allow routes with several partial deliveries in an integer solution. The overall branch-and-price method includes specialized branching decisions and the generation of cutting planes.

The proposed method was tested on a set of 504 benchmark instances, involving 25, 50, or 100 customers. It succeeded to solve to optimality 176 of these instances within one hour of computational times. Previously, only 27 of these instances were reported to be solved in the literature. These results clearly show the effectiveness of the new branch-and-price-and-cut algorithm.

(*Operations Research*, to appear)

***Guy Desaulniers**, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal and GERAD*



Multivariate Trees for Mixed Outcomes

Abdessamad Dine, Denis Larocque and François Bellavance

Tree-based methods are well appreciated among practitioners because they can produce simple and easy to interpret rules relating an outcome to a set of explanatory variables by recursively dividing the data into nodes that are as homogeneous as possible with respect to the response variable. Standard tree algorithms can accommodate either a continuous or a categorical outcome.

In most research projects in many areas of social, business, biological and medical sciences, it is common that multiple outcomes are observed on individual experimental units. Generalizations of tree-based methods to the case of multiple outcomes have appeared recently in the literature, but are limited to multiple outcomes that are all of the same type (i.e. all continuous, count, binary, ordinal or polytomous). However, cases where multiple outcomes of different types are observed are frequent. For example, the health status of an individual is complex and not directly observable with a single outcome measure. Instead, multiple outcome measures, such as the head diameter or circumference (continuous), the presence or absence of any minor or major malformation (binary), and the presence or absence of growth retardation (binary) are used as surrogates of the underlying health condition of infants.

It is obviously possible to grow as many univariate trees as there are outcomes. But this will generally lead to different sets of decision rules and the overall structure may become difficult to interpret. Hence, the parsimony of a single tree for the multiple mixed type outcomes is interesting from an exploratory point of view. Hence, the main motivation of this work is to develop a method to build a single tree for a mixture of continuous and categorical outcomes. The proposed tree-growing method is based on the log-likelihood function that combined the log-likelihood of the continuous and categorical response variables respectively. The method reduces to well-established standard tree-growing procedures when dealing with a single continuous or categorical outcome. To the best of our knowledge, this method is the first one that can accommodate multivariate outcomes of mixed types for classification and regression trees.

The paper presents two examples to illustrate the proposed method. The first example assesses the effect of having seizures and using antiepileptic drugs, alcohol, cigarettes, cocaine or other illicit drugs during pregnancy on the health of newborns as measured by their head diameter and the presence or absence of either a malformation or growth retardation. The final tree has four terminal nodes: mothers in the sample who had two seizures during pregnancy had newborns with the smallest average head diameter and a high proportion of them had malformation; newborns of mothers who had zero or one seizure and self-reported using cocaine or other illicit drug during pregnancy, had the highest proportion of malformation and a small average head diameter; mothers who had at most one seizure and did not report using illicit drugs but were smoking, had newborns with a slightly below average head diameter and a relatively high proportion of malformation; finally, mothers who had at most one seizure, did not report using illicit drugs nor cigarette smoking, had on average the healthiest newborns i.e. with the largest average head diameter and the lowest proportion of malformation.

The second example explores the use of health care services by seniors after a visit to a hospital emergency department (ED). Three outcomes are modeled: in the period of 30 days after the ED visit, the number of visits to a medical doctor, any return to a hospital ED, and any hospitalisation. Twenty-one explanatory variables were considered for the tree-growing, eighteen describing the characteristics of the patients and the three others the characteristics of the hospital EDs. The final tree has 31 terminal nodes. The top three levels of the tree are presented in the paper.

(*Computational Statistics and Data Analysis*, 53, 3795-3804, 2009)

***Abdessamad Dine, Denis Larocque, François Bellavance**, Department of Management Sciences, HEC Montréal and GERAD*

Mean-Variance Efficiency with Extended CIR Interest Rates

René Ferland and François Watier

Many complex dynamic systems are modeled successfully by stochastic processes (random variables evolving over time). This is the case, in particular, for stock markets. In a financial market, it is quite common for investors to face the problem of finding an optimal strategy that reaches an expected monetary objective within a given maturity date. In order to do this, they must base their decisions on a continually updated information flow without being able to predict exactly the market fluctuations.

Among these problems, the best known is most likely that of a stochastic optimization known as "mean-variance:" given an investment maturity date and an objective of obtaining a targeted terminal mean wealth, the goal is to find an investment strategy minimizing the variance (a measure of variation about the mean) of this wealth. In its original form (discrete time with a single investment period), this problem goes back to a fundamental article by H.M. Markowitz (1952), which is often considered the cornerstone of modern finance relating to portfolio management. Moreover, his work was rewarded with a Nobel Prize for economics in the 1970s.

Since then, the problem has evolved greatly, in particular by modeling markets in continuous time by means of stochastic differential equations. In a market where one can invest either in a non-risky instrument (for example, a bank account) or in risky securities (for example, stocks on the stock exchange), one can use Brownian motion as a main source of random components. Many authors have succeeded in developing optimal strategies in this way.

Considering the techniques available at the time, many researchers had to restrict themselves to cases where either the interest rate was of a deterministic nature (fluctuations foreseen in advance) or random but with a hypothesis of uniform boundedness (a ceiling). Unfortunately, these restrictions exclude the use of a certain number of stochastic interest rate models (such as those of Vasicek, Hull-White,Cox-Inngersoll-Ross(CIR) et al.) that are of prime importance for practitioners.

With the particular aim of overcoming this obstacle, some authors have integrated into their models the possibility of buying or selling term coupons (zero-coupons), a financial instrument that guarantees its holder at the moment of purchase to yield a predetermined fixed amount at a given future maturity date.

An initial result along these lines can be found in an article by Besnainou and Portrait (1998) where the privileged interest rate is the model of Vasicek. However, this rate model can generate negative interest rates which are not desirable. Several years later Deelstra et al. (2000) considered the classic CIR model that generates positive rates. Although their problem is basically that of the maximization of expected utility, their methodology could conceivably be adapted for solving the mean-variance problem.

Now, the classic CIR interest rate is a model with only three constant parameter, and articles such as that of Maghsoodi (2000) on the study of American Treasury bills over a period of 25 years, instead suggests using a generalized CIR model (that is, a model in which the three parameters are replaced by functions evolving over time) in order to reproduce better the real fluctuations of interest rates in financial markets.

It is in this spirit that we have pursued our research. In our recent article, we borrowed notions from linear quadratic stochastic theory (stochastic LQ theory) in optimal control and have succeeded in obtaining a strategy in explicit form, by reducing the stochastic optimization problem to the simple solution of two ordinary differential equations of the Riccati type, the latter being solved easily by numerical methods.

We hope that the results obtained up to now will allow us to develop more successful new tools for decision analysis in the field of portfolio management.

(*Applied Stochastic Models in Business and Industry*, to appear)

***René Ferland**, Department of Mathematics, Université du Québec à Montréal*

***Francois Watier**, Department of Mathematics, Université du Québec à Montréal and GERAD*

A Solution Method for a **Car Fleet** Management Problem with Maintenance Constraints

Alain Hertz, David Schindl and Nicolas Zufferey

The problem retained for the ROADEF'99 international challenge was an inventory management problem for a car rental company. It consists in managing a given fleet of cars in order to satisfy requests from customers asking for some type of cars for a given time period. More precisely, the car rental company receives requests from customers asking for cars of specific types for a given time horizon. Basically a request is characterized by its start and end times, by a required car type, and by the number of required cars. All requests are supposed to be known for a given time horizon (for example, a few months or a year). The satisfaction of all customer requests is mandatory.

If there are not enough cars available in stock, the company can react in three different ways:

- it can offer an upgrade to the customer, which means that some desired cars are replaced by cars of a "better" resource type (e.g., larger, more comfortable and more expensive cars). The customer of course receives a bill according to his request, and the company has to pay for the upgrade cost;
- the company can decide to subcontract some requests to other providers, which is generally a very expensive alternative;
- the third possibility is to purchase new cars, which then belong to the stock of the company for the rest of the time horizon.

Each one of the above alternatives has a known cost, and the problem is to satisfy all requests at minimum cost. The problem is further complicated with constraints that impose to perform a maintenance on each car on a regular basis. More precisely, a maximum time of use without maintenance is given for each car type, and each maintenance is characterized by a duration and a number of workers needed to perform it. The company has a fixed number of maintenance workers which means that the maintenances should be scheduled so that the capacity of the workshop is never exceeded.

The literature that considers the car rental business mainly deals with revenue management and pool control systems. Fink and Reiners have recently proposed a model and a solution method for a car rental logistics problem that involves short-term decisions about the transportation and deployment of cars with regard to optimizing fleet utilization while maintaining a high service level. We complement the above developments by proposing optimization techniques for the assignment of cars to customers, taking into account maintenance constraints.

Thirteen competitors took part to the ROADEF'99 challenge, and each one has developed a heuristic algorithm to solve the problem. We have designed a new heuristic that combines graph optimization procedures (for vertex coloring, and maximum weight stable set problems) with the solution of integer programs and the use of two tabu search algorithms.

Experiments on real-world problems clearly show that our solution technique outperforms all existing algorithms.

(*Journal of Heuristics*, 15, 425-450, 2009)

***Alain Hertz**, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal and GERAD*

***David Schindl**, Haute École de Gestion de Genève, Switzerland*

***Nicolas Zufferey**, Université de Genève, Switzerland and GERAD*

Locating a **Metro Line** in a Historical City Centre, Application to Sevilla

Gilbert Laporte, Juan Antonio Mesa, Francisco A. Ortega and Miguel Ángel Pozo

When constructing a metro alignment under a historical city centre, it is important to stay clear of historical and patrimonial buildings. One reason is to avoid digging too close to these buildings and thus incur the risk of weakening their foundations, namely because landslides often occur during the construction. It is also preferable to construct the metro alignments far from fragile buildings to reduce the effects of vibrations. The inclusion of this consideration in the design forces a circumvoluting pattern and increases construction costs. A question of interest is how to generate such non-linear alignments without deviating too much from the most direct trajectory.

This question was recently examined by Gilbert Laporte, together with Juan Antonio Mesa, Francisco Ortega and Gema Luis y Miguel Angel Pozo. The authors have studied the location of Line 2 in Sevilla, between the Plaza de Armas bus station (point A) and the Santa Justa railway station (point B). This portion of the line is entirely located under the historical centre of Sevilla and the presence of very narrow streets prevents excavation. The problem is therefore to design an alignment between A and B while remaining reasonably close to the stortest path and yet staying outside a given security radius of 80 m around each of 75 classified buildings.

The methodology employed to solve this problem is rather simple. It has been demonstrated that if a Voronoi diagram is constructed around the buildings, then any alignment lying as far as possible from any of the buildings will follow some of the edges of the diagram. In a preprocessing phase, one can first remove any edge of the diagram lying within 80 m of a building, A shortest path between points A and B is then computed using the remaining edges. The edge of that path closest to a building is removed and the process is reiterated until no feasible path exists. This process provides the decision maker with a set of solutions having different lengths and different proximities to the historical buildings. It can be computed within a fraction of a second.

The method was successfully applied to a data set provided by the city of Sevilla. In July 2008, the Spanish newspaper ABC devoted its entire page 2 to this problem and its solution.

(*Journal of the Operational Research Society*, 60, 1462-1466, 2009)

***Gilbert Laporte**, Department of Management Sciences, HEC Montréal and GERAD*

***Juan Antonio Mesa**, Departamento de Matemática Aplicada II, Escuela Técnica Superior de Ingenieros, Universidad de Sevilla, Spain*

***Francisco A. Ortega**, **Miguel Ángel Pozo**, Departamento de Matemática Aplicada I, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Spain*

Durable Products with Multiple **Used Goods** Markets: Product Upgrade and Retail Pricing Implications

Saibal Ray, Shuya Yin, Haresh Gurnani and Animesh Animesh

The authors investigate what effects (if any) the recent popularity of electronic peer-to-peer (P2P) markets have on the product upgrade strategy of manufacturers and the pricing strategy of retailers. In the process they answer a question which is of interest to many academicians – why are there so frequent releases of new editions of college textbooks and why are the prices of college textbooks rising so fast?

Electronic P2P markets where consumers buy/sell used products among themselves (e.g., e-Bay, Amazon.com) are rapidly growing in popularity. This phenomenon is particularly relevant for durable products like college textbooks and video games, which have retailer-owned used goods markets operating for quite some time (e.g., campus bookstores for textbooks, retailers like GameStop for video games). Interestingly, the retail and P2P used goods markets referred to above are quite different in terms of how they operate. The retailer explicitly decides on the price for his used goods by adding a proper margin to the buyback price. In contrast, the P2P market is almost frictionless, where the price is determined primarily by the amount of used goods available for sale there. Customers' valuations for used products from the two markets are also usually different. The authors focus on understanding the effects that successive addition (to the primary market for unused products) of the two used goods markets – first retail and then P2P – on product upgrade frequency and temporal retail pricing.

Durable products such as college textbooks and video games have recently generated considerable interest due to rising retail prices and frequent releases of new versions. The average retail price for an unused video game has increased 50% in 6 years – from $40 in 2002 to $60 in 2008. As for unused college textbooks, prices have risen at twice the rate of inflation over 1987-2004 – 6% versus 3% per year (the textbook prices have nearly tripled during that time), while the frequency of new edition releases has also increased from every 4-5 years to every 3-4 years. A common belief puts the blame for the above events on retail buybacks (i.e., retail used goods market). The rationale is that manufacturers frequently launch upgraded versions in order to reduce the value of used products bought back by the retailer. The costs associated with developing new versions, in turn, result in price increases.

In order to shed light on the role played by the rise of multiple used goods markets, the authors address the following issues in their paper.

- How does a retail-operated used goods market, as the first source of used goods, affect the manufacturer's product upgrade strategy and increase in retail prices for unused products (over time)?
- How does the further addition of a second used goods channel in the form of P2P markets affect the above product upgrade and retail pricing decisions (and also channel profits)?

The authors analyze and compare three scenarios – no used goods market, only retail used goods market and both retail and P2P used goods markets – to answer the above questions (the primary market selling unused goods is present in all three scenarios).

The most important finding of the paper is that the effects of the second used goods market (P2P) on the channel deci-

*Please see **Durable Products** on page 16 …*

Computational Aspects of Multimarket **Price Wars**

Nithum Thain and Adrian Vetta

Price wars and predatory pricing are tactics applied by firms to increase market share, force competitors out of a market (competition reduction), or intimidate potential competitors from entering a market (entry deterrence). Given the possible rewards for firms engaging in predatory behaviour, it is not surprising that it has been a recurrent theme over time. For example, the late 19th century saw cartels engaging in predation in a plethora of industries. Prominent cases include the use of "fighting ships" by the British Shipping Conferences to control trade routes, and the setting up of phony independents by the American Tobacco Company to undercut smaller competitors.

Predatory practices are not specific to cartels but, as these examples illustrate, they were often associated with them. In fact, it was in reaction to perceived abuses by cartels that antitrust laws (or competition laws) were enacted throughout the world to prohibit predatory practices. The most important example of such legislation was the Sherman Act of 1890. This act was applied in 1911 to break-up perhaps the most infamous of the cartels: Standard Oil under the leadership of John D. Rockefeller. More recently, this was the legislation used to break-up American Telephone and Telegraph (AT&T) in 1982.

Consequently, it is not possible to study predation without considering both the economic and the legal aspects. Indeed the two are intertwined; current law (in the United States) is based on early economic work of McGee (1958) suggesting that predatory pricing was not rational. As a result, the US Supreme Court now considers predatory pricing to be generally implausible and applies the following strict definition to test for predatory practices: (i) the predator is pricing below its short-run costs, and (ii) the predator has a strong chance or recouping the losses incurred during the price-war. The established way for the Court to test for the first requirement is the Areeda-Turner Rule (1975) which established marginal cost (or, as an approximate surrogate, average variable cost) as the primary criteria for predatory pricing.

Evidently, given the economic magnitude of this issue and the social and political importance of many of the firms involved, predatory practices have been studied intensively from both an economic and legal perspective. The goal of our paper is to consider an aspect that is less well understood: the complexity of (legal) decision making for potential predators.

First we present multi-market extensions of the classical oligopolistic single-market models of Bertrand, Cournot and Stackelberg. These multimarket models allow us to examine a broader and more realistic set of interactions between firms. We incorporate the necessary legal elements in these models by allowing only strategies that satisfy the Areeda-Turner Rule; the second legal requirement essentially states that the "short-run loss is an investment in prospective (monopoly) profits" and this is implicit in our models.

We then formulate a problem that generalises the entry-deterrence and competition-reduction scenarios. Specifically, we consider the budget required by a firm in order to successfully launch a price war. That is, how large a budget is required by the firm so that it has a legal strategy for which the short-term losses incurred in a price war are outweighed by the resultant future profits. We dub this the War Chest Minimization Problem and study its computational complexity. On the negative side we show that, even with complete information, it is hard to obtain any multiplicative approximation guarantee for this problem. Moreover, these hardness results hold even in the simple case of linear demand and cost functions for the markets. On the other hand, we give algorithms with arbitrarily small additive approximation guarantees for the Bertrand and Stackelberg multimarket models with linear demand and cost functions. Furthermore, in the absence of fixed costs, this problem is solvable in polynomial time in all our models.

(To appear in the 5th Workshop on Internet and Network Economics (WINE), Rome, December 2009)

***Nithum Thain**, Department of Mathematics and Statistics, McGill University*

***Adrian Vetta**, Department of mathematics and Statistics and School of Computer Science, McGill University and GERAD*

… **Durable Products** from page 14

sions of interest (product upgrade and retail prices) are almost opposite to those of the first one (retail). When the retailer initiates the first used goods market by offering buybacks, such an action actually reduces the incentive for the manufacturer to frequently upgrade, and also reduces the extent of increase in retail prices for unused products over time. On the other hand, recent emergence of P2P markets as the second source for used goods indeed encourages the manufacturer to frequently introduce upgraded versions, and also (usually) amplifies the temporal increase in retail prices for unused products. The above contrasting effects are quite robust; they hold true irrespective of whether the end customers are myopic or forward-looking. Moreover, data from college textbook industry supports our finding about the effect of the introduction of the P2P market on product upgrades. To summarize, the authors show that frequent product upgrades and rising retail prices for certain durable products, as indicated in government/business reports, are due to the interaction between the two used goods markets, rather than due to retail used goods market only.

(*Marketing Science*, to appear)

Saibal Ray, *Desautels Faculty of Management, McGill University and GERAD*

Shuya Yin*, University of California, Irvine, USA*

Haresh Gurnani*, School of Business, University of Miami, USA*

Animesh Animesh*, Desautels Faculty of Management, McGill University*

… **Information Acquisition** from page 5

predictive value about market potential; and (v) customer price sensitivity is relatively low. Consequently, this practice is of most value to industries such as high technology, apparel, and pharmaceutical. Finally, extending our framework to a setting where the manufacturer sells the installed capacity by dynamically adjusting prices in the selling season, we bridge the capacity and revenue management literatures. Our results indicate that dynamic pricing of installed capacity improves profits but only to a limited extent. Hence, dynamic pricing during the selling season is only a partial substitute for dynamic pricing during advance selling periods.

(*Operations Research*, to appear)

Tamer Boyaci*, Desautels Faculty of Management, McGill University and GERAD*

Özalp Özer*, School of Management, University of Texas at Dallas, USA*

GERAD Newletter
Published twice a year by GERAD

Editor
Georges Zaccour
georges.zaccour@gerad.ca

GERAD
HEC Montréal
3000, chemin de la Côte-Sainte-Catherine
Montréal (Québec) Canada H3T 2A7
Telephone: 514 340-6053

Web site
www.gerad.ca
bulletin@gerad.ca

Translation
Communications Marie-Carole Daigle enr.
Benjamin T. Smith

Coordinator
Marie Perreault

Edition Coordinator
Francine Benoît

Graphic Design
HEC Montréal

Legal deposit: 4th quarter 2009
Bibliothèque nationale du Québec