

# **ICDRiA**

INTERNATIONAL CENTER FOR  
DECISION AND RISK ANALYSIS

## **Annual Meeting**

**18 November 2011**



**Naveen Jindal**  
School of Management

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Naveen Jindal School of Management  
Alain Bensoussan  
Ashbel Smith Chair Professor  
Director

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**ICDRiA Advisory Board Meeting**  
*Held at UTDallas Executive Education Center, Room SOM 1.516*

**Agenda**

*November 18<sup>th</sup> 2011*

**11:00 AM**      *Message from the ICDRiA Chair*

- **Bill Krenik, Chief Technologist, Standard Linear and Logic Products, Texas Instruments**

**11:10 AM**      *ICDRiA Activity Report*

- **Sumit Sarkar, Academic Director, ICDRiA**
- **Srinivasan Raghunathan, Professor, School of Management**
- **Alain Bensoussan, Director, ICDRiA**

**11:40 AM**      *Presentation of Texas Institute*

- **Jonathan Shapiro, CEO, Texas Institute**

**12:00 PM**      *Presentation of Cyber Security Research*

- **Celine Hoe, Assistant Professor, Department of Economics and Finance, Texas A&M University - Commerce**

**12:20 PM**      *General Discussion*

**12:30 PM**      *Lunch*



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## **ICDRiA Advisory Board Members**

### **Industry Members**

**Chair: Bill Krenik**, Chief Technologist, Standard Linear and Logic Products, *Texas Instruments*

**John Carrier**, President, Essilor North America

**Jean-Marc Chemla**, Financial Advisor, Ameriprise Financial

**Monty Humble**, Managing Director, Texas Institute for Sustainable Energy

**David Kohl**, Senior Vice President, Roach Howard Smith & Barton

**Tahar Mjigal**, Representative, Global Association of Risk Professionals (GARP)

**Laslo Olah**, President/CEO, TxIS

**Daniel Parry**, Chief Credit Officer, Exeter Finance Corp.

**Arun Ratnam**, Representative, Global Association of Risk Professionals (GARP)

**Peter Reid**, Chief Privacy Officer, HP

**Ray Russo**, Civil Works Program Manager, USACE

**Jonathan Shapiro**, CEO, Texas Institute for Sustainable Energy

**David Shaw**, President, Global Uni-Docs Corporation

**Yoram Soloman**, Vice President, Corporate Strategy & Business Development, Interphase Corporation

**Greg Turi**, Forecast Analyst, Rent-A-Center

**Jean Paul Vignal**, Partner, JP2Consultants

**J. Chris White**, President, ViaSim Solutions and ICDRiA Director of Development

### **UTD Affiliates**

**Hobson Wildenthal**, Provost

**Bruce Gnade**, Vice President for Research

**Hasan Pirkul**, Dean, School of Management

**Metin Çakanyildirim**, Operations Management

**Ganesh Janakiraman**, Operations Management

**Murat Kantarcioglu**, Computer Science

**Robert Kieschnick**, Finance and Managerial Economics

**Vijay Mookerjee**, Information Systems

**Radha Mookerjee**, Informations Systems

**Alp Muharremoglu**, Operations Management

**Ozer Ozalp**, Operations Management

**Suresh Radhakrishnan**, Accounting and Information Management; Director of Research, Institute for Excellence in Corporate Governance

**Srinivasan Raghunathan**, Information Systems

**Divakar Rajamani**, Managing Director of the Center for Intelligent Supply Networks

**Sumit Sarkar**, Information Systems

**Suresh Sethi**, Director of the Center for Intelligent Supply Networks

**Kathryn Stecke**, Operations Management

**Bhavani Thuraisingham**, Director of Cyber Security Research Center

**Janos Turi**, Department of Mathematics

**Mathukumalli Vidyasagar**, Mechanical Engineering



## ICDRiA Activity Report November 18, 2011

### **1. Introduction**

The International Center for Decision and Risk Analysis was created in September of 2004 as a Research Center of the School of Management. The objective of the center is to develop education and research programs in the field of Risk Analysis and Decision Making. We report in this document the accomplishments during the period 2011.

It is important to mention that our School of Management has been extremely successful this year in terms of recruitment and rankings. The most spectacular achievement is in obtaining donations from Alumni. As a consequence, the school has now a name—the Naveen Jindal School of Management. As a sign that globalization and internationalization have now a major impact on the activities of universities, it is important to notice that Naveen Jindal is a successful businessman in India. We fully believe in this trend and we are confident that our center will benefit from it.

At our modest level, we have obtained two grants from France, and two grants in Hong Kong for the Hong Kong branch. These international successes emphasize also that we have not been successful in the U.S. We have difficulties identifying opportunities either from government agencies or from industry. One reason is that, in spite of the growing attention attached to Risk Management, there is no natural funding channel for this activity.

### **2. Hong Kong and Korea Branches**

We recall that a tri-lateral agreement has been signed between ICDRiA, ICMS (the International Center for Maritime Studies) in Hong Kong PolyU and the WCUP-GDFE (World Class University Project and Graduate Department of Financial Engineering) in Ajou University. This agreement has been endorsed by the three Deans to whom these centers report.

We have preferred a light structure to avoid administrative hurdles. Unlike the flexible approach which is adopted at UTD, with a substantial autonomy given to our school, opening an ICDRiA branch at PolyU or Ajou could be considered as creating a new research center, which requires a heavy administrative process. The drawback is that we may be dependent of change of leadership. The Director of ICMS has left PolyU and the Dean has taken a new responsibility. Presently, these positions are vacant. That situation creates some uncertainties. Nevertheless, since the start in 2009, the activity has moved forward.

We operate in a decentralized way. In particular, there is no exchange of funds and no consolidation of financial accounts, since there is no new legal entity. In PolyU, the University has put some seed money and ICMS has also provided some support. Ajou University in Korea has won a national competition in the domain of Financial Engineering under the World Class University program. The funding comes under this program. However, this funding is only for 4 years. We may be dependent on a renewal.

Some exchange has already taken place. Two Korean students have spent a few months in Hong Kong with Korean support. Two Faculty and one Research Assistant working on a project hosted in UTD have also spent time in Hong Kong.

An interesting outcome took place in Hong Kong. A contact with the French Bank ODDO starting operations in Hong Kong has resulted in the recruitment of a PhD student jointly supervised by A. Bensoussan and John Liu. This provides us with an opportunity of research in the field of market makers activity. This is an important and innovative domain, with concrete applications. We will approach the domain with a team involving a post-doc from ICDRiA in Dallas and one professor of mathematical finance who has left PolyU and is presently in Chinese University of Hong Kong. The topic is of interest in Korea and the bank is quite interested in the Korean market. While we believe we have the elements of a fruitful integrated research activity, the extreme volatility of markets has caused a delay of support expected from the bank (even though volatility should encourage increased research activity.) Additional common activities can be reported in the following domains

- Real Options and uncertainties in investment decisions
- Mutual Insurance
- Alternative Energies

Activities in Real Options and uncertainties in investment decisions correspond to a joint interest at UTD and Ajou in coherence with the general program in Financial Engineering that is being developed in Korea. In UTD, a former post-doc who has now taken an academic position at Texas A&M and a new post-doc are involved. In Ajou, one Professor is also working in this area.

Mutual Insurance corresponds to a specific aspect of Hong Kong, where Maritime transport is an important activity. In maritime transport, the insurance of risks is organized in a mutual way, unlike other transport industries. This activity was initiated by our partner ICMS. Unfortunately, the departure of the ICMS Director, who had initiated contacts with the local insurance players, is creating a standstill. Independently, the Ajou scientists are working in the issue of incentives in insurance and have become naturally interested in incentives in mutual insurance. Some research is progressing in this area.

Finally, alternative energies are expanding very fast everywhere. The unfortunate Fukushima accident has certainly increased this trend. Very similar questions arise in the US as well as in China. It makes particular sense to coordinate the researches in this domain. Here again, our preliminary contacts in Hong Kong with China Power Limited thanks to ICMS had started quite well but are now in a waiting stage. Nevertheless, although we have not obtained a financial support, we have obtained useful data. These data complement those obtained from Electricité de France.

Another important initiative had been planned at the beginning of the cooperation. It concerned the organization of a conference, which took place in Hong Kong on December 15-17, 2010. The title of the conference (“What can the Academic Community learn from the global crisis?”) indicates that the objective is to encourage scientists to look at the global crisis as an opportunity as well as a necessity for evolution of models, concepts and transfer actions. This hopefully will lead to new research directions and educational activities. New York University, College de France, INRIA and Shandong University have joined PolyU, UTD and Ajou to form the group of sponsoring institutions.

The publisher, IOS Press, is also supporting this initiative. Special issues of the journal Risk and Decision Analysis will be devoted to articles coming out of the conference. The symposium has been quite successful and several issues of the journal Risk and Decision Analysis are already decided.

### **3. New Funding**

*Modeling Wind Uncertainties*

Electricité de France (EDF)

Alain Bensoussan (PI)

\$192,052, February 1, 2011- November 30, 2013

*Seismic Risk and Elastic-Plastic Oscillators Modeling,*

French Atomic Energy Agency (CEA)

Alain Bensoussan (PI)

\$225,000, July 1, 2011 – December 31, 2013

*TC: Large: Collaborative Research: Privacy-Enhanced Secure Data Provenance*

National Science Foundation

Alain Bensoussan (Co-PI)

1 week per year, August 8, 2011-July 31, 2016

*A framework for Managing Assured Information Life Cycle*

United States Air Force

Alain Bensoussan (Co-PI)

Two weeks per summer, To be renewed by September 3, 2013

### **Grants obtained in HONG KONG**

*Stochastic Differential Games and Partial Differential Systems in Financial Markets*

Germany-Hong Kong Research Program G-HK 036/039

Alain Bensoussan (PI)

HK support: HK\$ 57,400, January 1<sup>st</sup> 2010- December 31<sup>st</sup> 2011

*Advanced Problems in Inventory Theory*

RGC General Research Fund B-Q 26Z

Alain Bensoussan (PI)

HK\$ 1,052,000, January 1<sup>st</sup> 2012- (3 years)

### **4. Education Program**

Risk and Decision Analysis is now included in the education programs of the School of Management. The course is taught in the fall and is also part of the new program, Systems Engineering and Management, which is a joint venture of the School of Engineering and the School of Management. The class is given by Professor Mathukumalli Vidyasagar from the School of Engineering. Currently, this program is an executive education program. The course will become a regular program next year offered by the two schools, with M. Vidyasagar and A. Bensoussan involved in the teaching.

The course “Introductory Mathematical Finance” has been offered as a part of the Master in Finance in fall 2008, 2009, 2010, and 2011. The class attracts motivated students and is attended by doctoral level students as well. Note that this is included in the Finance area of the school, whereas Risk and Decision Analysis is included in the Operations Management area. We believe that the education programs of our center should be part of various programs. Administrative issues have however to be resolved to implement this desirable feeling.

## **5. Research program**

The activities of the center are presented in 5 domains: Risks and Uncertainties in Information Systems; Risks in Supply Chain Management; Risks in Financial and Economic Systems; Risks and Uncertainties in alternative energies; and Risks in Technical Systems.

### **5.1. Risks and Uncertainties in Information Systems**

The center benefits from the activity of a group of faculty focused on security issues in information systems, a major strength of the School of Management. The center cooperates also with the Cyber-security Center of the School of Engineering, headed by Professor Bhavani Thuraisingham. Through this center, we have been associated to a MURI project, *Assured Information Systems sharing* supported by Air Force, Alain Bensoussan is also co-PI in a grant from ONR, of which Professor Murat Kantarcioglu is P.I. Under this grant, we are sub-contractors of Purdue University. The topic is “A Systematic Defense Framework for Combating Botnets.” There is also a new project on Privacy-Enhanced Secure Data supported by NSF.

Concerning the Assured Information Systems project, we have proposed a model of access to information based on a scoring procedure which has analogies with that of a credit score. There are some common issues in both situations; one of which is the idea of building trust. Based on a good or bad score (using the score as an indicator of trust) the access to information (as the access to credit) is more or less difficult.

In the botnet project, the interesting aspect is that there is a market of malignant actions. An entity interested in being harmful to another entity buys the services of a botnet herder. A botnet herder has contaminated a network of computer systems without the owner’s knowledge. He can drive these systems to perform damages on targeted systems. The problem that we have treated is the calibration of the defense effort.

One can define a criterion for the botnet herder. This criterion is itself the result of equilibrium on the market. There is a price for the malignant actions and the herder optimizes an objective based on his profit and costs (including risks). The defense can then formulate a game based on its’ own criterion and that of the botnet herder. We have considered and solved completely a dynamic game based on these considerations.

With Professors Vijay and Radha Mookerjee from the School of Management Information Systems area, we have considered the defense against hackers. We use a cost benefit point of view. There is an optimal dynamic policy to be put in place optimizing a payoff combining expenses to improve security with benefits in lowering the damages caused by intrusions. The methodology is Control Theory. The state of the system is an indicator of resistance to intrusion. Without active defense this indicator will deteriorate according to some deterministic or stochastic law (there may be shocks).

### **5.2. Risks in Supply Chain Management**

In the “supply chain “area, the center relies mainly on the expertise of the Operations Management department. Risk arises from uncertainties at all stages of the supply chain. In particular, there are uncertainties on key variables needed to make decisions. For instance, one does not know the inventory and one must decide on the level of replenishment. Uncertainties on inventories have been at the core of our research since 2005, when we were awarded an NSF grant to support the research in this topic over a period of three years.



This grant supported four post-doc and doctoral students. We developed a general methodology which provides the optimal policy for managing inventories in the context of uncertainties. This is an original result that was not known before. We have shown numerically that this optimal policy provides a real improvement in lowering cost compared to a policy based on the best estimate of the inventory. We have also introduced efficient and easy-to-implement approximate policies based on the mean and the variance of the inventory. This research was also funded by a two-year grant awarded by the ARP-ATP program of the state of Texas.

We have been addressing recently a new source of uncertainty, called shrinkage, which may imply serious uncertainties on the inventory. The Inventory Manager observes the level of sales. Our general methodology applies.

We now would like to explore other sources of uncertainties around demand in addition to the inventory. Demand is of course an essential source of risk for companies and also provides a wide diversity of modeling possibilities. We have had successful cooperation in this area with Blueline-Rediform using statistical methods to deal with seasonality factors. As a major outcome, the student supported on this grant has been hired by the company. His work is at the origin of a new approach to forecast the demand that is now operational.

Inventory Management in the context of global supply chain is the source of numerous research problems. In fact, it is more and more connected to the definition of contracts with suppliers. Big issues concern the setting of incentives, the issue of moral hazard, the sharing of risks and the lack of information.

### **5.3. Risks in Financial and Economic Systems**

In the third direction, we have considered several questions. Financial Engineering is a particularly challenging domain, and the present crisis will transform the needs. We expect many opportunities in the mid- and long-term. More research is needed that would make stronger connections between financial decisions and risk management and between the financial world and the 'real world'. This objective is at the core of the future activities in common between the three universities as partners of ICDRiA.

In the context of coupling the financial world to the real world, we are particularly active in the area of "Real options," which aims at adapting techniques from financial engineering in project risk management. We have seen in particular that the pharmaceutical industry and the aeronautical industry are making use of these methods for R&D projects. We want to apply this theory to investments in energy and water resources problems.

Thanks to support from the University of Texas at Dallas, we have financed a post-doc to study desalination projects, applying concepts and methods from real options theory. We are pursuing this direction in coupling desalination and wind energy, which is an attractive combination, that we see occurring in many countries.

Unfortunately, we cannot move fast in the direction of water resources management, since there has been no appropriation of the authorized funds included in the Water Resource Development legislation to support ICDRiA. The Institute of Water Resources (IWR) has clearly indicated that they could not support any specific study without additional funding. This direction is now stopped, in expectation of opportunities.

On the more theoretical side, we have been working on problems of real options when there is competition. This is an extremely interesting but challenging problem. In real options, the number of competitors is generally limited whereas in financial options the multiplicity of players allows to assume

that a single player cannot alone modify significantly the market (this is of course not always true). Therefore, integrating competition in the model is important.

We have obtained significant results, with Celine Hoe, who now holds a position at Texas A&M. With a new post-doc, we are exploring the joint problem of real options and building capital. These questions have been considered separately in the literature. They are obviously linked. We believe that we can obtain significant results in this area.

Also, in Ajou University we have been considering interesting questions related to credit risk. We solved a problem of defining the relation between a loan and its reimbursement taking into account the possibility of default.

We also work on mean-field games. This has been initiated thanks to a grant obtained under the Hong Kong-Germany cooperative agreement. We have been able to work with an excellent team from the University of Bonn.

#### **5.4. Risks and Uncertainties in Alternative Energies**

Fortunately, our preliminary work on wind resource forecasting raised interest with Electricité de France (EDF), which has accepted to support research in that direction. A grant has been given this year.

There are many forecasting situations in this context. In particular, one must differentiate the investment phase from the operational phase. In the investment phase, the situation is to decide whether or not to install a wind farm in a specific region. This is typically a situation where the methodology of real options applies. However, we are not at this phase yet. Besides, it will involve confidential information, which is not accessible. We are at the forecasting phase. There are government and industry data that can easily be made anonymous so that confidentiality of data is not a real problem. We have obtained data from EDF and CPL (China Power Limited) in Hong Kong, so we are in a comfortable situation to progress.

The problem at the investment phase is to forecast accurately the annual production. It is important not only to forecast its mean but also quantities to assess the risk. We have developed a methodology for that purpose which has been well received by EDF. We have shown that a substantial amount of risk is presently overlooked in the literature and by practitioners.

At the operational level the problem is to make an accurate short-term forecast. Indeed, wind energy is most commonly coupled with another energy source, and it is important to assess how much is needed. In addition, the potential surplus of wind energy is a problem since a storage facility has to be available. We are not yet working on this problem except for promising discussions with Mario Rotea, Professor and Program Head of Mechanical Engineering at UTD.

#### **5.5. Risks on Technical Systems**

In the fifth domain, we work on technical risk management. This research was initiated by a contract with the French Atomic Energy Agency (CEA) to study the effect of vibrations on mechanical structures. This potentially leads to assessing the risk of collapse of buildings subject to seismic vibrations. We have developed new methods and new mathematical tools which were sufficiently promising to justify a proposal to NSF which was awarded in July 2007. The CEA has also increased its support to our group. We have partly supported two PhD students. One has obtained his PhD in the Mathematics department. The other will get his PhD in 2011 from the University Pierre et Marie Curie. This research is done in cooperation with Professor Janos Turi from the Mathematics Department. In relation with the NSF contract, we have obtained an international supplement to cooperate with the Hungarian Academy of

Sciences. The NSF grant will end in 2011. Although CEA has extended its support, we have failed to obtain an extension from NSF. This is very unfortunate, since the research has progressed greatly.

## **6. Present Activities**

### **6.1. Activities in the Security in Information Systems Domain**

#### **6.1.1. Information Security in Networked Supply Chains: Impact of Network Vulnerability and Supply Chain Integration on Incentives to Invest**

Participants: Tridib Bandhopadhyay, Varghese Jacob, Srinivasan Raghunathan

Recent supply chain reengineering efforts have focused on integrating firms' production, inventory and replenishment activities with the help of communication networks. While communication networks and supply chain integration facilitate optimization of traditional supply chain functions, they also exacerbate the information security risk: communication networks propagate security breaches from one firm to another, and supply chain integration causes breach on one firm to affect other firms in the supply chain. We study the impact of network security vulnerability and supply chain integration on firms' incentives to invest in information security. We find that even though an increase in either the degree of network vulnerability or the degree of supply chain integration increases the security risk, they have different impacts on firms' incentives to invest in security. If the degree of supply chain integration is low, then an increase in network vulnerability induces firms to reduce, rather than increase, their security investments. A sufficiently high degree of supply chain integration alters the impact of network vulnerability into one in which firms have an incentive to increase their investments when the network vulnerability is higher. Though an increase in the degree of supply integration enhances firms' incentives to invest in security, private provisioning for security always results in a less than socially optimal security level. A liability mechanism that makes the responsible party partially compensate for the other party's loss induces each firm to invest at the socially optimal level. If firms choose the degree of integration, in addition to security investment, then firms may choose a higher degree of integration when they decide individually than when they decide jointly, suggesting an even greater security risk to the supply chain.

Bandhopadhyay, T., V. Jacob and S. Raghunathan. Information Security in Networked Supply Chains: Impact of Network Vulnerability and Supply Chain Integration on Incentives to Invest , *Information Technology and Management*, 11(1) (2010) pp. 7-23.  
<http://www.springerlink.com/content/2054567np5283j13/>

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#### **6.1.2. Outsourcing Information Security: Contracting Issues and Security Implications**

Participants: Huseyin Cavusoglu, Asunur Cezar, Srinivasan Raghunathan

We examine the implications of a firm outsourcing both (i) security device management which attempts to prevent security breaches and (ii) security monitoring which attempts to detect security breaches to managed security service providers (MSSPs). In the context of security outsourcing, the firm not only faces the traditional moral hazard problem as it cannot observe an MSSP's prevention or detection effort, but also observes the security breach outcome only imperfectly. Furthermore, outsourced prevention and detection services are separate but interrelated security functions, and thereby cannot be considered independently. Hence, the firm needs to carefully design a contract or contracts to induce the desired efforts from the service providers to effectively manage the cost of information security. We first show

that the current practice of outsourcing both device management and monitoring functions to the same MSSP using a contract that imposes a penalty on MSSP when the MSSP is deemed responsible for a breach results in a higher than the first-best prevention effort and zero (and less than the first-best) detection effort. This is due to the conflict of interest faced by the MSSP and the substitutable nature of prevention and detection services. We then propose two new contracts, both of which achieve the first-best outcomes. The first contract imposes a penalty for a breach and offers a reward for detecting and revealing breaches to the firm and the second contract calls for the firm to use two different MSSPs - one for prevention and the other for detection. The required penalty and reward are smaller when the firm uses two MSSPs than when it uses a single MSSP. It is possible for all three types of contracts to fail to satisfy the fairness criterion – the penalty does not exceed the firm’s loss from a security breach -, and also fail to achieve the first-best efforts when there are limits on penalty and/or reward. However, the two-MSSP contract meets the fairness criterion whenever the other two contracts do. An increase in the prevention cost relative to the detection cost increases the likelihood that the two-MSSP contract meets the fairness criterion, making the two-MSSP contract even more attractive relative to the single MSSP contract with penalty and reward. Despite these advantages of the two-MSSP contract over single MSSP contracts, the firm may be better off outsourcing both prevention and detection functions to the same MSSP with a penalty-and-reward-based contract if a strong cost complement exists between the two functions.

Paper presented at The Ninth Workshop on the Economics of Information Security (WEIS 2010)

Asunur, C., H. Cavusoglu, and S. Raghunathan. Outsourcing Information Security: Contracting Issues and Security Implications. Proceedings of the Ninth Workshop on the Economics of Information Security (WEIS) (June 2010).

<http://weis2010.econinfosec.org/program.html>

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### 6.1.3. An Analysis of the Impact of Passenger Profiling for Transportation Security

Participants: Huseyin Cavusoglu, Byungwan Koh, Srinivasan Raghunathan

The proponents of airline passenger profiling claim that profiling will reduce the cost of security, improve the detection of attackers, increase the reliability of signals from screening devices, and reduce the inconvenience to normal passengers. In this paper we show that if the Transportation Security Administration (TSA) manually inspects all those passengers classified as likely attackers and sends others through a screening system, as it did when it deployed the Computer Assisted Passenger Prescreening System (CAPPS), then it is superior to no profiling on all four performance measures if and only if the quality of the profiler vis-à-vis that of the screening system is sufficiently high. If the quality of the screening device is sufficiently high, profiling could be detrimental on all four performance measures. On the other hand, if the TSA deploys two screening devices along with the profiler—each screening device optimally configured for each of the two groups of passengers—then profiling improves the reliability of screening device signals, reduces the inconvenience caused to normal passengers, and improves the social welfare even when quality of the screening device is high. One of the implications of our findings is that the security architecture used by the TSA when it deployed CAPPS could provide a strong support to the arguments by some against the use of profiling; however, if the TSA deploys a two-screening device architecture, it might not only blunt the criticism that profiling is discriminatory but also benefit normal passengers and overall society economically.

Cavusoglu, K., B. Koh, S. Raghunathan. An Analysis of the Impact of Passenger Profiling for Transportation Security. *Operations Research*. (September/October 2010) 58 (5). pp. 1287-1302.

<http://or.journal.informs.org/cgi/content/abstract/58/5/1287>

#### 6.1.4. Economics of User Segmentation, Profiling, and Screening in Security

Participants: Srinivasan Raghunathan, Huseyin Cavusoglu, Bin Mai

User profiling is touted as an effective and efficient tool to detect security breaches because it allows firms to target their inspection efforts at likely attackers and reduce inspection of likely normal users. However, because profiling uses superficial individual-specific criteria, it is susceptible to gaming by attackers who may be able to fake their attributes to trick the profiler into classifying them as normal users. We first analyze the impact of gaming by attackers on the firm for two types of profiling commonly used in practice – the profiler separates out attackers and the profiler separates out normal users. For both of these cases, we show that profiling hurts the firm if the profiling accuracy is sufficiently low. Surprisingly, we find that profiling may hurt the firm also when the profiling accuracy is sufficiently high. The latter result occurs because an increase in the profiling accuracy makes faking more attractive to attackers. Therefore, even when profiling is better than not profiling, the optimal profiling accuracy, which depends on the faking cost, could be less than 100%. A lower faking cost expands the region in which the firm realizes a lower payoff when it uses profiling than when it does not. We also find that, contrary to the conventional wisdom, as the firm becomes better at discriminating attackers and normal users, the inspection rates for the two groups become more similar when faking is an issue. We show that the negative effects of profiling can be mitigated if the firm uses two screening devices, one for each user group. However, the additional cost of operating a second screening device may offset the gain.

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#### 6.1.5. Cyber Security Risk Management: Public Policy Implications of Correlated Risk and Imperfect Ability to Prove Loss

Participants: Hulusi Ogut, Nirup M. Menon, Srinivasan Raghunathan

The correlated nature of security breach risks, the imperfect ability to prove loss from a breach to an insurer, and the inability of insurers and external agents to observe firms' self-protection efforts have posed significant challenges to cyber security risk management. Our analysis finds that a firm invests less than the social optimal levels in self-protection and in insurance when risks are correlated and the ability to prove loss is imperfect. We find that the appropriate social intervention policy to induce a firm to invest at socially optimal levels depends on whether insurers can verify a firm's self-protection levels. If self-protection of a firm is observable to an insurer so that it can design a contract that is contingent on the self-protection level, then self-protection and insurance behave as complements. In this case, a social planner can induce a firm to choose the socially optimal self-protection and insurance levels by offering a subsidy on self-protection. We also find that providing a subsidy on insurance does not provide a similar inducement to a firm. If self-protection of a firm is not observable to an insurer, then self-protection and insurance behave as substitutes. In this case, a social planner should tax the insurance premium to achieve socially optimal results. The results of our analysis hold regardless of whether the insurance market is perfectly competitive or not, implying that solely reforming the currently imperfect insurance market is insufficient to achieve the efficient outcome in cyber security risk management.

Menon, N., H. Ogut, and S. Raghunathan. Cyber Security Risk Management: Public Policy Implications of Correlated Risk and Imperfect Ability to Prove Loss, *Risk Analysis Journal* ( March 2011) 31(3) pp. 497-512. <http://onlinelibrary.wiley.com/doi/10.1111/j.1539-6924.2010.01478.x/abstract>

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### 6.1.6. Intrusion-Detection Policies for IT Security Breaches

Participants: Hulusi Ogut, Huseyin Cavusoglu and Srinivasan Raghunathan

Intrusion-detection systems (IDSs) form an important component of IT security architectures, but the low proportion of hackers in the user population severely limits the usefulness of IDSs. Thus, even when the IDS is good, an intrusion signal may not imply that the user is more likely to be a hacker than a normal user. Ignoring the low base rate for the proportion of hackers results in acting on every intrusion signal, which is costly because of high rate of false alarms. This problem is known as the base-rate fallacy in IDSs. On the other hand, ignoring intrusion signals renders them useless. We propose and analyze waiting-time policies, which specify a response to signals from IDSs. We formulate the problem as a stochastic dynamic programming model and derive the optimal waiting time before acting upon an intrusion signal. Because the optimal policy is difficult to implement in many situations, we also derive and theoretically analyze a myopic policy. Our simulations suggest that the behavior of the myopic policy is qualitatively similar to that of the optimal policy. Further, the myopic policy performs better than other policies often used in practice, such as the Bayes policy and m-strike policies. The myopic policy can be implemented easily in a decision support system that supplements an IDS to mitigate the base-rate fallacy, and improve the value of the IDS.

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### 6.1.7. Contracting Information Security in the Presence of Double Moral Hazard

Participants: Geng X, Chul Ho Lee, and Srinivasan Raghunathan

In information security outsourcing, it is the norm that the outsourcing firms and the outsourcers (commonly called managed security service providers, MSSPs) need to coordinate their efforts for better security. Nevertheless, efforts are often private and thus both firms and MSSPs can suffer from double moral hazard. Furthermore, the double moral hazard problem in security outsourcing is complicated by the existence of strong externality and the multi-client nature of MSSP services. We first show that the prevailing contract structure in security outsourcing, bilateral refund contract, cannot solve double moral hazard. A money burning mechanism cannot solve double moral hazard either. Furthermore, positive externality can worsen double moral hazard. We then propose a new contract structure termed multilateral contract and show that it can completely solve double moral hazard and induce first-best efforts from all contractual parties when an MSSP serves two or more client firms, regardless of the externality. Firm-side externality significantly affects how payments flow under a multilateral contract when a security breach happens. When the number of client firms for an MSSP increases, we show that the contingent payments under multilateral contracts for any security breach scenario can be easily calculated using an additive method, and thus are computationally simple to implement.

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### 6.1.8. When and How Tighter Standards Harm Organizational Information Security

Participants: Xianjun Geng, Chul Ho Lee, and Srinivasan Raghunathan

This paper studies when and how mandatory standards can harm firm security. We consider a setting where a firm has two security controls – one directly regulated by a security standard while the other one not -- that are linked in either a serial or a parallel configuration. We also consider strategic attacker behavior and liability issues. Our findings are the following. First, under serial configuration, firm security can decrease in the standard when this standard is not too high. Second and surprisingly, such

decrease is more likely to happen when the firm cares more about security. Third, under parallel configuration firm security can decrease in the standard only when the standard is high enough and the firm investment on the regulated control can significantly reduce its liabilities upon breach. Fourth and interestingly, when the standard is not too high, strategic attacking behavior can augment the effectiveness of the standard in that the firm will invest more on security (than that under nonstrategic attacks).

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#### 6.1.9. An Analysis of Voluntary Profiling in Online Markets

Participants: Byungwan Koh and Srinivasan Raghunathan

Consumer profiling in online marketplaces has been a subject of intense debate. While industry groups tout benefits of profiling such as a reduction in consumer search cost and product misfit cost, profiling opponents cite price discrimination and loss of privacy. The U.S. government has favored the voluntary profiling approach in which consumers are given the option to participate in profiling. The implicit assumption underlying the voluntary profiling policy is that since only consumers that expect to benefit will participate in profiling, no consumer will be worse off under the voluntary profiling policy than under the no profiling policy. In this paper, however, we show that every consumer that chooses to not participate in profiling and, more importantly, some consumers that choose to participate in profiling are worse off under the voluntary profiling policy than under the no profiling policy. Furthermore, neither social welfare nor the total consumer surplus is necessarily higher under the voluntary profiling policy than under the no profiling policy. The voluntary profiling policy is *Pareto optimal* only when the search cost is sufficiently high but the accuracy with which the firm can infer a consumer's valuation is not sufficiently high. If the firm can infer the valuation of each consumer with high accuracy, profiling may or may not benefit the society but always hurts consumers. If the policy maker bans price discrimination the voluntary profiling policy is always Pareto optimal, whereas reduction in privacy cost does not guarantee the Pareto optimality.

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#### 6.1.10. Evaluation of Intrusion Detection Systems under an Inspection Constraint

Participants: Young U. Ryu and Hyun-Suk Rhee

An intrusion detection system (IDS) plays an important role in a firm's overall security protection. The IDS's main purpose is to identify potentially intrusive events and alert the security personnel to the danger. A typical intrusion detection system, however, is known to be imperfect in detection of intrusive events, resulting in high false-alarm rates. Nevertheless, current intrusion detection models unreasonably assume that upon alerts raised by a system, an information security officer responds to all alarms without any delay and avoids damages of hostile activities. This assumption of responding to all alarms with no time lag is often impracticable. As a result, the benefit of an IDS can be overestimated by current intrusion detection models. In this article, we extend previous models by including an information security officer's alarm inspection under a constraint as a part of the process in determining the optimal intrusion detection policy. Given a potentially hostile environment for a firm in which the intrusion rates and costs associated with intrusion and security officers' inspection can be estimated, we outline a framework to establish the optimal operating points for IDSs under security officers' inspection constraint. The optimal solution to the model will provide not only a basis of better evaluation of IDSs but also useful insights into operations of IDSs. The firm can estimate expected benefits for running IDSs and establish a basis for increase in security personnel to relax security officers' inspection constraint.

### 6.1.11. Protecting Privacy against Record Linkage Disclosure: A Bounded Swapping Approach for Numeric Data

Participants: Xiao-Bai Li and Sumit Sarkar

Record linkage techniques have been widely used in areas such as anti-terrorism, crime analysis, epidemiologic research, and database marketing. On the other hand, such techniques are also being increasingly used for identity matching that leads to the disclosure of private information. Such a technique can be used to effectively re-identify records even in de-identified data. Consequently, the use of such a technique can lead to individual privacy being severely eroded. This study addresses this important issue and provides a solution to resolve the conflict between privacy protection and data utility. We propose a data masking method for protecting private information against record linkage disclosure, while preserving the statistical properties of the data for legitimate analysis. Our method recursively partitions a dataset into smaller subsets such that data records within each subset are more homogeneous after each partition. The partition is made orthogonal to the maximum variance dimension represented by the first principal component in each partitioned set. The attribute values of a record in a subset are then masked using a double-bounded swapping method. The proposed method, which we call multivariate swapping trees, is nonparametric in nature and does not require any assumptions about statistical distributions of the original data. Experiments conducted on real-world datasets demonstrate that the proposed approach significantly outperforms existing methods in terms of both preventing identity disclosure and preserving data quality.

Li, Xiao-Bai and S. Sarkar. Protecting Privacy against Record Linkage Disclosure: A Bounded Swapping Approach for Numeric Data. *Information Systems Research*. Forthcoming.

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### 6.1.12. No Free Lunch: Price Premium for Privacy Seal-Bearing Vendors

Participants: Bin Mai, Nirup M Menon, and Sumit Sarkar

Privacy is a significant concern of customers in the business-to-consumer online environment. Several technical, economic, and regulatory mechanisms have been proposed to address online privacy. A current market-based mechanism is the privacy seal, under which a third-party assures adherence by a vendor to its posted privacy policy. In this paper, we present empirical evidence of the impact of displaying a privacy seal on the product prices of online vendors of electronic books, downloadable audio books, and textbooks. Using data collected on these relatively homogeneous products sold by online vendors, we find, while controlling for vendor-specific characteristics, that vendors bearing privacy seals charge a premium for such products compared to vendors not bearing a seal. The paper provides empirical evidence of the economic value of privacy assurance from the customers' perspective as measured by the price premium charged for products. The research has implications for researchers and policy makers by providing evidence that privacy is another factor that creates friction in e-commerce, and that prices on the internet for homogeneous products need not converge.

Mai, Bin, N. Menon, and Sumit Sarkar. No Free Lunch: Price Premium for Privacy Seal-Bearing Vendors, *Journal of Management Information Systems*, 27(2) (2010) pp. 189 – 212.

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### 6.1.13. Data Clustering and Micro-Perturbation for Privacy-Preserving Data Sharing and Analysis

Participants: Xiao-Bai Li and Sumit Sarkar

Clustering-based data masking approaches are widely used for privacy-preserving data sharing and data mining. Existing approaches, however, cannot cope with the situation where confidential attributes are categorical. For numeric data, these approaches are also unable to preserve important statistical properties such as variance and covariance of the data. We propose a new approach that handles these problems effectively. The proposed approach adopts a minimum spanning tree technique for clustering data and a micro-perturbation method for masking data. Our approach is novel in that it (i) incorporates an entropy-based measure, which represents the disclosure risk of the categorical confidential attribute, into the traditional distance measure used for clustering in an innovative way; and (ii) introduces the notion of cluster-level micro-perturbation (as opposed to conventional micro-aggregation) for masking data, to preserve the statistical properties of the data. We provide both analytical and empirical justification for the proposed methodology.

Awarded Second Runner-Up Award for the Best Conference Paper at the *International Conference on Information Systems*, Dec 2011

Li, Xiao-Bai and Sumit Sarkar. *Data Clustering and Micro-perturbation for Privacy-Preserving Data Sharing and Analysis*. ICIS 2010 Proceedings, Paper 58, (2010).

[http://aisel.aisnet.org/icis2010\\_submissions/58](http://aisel.aisnet.org/icis2010_submissions/58)

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### 6.1.14. When Hackers Talk: Managing Information Security Under Variable Attack Rates and Information Dissemination

Participants: Vijay Mookerjee, Wei Yue, Radha Mookerjee, and Alain Bensoussan

This paper analyzes interactions between a firm that seeks to discriminate between normal users and hackers that try to penetrate and compromise the firm's information assets. We develop an analytical model in which a variety of factors are balanced to best manage the detection component within information security management. The approach not only considers conventional factors such as detection rate and false-positive rate, but also factors associated with hacker behavior that occur in response to improvements in the detection system made by the firm. Detection can be improved by increasing the system's discrimination ability (i.e., the ability to distinguish between attacks and normal usage) through the application of maintenance effort. The discrimination ability deteriorates over time due to changes in the environment. Also, there is the possibility of sudden shocks that can sharply degrade the discrimination ability. The firm's cost increases as hackers become more knowledgeable by disseminating security knowledge within the hacker population. The problem is solved to reveal the presence of a steady-state solution in which the level of system discrimination ability and maintenance effort are held constant. We find an interesting result where, under certain conditions, hackers do not benefit from disseminating security knowledge among one another. In other situations, we find that hackers benefit because the firm must lower its detection rate in the presence of knowledge dissemination. Other insights into managing detection systems are provided. For example, the presence of security shocks can increase or decrease the optimal discrimination level as compared to the optimal level without shocks.

Bensoussan, A., R. Mookerjee, V. Mookerjee and W.T. Yue. When Hackers Talk: Managing Information Security under Variable Attack Rates and Information Dissemination, *Information Systems Research*, (online 2010), 22(3) pp. 606. doi: 10.1287/isre.1100.0341

<http://isr.journal.informs.org/content/early/2011/04/08/isre.1100.0341.full.pdf+html>

### 6.1.15. Managing Information Security Under Continuous Drift and Sudden Shocks

Participants: Vijay Mookerjee, Wei Yue, Radha Mookerjee, and Alain Bensoussan

This paper analyzes the optimal amount of effort that should be exerted to best maintain a detection component within information security management. We consider a problem over an infinite horizon in which detection system suffers continuous and sudden deterioration of performance quality. The firm exerts maintenance effort to counter the drop in performance quality. We develop an analytical model in which the performance quality of the detection system can be improved (i.e., the ability to distinguish between attacks and normal usage) through the application of maintenance effort. The discrimination ability deteriorates over time due to changes in the environment (e.g. hacker behavior). Also, there is the possibility of sudden shocks that can sharply degrade the discrimination ability. We find the presence of shocks will result in the system maintained at a lower discrimination ability level. When shocks can be eliminated if the discrimination ability of the system is to be maintained at a certain threshold level, surprisingly, the optimal decision may not be to maintain the system at this threshold level.

Bensoussan, A., R. Mookerjee, V. Mookerjee and W.T. Yue. Managing Information Security Under Continuous Drift and Sudden Shocks, *Conference on Information Technologies and Systems (CIST)* Charlotte, N.C., November, 2011. Forthcoming.

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### 6.1.16. A Game-Theoretical Approach for Finding Optimal Strategies in a Botnet Defense Model

Participants: Alain Bensoussan, Celine Hoe and Murat Kantarcioglu

In many cases, botnet herders are motivated by economic incentives and try to significantly profit from illegal botnet activity while causing significant economic damage to society. To analyze the economic aspects of botnet activity and suggest feasible defensive strategies, we provide a comprehensive game theoretical framework that models the interaction between the botnet herder and the defender group (network/computer users). In our framework, a botnet herder's goal is to intensify his intrusion in a network of computers for pursuing economic profits whereas the defender group's goal is to defend botnet herder's intrusion. The percentage of infected computers in the network evolves according to a modified SIS (susceptible-infectious-susceptible) epidemic model. For a given level of network defense, we define the strategy of the botnet herder as the solution of a control problem and obtain the optimal strategy as a feedback on the rate of infection. In addition, using a differential game model, we obtain two possible closed-loop Nash equilibrium solutions. These results indicate that in some cases trying to defend against botnet activity may not be economically feasible, instead the goal should be to limit the damage to an acceptable level. Also when significant resources are allocated to defend against particular botnet activity, botnet herders will choose to reduce their attack effort even if the defensive strategies are not very effective. To our knowledge, none of previous works suggested these two different equilibrium strategies.

Bensoussan, A., C. Hoe, and M. Kantarcioglu. *A Game-Theoretical Approach for Finding Optimal Strategies in a Botnet Defense Model*. Decision and Game Theory for Security First International Conference, GameSec 2010, Berlin, Germany, November 22-23, 2010. Proceeding, T. Alpcan, L. Buttyan, and J. Baras (Eds.), Vol. 6442, pp. 135-148.  
<http://www.springerlink.com/content/2523105t4nj6knrg/>

### 6.1.17. When Do Firms Invest in Privacy-Preserving Technologies?

Participants: Alain Bensoussan, Celine Hoe, Murat Kantarcioglu

Privacy is a central concern in the information age. In some circumstances, customers' decisions whether to use firms' services rely on the extent of privacy that firms are able to provide. On the other hand, firms make investment decisions about privacy-preserving technologies, which require the technology adoption to yield them enough compensation for making investment. We are interested in assessing privacy-preserving technologies to formulate useful guidelines for firms' investment decisions and to make inferences, if any, about the necessity of government intervention to encourage firms' investment in privacy-preserving technologies. Two unique factors affect firms' investment valuation in our model: (1) a customer's valuation of his private information and (2) a customer's profitability to a firm. We view firms' evaluation processes as a variant of Stackelberg type leader-follower game under complete information with customers taking the role of the follower. Rational utility maximizing customers optimally decide whether to use firms' services by linking to their own decision threshold which is their own fair valuation of privacy connected to their private information. We employ copula functions to allow sufficient flexibility in formulating bivariate distribution functions. We find that dependence structures and underlying univariate distributions have significant impacts on investment valuation. Our results also identify several cases where the government intervention may be required to have firms invest in privacy-preserving technologies.

Bensoussan, A., C. Hoe, and M. Kantarcioglu. *When Do Firms Invest in Privacy-Preserving Technologies?* Decision and Game Theory for Security First International Conference, GameSec 2010, Berlin, Germany, November 22-23, 2010. Proceeding, T. Alpcan, L. Buttyan, and J. Baras (Eds.), Vol. 6442, pp. 72-86.

<http://www.springerlink.com/content/b061756178254140/>

Bensoussan, A., S. Hoe and M. Kantarcioglu. When Do Firms Invest in Privacy-Preserving Technologies? *E-Letter of Multimedia Communications Technical Committee (MMTC), IEEE Communications Society*, 6(4), April 2011, pp. 15-17.

Bensoussan, A., S. Hoe and M. Kantarcioglu. Impact of Security Risks on Cloud Computing Adoption, *Proceedings of Forty-Ninth Annual Allerton Conference*. Forthcoming.

Bensoussan, A., S. Hoe and M. Kantarcioglu Investment in Privacy-Preserving Technologies under Uncertainty, *GamSec 2011, LNCS Vol 7037*. Forthcoming.

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## 6.2. Activities in the Supply Chain Domain

### 6.2.1. Partially Observed Inventory Systems

Participants: Alain Bensoussan, Metin Çakanyildirim and Suresh Sethi

In some inventory control contexts, such as Vendor Managed Inventories, inventory with spoilage, misplacement, or theft, inventory levels may not always be observable to the decision makers. However, shortages, delayed inventory/demand observations are observable and are called signals. The signals provide partial information. We study such inventory control problems, where orders must be decided on the basis of partial information to minimize costs.

Bensoussan, A., M. Çakanyildirim, J.A. Minjarez-Sosa, S.P. Sethi, and R. Shi. An Incomplete Information Inventory Model with Presence of Inventories or Backorders as Only Observations, *Journal of Optimization Theory and Applications*, 146(3), (September 2010) pp. 544-580.

Bensoussan, A., Q. Feng, and S.P. Sethi. Achieving a Long-Term Service Target with Periodic Signals: A Newsvendor Framework, *Manufacturing & Service Operations Management (MSOM)* (May 2010).

Bensoussan, A., M. Çakanyildirim, and S.P. Sethi. Filtering for Discrete-Time Markov Processes and Applications to Inventory Control with Incomplete Information, *Handbook on Nonlinear Filtering*, D. Crisan and B. Rozovsky (Eds.), Oxford University Press (April 2011) pp. 500-525.

Bensoussan, A., M. Çakanyildirim, J.A. Minjarez-Sosa, S.P. Sethi, and R. Shi. Computation of Approximate Optimal Policies in Partially Observed Inventory Model with Rain Checks, *Automatica*, 47(8), (27 July 2011 online), pp. 1589-1604.

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### 6.2.2. Inventory Control with a Cash Register: Sales Recorded but Not Demand or Shrinkage

Participants: Alain Bensoussan, Metin Çakanyildirim, Meng Li, Suresh Sethi

Inventory inaccuracy is common at retailers. At many retailers, a cash register records incoming orders and outgoing sales, but not the demand or the shrinkage. The shrinkage refers to spoilage or pilferage of inventory. The demand differs from the sales in the periodic-review lost-sales inventory model presented in this paper. The inventory is subject to a unobserved shrinkage which happens both before and after the demand. When the remaining inventory exceeds the demand, the unmet demand is lost and unobserved. Our objective is to minimize the expected discounted cost related to inventory holding and shortage over an infinite horizon. We use dynamic programming along with the concept of unnormalized probability, and prove the existence of an optimal feedback policy and that the value function is the solution of the dynamic programming equation. We obtain a theoretical lower bound for the cost via the formulation of a fictitious inventory problem. We develop an iterative algorithm, and compare its solution to a myopic solution and a lower bound. We identify many cases of parameter values for which the solution of the iterative algorithm performs significantly better than the myopic solution. Moreover, the achieved cost is close to the lower bound.

Bensoussan, A., M. Çakanyildirim, M. Li and S.P. Sethi. *Existence and Uniqueness of Solutions for a Partially Observed Stochastic Control Problem*, World Scientific. Forthcoming.

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### 6.2.3. Optimal Policy and Value of Information in an Inventory Model with Lost Sales and Demand Updates

Participants: Alain Bensoussan, Metin Çakanyildirim, Qi Feng, Suresh Sethi

Under many circumstances, demand observations are often censored due to the lack of tracking lost sales caused by stockouts. To understand the impact of the lost sales information on the ordering decisions, a periodic-review inventory model is formulated in which only the sales information is obtained immediately upon the realization of the demand. Subsequently, the lost sales information is obtained after a delay. In the resulting model, an optimal policy, if exists, reveals a very complex structure. By decomposing the derivative of the value function, we demonstrate two different roles of inventory in our

model: satisfying the demand and deducing the demand information. We show that the optimal inventory levels under the delayed observation of the lost sales are always higher than those for which the demands are fully observed. Moreover, as illustrated in numerical examples, the optimal policy possesses a counterintuitive behavior with respect to the problem parameters. To understand the key drivers of the optimal decisions, we further compare the costs under different demand observations. Two important observations are made. First, a lower cost is obtained when the realized demand is observed than when the demand is only observed to be higher than that level, and, furthermore, the cost difference represents the value of demand information. Second, if the demand observation is censored, improved demand information may not always be desirable as it may actually lead to an increased expected cost.

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#### 6.2.4. Numerical Analysis of Partially Observable Inventory System: Economic Loss from Mean Based Policy

Participants: Alain Bensoussan, Metin Çakanyildirim, Celine Hoe, Suresh Sethi

In this paper we provide numerical solutions for a partially observed inventory system named Zero Balance Walk Model. In this model, demand is not observed, inventory level is observed only when it reaches zero, and orders are made to minimize the total discounted cost. We prove that solutions can be obtained in a Hilbertian framework and propose a numerical procedure combining a Chebyshev representation of the conditional density of the inventory level and a policy iteration algorithm. Extensive numerical examples are studied to analyze the economic loss if the model is misspecified by the mean-based policy. An approximation scheme is introduced for the computation of costs. Numerical results show that the loss is significant and is positively related to the discount factor as well as the uncertainty embedded in the inventory level. Our study thus suggests inventory managers the importance of their awareness to the partially observable inventory system.

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#### 6.2.5. Multiple In-Cycle Transshipments with Positive Delivery Times

Participants: Metin Çakanyildirim, Kathryn Stecke, Nagihan Çömez

We study a centralized inventory sharing system of two retailers that are replenished periodically. Between two replenishments, a unit can be transshipped to a stocked-out retailer from the other. It arrives a transshipment time later, during which the stocked-out retailer incurs backorder cost. Without transshipment, backorder cost is incurred until the next replenishment. Since the transshipment time is shorter than the time between two replenishments, transshipments can reduce the backorder cost at the stocked-out retailer and the holding costs at the other retailer. The system is directed by a centralized inventory manager, who minimizes the long-run average cost consisting of replenishment, holding, backorder, and transshipment costs. The transshipment policy is characterized by hold-back inventory levels, which are non-increasing in the remaining time until the next replenishment. The transshipment policy differs from the literature because we allow for multiple transshipments between replenishments, positive transshipment times, and backorder costs. We also discuss the challenges associated with positive replenishment time and develop upper and lower bounds of average cost in this case. Bounds are numerically shown to have an average gap of 1.1%. The heuristic solution is based on the upper bound and differs from the optimal cost by at most this gap.

Çömez, N., K. Stecke, and M. Çakanyildirim. Multiple In-Cycle Transshipments with Positive Delivery Times. *Production and Operations Management*. Forthcoming.

Bensoussan, A., M. Çakanyildirim, S.P. Sethi, M. Wang and H. Zhang. Average Cost Optimality in Inventory Models with Dynamic Information Delays. *IEEE Transactions on Automatic Control*. Forthcoming.

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#### 6.2.6. Optimal Transshipments and Reassignments under Periodic or Cyclic Holding Cost Accounting

Participants: Metin Çakanyildirim, Kathryn Stecke and Nagihan Çömez

In a centrally-managed system, available inventory at a retailer can be transshipped to a stocked-out retailer to meet customer demand. On the other hand, since the inventory at the former retailer may be in demand for future customers of that retailer and transshipment time/cost is non-negligible, it can be more profitable to not transship. An optimal transshipment policy suggests transshipping in some situations, but not always. Unsatisfied customer demand can be backordered. As demand uncertainty resolves over time, the cost trade-off between backordering at the stocked-out retailer and holding inventory at the other retailer changes. Hence reassignment of inventory to a previously backordered demand can perhaps become profitable. Despite this intuition, we prove that no reassignments are necessary for cost optimality under periodic holding cost accounting. On the contrary, reassignments become necessary when holding costs are accounted only at the end of each cycle. But they save costs a little. These results facilitate efficient optimization of transshipments over time.

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#### 6.2.7. In-Season Transshipments among Competitive Retailers

Participants: Metin Çakanyildirim, Kathryn Stecke and Nagihan Çömez

A decentralized system of competing retailers that order and sell the same product in a sales season is studied. When a customer demand occurs at a stocked-out retailer, that retailer requests a unit to be transshipped from another retailer who charges a transshipment price. If this request is rejected, the unsatisfied customer may go to another retailer with a customer overflow probability. Each retailer decides on the initial order quantity from a manufacturer and on the acceptance/rejection of each transshipment request. For two retailers, we show that retailers' optimal transshipment policies are dynamic and characterized by chronologically non-increasing inventory holdback levels. We analytically study the sensitivity of holdback levels to explain interesting findings, such as smaller retailers and geographically distant retailers benefit more from transshipments. Numerical experiments show that retailers substantially benefit from using optimal transshipment policies compared to no sharing. The expected sales increase in all but a handful of over 3000 problem instances. Building on the two-retailer optimal policies, we suggest an effective heuristic transshipment policy for a multi-retailer system.

Çömez, N., K. Stecke, and M. Çakanyildirim. In-Season Transshipments among Competitive Retailers. *Manufacturing and Service Operations Management*. Forthcoming.

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### 6.2.8. Analysis of Product Rollover Strategies in the Presence of Strategic Customers

Participants: Metin Çakanyildirim, Suresh Sethi and Chao Liang

Frequent product introductions emphasize the importance of product rollover strategies. With single rollover, when a new product is introduced, the old product is phased out from the market. With dual rollover, the old product remains in the market together with the new product. We study the interaction between product rollover strategies and strategic customers' purchase behavior. We find that single rollover is more valuable when the innovation of the new product is low and the number of strategic customers is high. Interestingly and counter to intuition, the firm may suffer from a high value disposal option for the old product.

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### 6.2.9. On the Selection of Supply Chain Coordinating Contracts: The Role of Capital Constraints

Participants: Yi Xu and Jun Zhang

This paper considers a supply chain with a manufacturer and a financially constrained retailer, and examines the implications of the retailer's capital constraint on the selection of supply chain coordinating contracts. We demonstrate that the well-accepted result that buy-back, quantity discount, quantity-flexibility, sales-rebate, and revenue-sharing contracts can coordinate the supply chain and arbitrarily allocate the supply chain profit needs to be reexamined. Taking the retailer's capital constraint into account, we show that arbitrary allocation of the supply chain profit is no longer possible for all the contract forms, and that these contract forms are quite different in the flexibility in coordinating the supply chain and in allocating its profit. Surprisingly, there is a set of allocations of the supply chain profit that cannot be achieved by any of the existing contract forms. We then propose and study a new coordinating contract form: manufacturer financing contract in which the manufacturer provides financing for the retailer's purchase. We find that the manufacturing financing contract complements the existing contract forms in supply chain coordination and in profit allocation. Our study indicates that the financial status of the retailer, the gross margin of the product, and the power structure of a supply chain are important factors that influence the selection of coordinating contracts.

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### 6.2.10. Coordination of Supply Chains with Risk-Averse Agents

Participants: Xianghua Gan, Suresh P. Sethi and Houmin Yan

The extant supply chain management literature has not addressed the issue of coordination in supply chains involving risk-averse agents. We take up this issue and begin with defining a coordinating contract as one that results in a Pareto-optimal solution acceptable to each agent. Our definition generalizes the standard one in the risk-neutral case. We then develop coordinating contracts in three specific cases: (i) the supplier is risk neutral and the retailer maximizes his expected profit subject to a downside risk constraint, (ii) the supplier and the retailer each maximizes his own mean-variance trade-off, and (iii) the supplier and the retailer each maximizes his own expected utility. Moreover, in case (iii) we show that our contract yields the Nash Bargaining solution. In each case, we show how we can find the set of Pareto-optimal solutions, and then design a contract to achieve the solutions. We also exhibit a case in which we obtain Pareto-optimal sharing rules explicitly, and outline a procedure to obtain Pareto-optimal solutions.

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### 6.2.11. Channel Coordination with a Risk-Neutral Supplier and a Downside-Risk-Averse Retailer

Participants: Xianghua Gan, Suresh P. Sethi, Houmin Yan

We investigate how a supply chain involving a risk-neutral supplier and a downside-risk-averse retailer can be coordinated with a supply contract. We show that the standard buy-back or revenue-sharing contracts may not coordinate such a channel. Using a definition of coordination of supply chains proposed earlier by the authors, we design a risk-sharing contract that offers the desired downside protection to the retailer, provides respective reservation profits to the agents, and accomplishes channel coordination.

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### 6.2.12. A Two-Stage Newsvendor Problem with a Service Constraint

Participants: Alain Bensoussan, Qi Feng, Suresh Sethi

We extend the classical newsvendor problem by introducing a service constraint and a demand forecast update. The newsvendor orders an initial amount and has the possibility to adjust the initial order after she observes a demand updating signal. She also commits to a target service level before any forecast update is available. The resulting problem does not permit a dynamic programming formulation. We use the method of Lagrange multiplier to solve the problem, and we derive an analytical expression for the optimal ordering decisions. Various properties of the optimal policy are discussed, and numerical results are presented to provide further insights into the newsvendor's behavior.

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### 6.2.13. Coordination Mechanism for the Supply Chain with Leadtime Consideration and Price-Dependent Demand

Participants: Haoya Chen, Youhua Chen, Tsan-Ming Choi, and Suresh Sethi

We study a coordination contract for a supplier-retailer channel producing and selling a fashionable product exhibiting a stochastic price-dependent demand. The product's selling season is short, and the supply chain faces great demand uncertainty. We consider a scenario where the supplier reserves production capacity for the retailer in advance, and permits the retailer to place an order not exceeding the reserved capacity after a demand information update during the leadtime. We formulate a two-stage optimization problem in which the supplier decides the amount of capacity reservation in the first stage, and the retailer determines the order quantity and the retail price after observing the demand information in the second stage. We propose a three-parameter risk and profit sharing contract that coordinates the supply chain. The proposed contract permits any agreed-upon distribution of the supply chain profit to the channel members.

Haoya Chen, Youhua (Frank) Chen, Chun-Hung Chiu, Tsan-Ming Choi and Suresh Sethi. Coordination Mechanism for the Supply Chain with Leadtime Consideration and Price-Dependent Demand, *European Journal of Operational Research*, 203(1), (May 2010) Pages 70-80.

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#### 6.2.14. Procurement Flexibility under Price Uncertainty

Participants: Qi Feng and Suresh Sethi

This chapter examines the interaction between supply price uncertainty and demand uncertainty. We consider a manufacturer who sources a key component using different procurement options: a long-term order on a price-only contract, short-term orders on an adjustment contract, and short-term purchases directly from the market. At the beginning of the planning cycle, the manufacturer places a long-term order and reserves a certain amount of supply capacity for the purpose of adjusting the long-term order, if needed. Before the selling season, the manufacturer has multiple options to place supplementary orders from the reserved capacity or from the market. We compare two types of capacity arrangements: dedicated capacity and overall capacity. Under a dedicated capacity arrangement, the manufacturer reserves capacities separately for different adjustment opportunities. On the other hand, under an overall capacity arrangement, she keeps the flexibility of using the reserved capacity within the given period for possibly multiple adjustments. We discuss the optimal procurement strategies and the criteria for capacity allocations, as well as the policy behavior and service performance in different situations.

Cheng, T.C. Edwin, Choi, Tsan-Ming, Feng, Qi, and Suresh P. Sethi. *Procurement Flexibility under Price Uncertainty: Innovative Quick Response Programs in Logistics and Supply Chain Management*. International Handbooks Information System (Springer Berlin Heidelberg) 2010, pp. 63-90.

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#### 6.2.15. New Policies for the Stochastic Inventory Control Problem with Two Supply Sources

Participants: Anshul Sheopuri, Ganesh Janakiraman, Sridhar Seshadri

We study an inventory system under periodic review in the presence of two suppliers (or delivery modes). The emergency supplier has a shorter lead-time than the regular supplier, but the unit price he offers is higher. Excess demand is backlogged. We generalize the recently studied class of Dual Index policies (Veeraraghavan and Scheller-Wolf (2008)) by proposing two classes of policies. The first class consists of policies that have an order-up-to structure for the emergency supplier. We provide analytical results that are useful for determining optimal or near-optimal policies within this class. This analysis and the policies which we propose leverage our observation that the classical "Lost Sales inventory problem" is a special case of this problem. The second class consists of policies that have an order-up-to structure for the regular supplier. Here, we derive bounds on the optimal order quantity from the emergency supplier, in any period, and use these bounds for finding effective policies within this class. Finally, we undertake an elaborate computational investigation to compare the performance of the policies we propose with that of Dual Index policies. One of our policies provides an average cost-saving of 1.1 % over the Best Dual Index policy and has the same computational requirements. Another policy which we propose has a cost performance similar to the Best Dual Index policy but its computational requirements are lower.

Janakiraman, Ganesh, Seshadri, Sridhar and Anshul Sheopuri. New Policies for the Stochastic Inventory Control Problem with Two Supply Sources, *Operations Research*, 58(3), (May-June 2010) pp. 734-745.

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## 6.2.16. Average Cost Single-Stage Inventory Models: An Analysis Using a Vanishing Discount Approach

Participants: W.T. Huh, G. Janakiraman and M. Nagarajan

An important problem in the theory of dynamic programming is that of characterizing sufficient conditions under which the optimal policies for Markov decision processes (MDPs) under the infinite-horizon discounted cost criterion converge to an optimal policy under the average cost criterion as the discount factor approaches 1. In this paper, we provide, for stochastic inventory models, a set of such sufficient conditions. These conditions, unlike many others in the dynamic programming literature, hold when the action space is noncompact and the underlying transition law is weakly continuous. Moreover, we verify that these conditions hold for almost all conceivable single-stage inventory models with few assumptions on cost and demand parameters. As a consequence of our analysis, we partially characterize, for the first time, optimal policies for the following inventory systems under the infinite-horizon average-cost criterion, which have thus far been a challenge:

- (a) capacitated systems with setup costs,
- (b) uncapacitated systems with convex ordering costs plus a setup cost, and
- (c) systems with lost sales and lead times.

W.T. Huh, G. Janakiraman and M. Nagarajan, Average Cost Single-Stage Inventory Models: An Analysis Using a Vanishing Discount Approach. 2011. *Operations Research*. 59: 1: 143-155.

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## 6.2.17. Optimal Policies for Inventory Systems with a Generalized Cost Model.

Participants: W.T. Huh, G. Janakiraman, A. Muharremoglu and A. Sheopuri

We study a single-stage inventory system with a generalized shortage penalty cost that includes the following three components: (i) a cost that is an increasing function of the number of backordered units in a period, (ii) a fixed cost incurred for each period in which there is a backorder irrespective of how many units are backordered, and finally (iii) a cost that is an increasing function of the number of periods a customer is backordered. We show the problem can be transformed into one in which the backorder cost depends on the inventory position only. Then, we present two sets of conditions, the first one of which restricts attention to a special case of the generalized penalty cost model while the second restricts attention to stationary demand models with some distributional assumptions. Under the first (second) set of conditions, we show that the expected cost in a period can be expressed as a convex (quasi-convex) function of the after-ordering inventory position. We use this property to prove the optimality of order-up-to policies under both sets of conditions, and discuss extensions to the cases where either a fixed ordering cost or a batch ordering constraint is present.

W.T. Huh, G. Janakiraman, A. Muharremoglu and A. Sheopuri, Optimal Policies for Inventory Systems with a Generalized Cost Model. *Operations Research*. (2011) 59 (4) 1040-1047.

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## 6.2.18. On the Optimal Policies for Inventory Systems with Batch Ordering

Participants: W.T. Huh and G. Janakiraman

We study a periodically reviewed multi-echelon inventory system in series such that order quantities at every stage have to be multiples of a given stage-specific batch size. The batch sizes are nested in the

sense that the batch size for every stage is an integer multiple of the batch size for its downstream stage. The problem is that of determining the policy which minimizes the expected discounted sum of costs over a finite horizon. The result is that an echelon  $(R;nQ)$  policy is optimal when demands are independent across periods, or more generally, Markov-modulated. We also comment on algorithmic implications of our result and on extensions.

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#### 6.2.19. Capacitated Serial Inventory Systems: Bounds for Simple Policies

Participants: W.T. Huh, G. Janakiraman and M.

We study the following prototypical model of a large scale supply chain: A periodically reviewed multi-echelon serial inventory system with a capacity constraint on the order quantity at every stage. Our goal is to find policies that minimize the sum of the expected long run average holding and shortage costs for this system. It is well known that for this problem, characterizing the structure of the optimal policy and computing it are very difficult. This problem is a generalization of two well-understood and fundamental building blocks in inventory theory, namely the one of managing uncapacitated multi-echelon serial systems and that of managing capacitated single location inventory systems. We consider the use of echelon base-stock policies for our system (even though they are known to be sub-optimal) and propose algorithms for finding base-stock levels. Our algorithms are based on integrating existing optimal or near-optimal algorithms for the two building blocks and therefore easy to understand and implement (in fact, two of our three algorithms only involve newsvendor computations). We derive bounds on the ratios between the costs achieved by our algorithms and the optimal costs (over all policies). Our algorithms are shown to be asymptotically optimal in the sense that our bounds are close to one in high service-level environments. Next, we perform a computational investigation of the performance of our algorithms on a sample bed of problem instances in which the service levels range from modestly high (67%) to very high (99%). On each problem instance, we evaluate the costs of our algorithms and compare them with the cost of the best base-stock policy and with a lower bound on the optimal cost. The best of our algorithms achieves a cost which is only 1.7% more, on an average, than the cost of the best base-stock policy. Further, our computational investigation reveals that the cost of the best base-stock policy is, on an average, no more than 0.6% higher than a lower bound on the optimal cost. This seems to confirm that base-stock policies are effective (even though sub-optimal, in general) for managing capacitated serial inventory systems. Finally the development of our algorithms is robust in that they can immediately exploit advances made by researchers in the computations of policies for the two building blocks to provide heuristics for serial capacitated inventory systems.

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#### 6.2.20. Simple Policies for Managing Flexible Capacity

Participants: G. Janakiraman, M. Nagarajan and S. Veeraraghavan

In many production scenarios, a fixed capacity is shared flexibly between multiple products. To manage such multi-product systems, firms need to make two sets of decisions. The first one requires setting an inventory target for each product and the second decision requires dynamically allocating the scarce capacity among the products. It is not known how to make these decisions optimally. In this paper, we propose easily implementable policies that have both theoretical and practical appeal. We first suggest simple and intuitive allocation rules that determine how such scarce capacity is shared. Given such a rule, we calculate the optimal inventory target for each product. We demonstrate analytically that our policies are optimal under certain assumptions in two asymptotic regimes represented by high service levels (i.e. high shortage costs) and heavy traffic (i.e. tight capacity). We also demonstrate numerically that they

significantly outperform policies suggested previously over a wide range of problem parameters. In particular, the cost savings from our policies become more significant as the capacity gets more restrictive.

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#### 6.2.21. Analysis of Tailored Base-Surge Policies in Dual Sourcing Inventory Systems

Participants: G. Janakiraman, S. Seshadri and A. Sheopuri

We study a model of firm managing its inventory of a single product by sourcing supplies from two supply sources, a regular supplier who offers a lower unit cost and a longer lead time than a second, emergency, supplier. It has been observed that such a firm often uses a Tailored Base-Surge (TBS) Policy (Allon and Van Mieghem, 2010) to manage its inventory: Under this policy, the firm procures a constant quantity from the regular supplier in every period and dynamically makes procurement decisions for the emergency supplier. Allon and Van Mieghem describe this practice as using the regular supplier to meet a base level of demand and the emergency supplier to manage demand surges, and they conjecture that this practice is most effective when the lead time difference between the two suppliers is large. We present a set of analytical results to validate these statements. The most important of our analytical results are the following: (1) When demand is composed of a base demand random component plus a surge demand random component, which occurs with a certain small probability, the best TBS Policy is close to optimal (over all policies) in a well defined sense. (2) The performance of the best TBS policy improves as the lead time difference between the two suppliers grow. Moreover, the cost increase incurred because of the use of this simple policy relative to the complicated optimal policy is bounded by a constant for sufficiently large lead time differences. In addition to our analytical results, we also numerically investigate the cost-effectiveness of the best TBS policy on a test bed of problem instances. The emphasis of this investigation is the study of the effect of the lead time difference between the two suppliers. Our study reveals that the cost difference between the best TBS policy and the optimal policy decreases dramatically as the lead time of the regular supplier increases. On our test bed, this cost difference decreases from an average (over the test bed) of 21 % when the lead time from the regular supplier is two periods (the emergency supplier offers instant delivery) to 3.5 % when that lead time is seven periods.

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#### 6.2.22. Performance of the Clark-Scarf Algorithm for Lost-Sales Inventory Systems

Participants: M. Bijvank, W.T. Huh and G. Janakiraman

We study the optimal policy for a serial inventory system under periodic review when excess demand at the retailer (i.e., the most downstream stage) is lost. We focus on high service level environments" (i.e., systems where the cost of a lost sale is high compared to inventory holding costs). These environments are typical of products whose margins are high relative to their holding costs. When excess demand is backordered, the optimal policy is a base-stock policy with base-stock levels calculated using the algorithm of Clark and Scarf [1960]. In this paper, we first propose to use this algorithm in lost-sales inventory systems by setting the backorder cost parameter in the algorithm to be equal to the lost-sales cost parameter. We show that the resulting base-stock policy is asymptotically optimal as the lost-sales penalty cost parameter grows. We also show that this result is robust in the following sense: There is a large family of choices for the backorder cost parameter used in the algorithm such that the asymptotic optimality continues to hold. Next, we propose a specific choice for the backorder cost parameter based on a power approximation formula. While the theoretical results guarantee asymptotical optimality as the service level approaches one, our computational investigation of problem instances with moderately high

values for the service level (75%-99%) shows that the cost of the best base-stock policy is, on an average, 1.6% higher than the cost of the optimal policy, and the cost of the base-stock policy based on the power approximation is only 0.2% higher than that of the best base-stock policy.

### 6.2.23 Overbooking Limits for a Two-Dimensional Cargo Problem

Participants: L. Moussawi, and M. Çakanyildirim.

This article considers a two-dimensional cargo overbooking problem, with the objective of finding the optimal weight and volume overbooking limits that maximize the profit from shipping cargos on a particular flight. The pricing structure is nonlinear because it uses the chargeable weight of the showing up cargo, as implemented in practice, as opposed to the approximate additive structure considered in the literature. An aggregate formulation that does not require much data is provided and solved under infinite and finite booking requests. The optimal overbooking curve is shown to be a ‘box’, defined by only two threshold numbers, one for volume and one for weight. Furthermore, the aggregate formulation can be solved efficiently and its simple ‘box’ solution can be implemented with ease by air cargo practitioners. The aggregate formulation is then compared to the detailed or actual overbooking formulation, in which the revenues are computed individually cargo by cargo. Using real-life data, we show that our model approximates well the actual cargo problem, when the density of the cargo shipped is not highly variable, more specifically, when it ranges between 6.2 and 16.2 lb/ft<sup>3</sup>, which is the case for high-technology, low density products such as computers and consumer electronics. We find that this applies to 60 per cent of the flights. Also, we compare our model to the additive one, and numerically prove that savings up to 13.8 per cent can be achieved when implementing the aggregate model as opposed to the existing additive model.

Moussawi, L. and M. Çakanyildirim. Optimal Overbooking Limits for a Two-Dimensional Cargo Problem. *Journal of Revenue and Pricing Management*. Forthcoming.

## 6.3. Activities in Finance and Economics

### 6.3.1. Real Options and Game Models

Participants: Alain Bensoussan, David Diltz and Celine Hoe

We consider optimal investment strategies for projects under uncertainty, when there is competition. We study the situation of complete and incomplete markets. Both a Leader-Follower Stackelberg game and a Nash Equilibrium game are considered. The approach of real options bears similarity with that of American options in financial engineering. A major component of the decision is when to invest (or to enter into the market). It is a random time. Each of the players has to decide when to enter. However, in the Stackelberg game the follower cannot enter before the leader whereas in the Nash game both players face the preemption risk when making investment decisions. There is in addition a regulation which clarifies how they share the market, if they decide both to compete. The assumption of complete or incomplete markets plays a fundamental role in defining the objective functions of both players. As it is customary for optimal stopping time problems, Dynamic Programming leads to Variational Inequalities. However, new structures arise with interesting mathematical questions. In most cases, we are able to solve completely the problems and to obtain optimal stopping strategies. But the results are not intuitive.

Bensoussan, A., C. Hoe, and D. Diltz. Real Options Games in Complete and Incomplete markets with Several Decision makers, *SIAM J. of Financial Mathematics*,1(1) (online September 2010) pp. 666-728.

Bensoussan, A., S. Hoe and D. Diltz. Real Options and Competition, *Stochastic Analysis, Stochastic Systems, and Applications to Finance*. D. Nualart and G. Yin (Eds.), World Scientific. Forthcoming.

Bensoussan, A., S. Hoe and H-K Koo. *Real Options and Variational Inequalities*, Hyeng Kuen Koo and Jaeyoung Sung (Eds.), IOS Press. Forthcoming.

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### 6.3.2. Value of Population in Economic Growth Models

Participants: K.J. Arrow, Alain Bensoussan, Qi Feng, Suresh Sethi

Traditional economic growth models are based on capital as the state variable. It is clear that modern economies must take into account other state variables. Population is a very important one. Following models developed by K.J. Arrow, we have considered an economy in which the rate of change of population depends on population policy decisions. This requires population as well as capital as state variables. By showing the algebraic relationship between the shadow price of the population and the shadow price of the per capita capital stock, we are still able to depict the optimal path and its convergence to the long-run equilibrium on a two-dimensional phase diagram. Moreover, we derive explicitly the expression of genuine savings in our model to evaluate the sustainability of the system.

Arrow, K.J., A. Bensoussan, Q. Feng, and S.P. Sethi. *The Genuine Savings Criterion and the Value of Population in an Economy with Endogenous Fertility Rate*. Optimal Control of Age-structured Population in Economy, Demography, and the Environment, Series: Routledge Explorations in Environmental Economics, R. Boucekkine, N. Hritonenko, and Y. Yatsenko (Eds.), Routledge (Taylor & Francis, UK), Routledge, New York (September 2010) pp. 20-44.

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### 6.3.3. Cash Management

Participants: Alain Bensoussan, Suresh Sethi, A. Chutani

We consider problems of consumption and investment, with transaction costs. These transaction costs are materialized in the evolution of cash, considered as a state variable. The return on the investment is random. The decision variables are the rate of consumption, as well as the amount of cash invested in the stocks. This approach is centered on the cash management, whereas traditional approaches in Finance tend to eliminate the cash and to center on the portfolio management. The major advantage is to introduce the transactions costs as proportional to the rate of transformation of cash into stocks. Our theory is so far limited to one stock. In this case, we characterize the optimal strategy of investment, with several assumptions on the random behavior of the return on the stock.

Bensoussan, A., A. Cadenillas, H-K Koo and J. Sung. *Credit Risk with Selection of Effort and Volatility*, Hyeng Kuen Koo and Jaeyoung Sung (Eds.), IOS Press. Forthcoming.

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#### 6.3.4. Mutual Insurance

Participants: Alain Bensoussan, J. Liu, J. Yuan

This research takes place at PolyU. We consider a mutual insurance system whose reserve evolves as a Brownian motion, as a consequence of the occurrence of hazards. The controller tries to minimize the total cost by increasing or reducing the reserve by instant jumps. Both cases of zero and positive fixed costs are investigated. We apply the theory of Quasi-variational inequalities and make the connection between singular control and impulse control. The procedures to solve these systems are also studied. Mutual insurance is widely used in maritime transport.

Bensoussan, A., J. Liu, and J. Yuan. *Singular Control and Impulse Control with Application to Mutual Insurance Optimization, Decision and Control*, Joint 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference Shanghai, P.R. China, December 16-18, 2009 (January 2010).

[http://ieeexplore.ieee.org/xpls/abs\\_all.jsp?arnumber=5399852&tag=1](http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5399852&tag=1)

Bensoussan, A., J. Liu, and J. Yuan. Singular Control and Impulse Control: A Common Approach, *Journal of Discrete and Continuous Dynamical System*, 13(1) (January 2010)

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#### 6.4. Activities in Alternative Energies

6.4.1. Participants: Alain Bensoussan, P. Bertrand and A. Brouste

This research is supported by EDF. We have developed a new approach concerning the forecast of annual production of wind energy by a windmill. This is important at the investment level, since it is essential to obtain an accurate estimate of the potential energy to assess the profitability. As a matter of fact, we have shown that a substantial amount of uncertainty is overlooked by the current approaches, both in the literature and in the practitioners' techniques. We next would like to develop more accurate models. In a first step, we are interested in the seasonality aspects.

Bensoussan, A. and N. Farhi. *Uncertainties and Risks in Water Resources Management*. The Economics of Sustainable Development, H, J. Lasry, D. Lautier, D. Fessler (Eds.) *Economica*, pp. 163-179.

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#### 6.5. Activities in Risks on Technical Systems

6.5.1. Critical Excitation for Elasto-Plastic Systems

Participants: Alain Bensoussan, Keerthi Chandrasekaran, Janos Turi

Elasto-plastic oscillators are used as the simplest models in the study of the nonlinear response of structures under severe loads (like earthquakes). The response of the structure to an excitation typically can be described as a sequence of alternating elastic and plastic phases and the size of the accumulated plastic deformation plays a critical role in system reliability. In this project we are interested in finding the "critical excitation", i.e., the lowest energy input excitation that drives the system between prescribed initial and final states within a given time span. Critical excitation corresponds to identifying a particular input, out of inputs with given total energy, which creates the largest deformation in the structure. This is an optimal control problem for a state evolution for the variational inequality modeling the elasto-plastic

system. We provide a complete solution of this problem by extending classical results to a class of non-smooth systems which include the elasto-plastic case. We also derive an algorithm which provides good approximations of the critical excitation.

Bensoussan, A., K. Chandrasekaran, and J. Turi. Optimal Control of Variational Inequalities, *Communications in Information and Systems*, 10(4), (October 2010) pp. 203-220.

Bensoussan, A. and J. Turi. *On a Class of Partial Differential Equations with Nonlocal Boundary Conditions*, Applied and Numerical Partial Differential Equations: Simulation, Optimization, and Control in MultiApplications, W. Fitzgibbon, Y. Kuznetsov, P. Neittaanmaki, J. Periaux, and O. Pironneau (Eds.) ECCOMAS Springer Series, (January, 2010) pp. 9-24.

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### 6.5.2. Elastic-Plastic Systems Excited by Non-White Noise

Participants: Alain Bensoussan, Laurent Mertz

Elasto-plastic oscillators represent useful models for predicting the nonlinear response of structures when pressed beyond the elastic limit due to severe loads. In this project the case when the power spectral density (PSD) of the input excitation is non constant is investigated using the stochastic variational inequality framework. This input, which is given by an Orstein-Uhlenbeck process, is more realistic than the pure white-noise excitation investigated previously. Using an extension of Khasminskii's method the ergodic properties of the process are obtained and the corresponding invariant measure is characterized.

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### 6.5.3. New Results on Ergodicity of Elastic-Plastic Systems

Participants: Alain Bensoussan and Laurent Mertz

We have obtained new approaches for proving ergodicity of Elastic-Plastic Oscillators. They are purely analytic and are related to the solution of non-local P.D.E. We have also rigorously proved a well known result identified empirically by engineers using simulation. This concerns the variance of displacement during a period of time, which grows linearly with the length of the period. This has enhanced the credibility of our mathematical methods with respect to practitioners.

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### 6.5.4. Computing the Frequency of Deformations for Elasto-Plastic Oscillators

Participants: Laurent Mertz and Cyril Feau

Statistical properties of the response of an elasto-plastic oscillator under white noise excitation is considered by means of its invariant measure and a modification of Rice's formula for the frequency of threshold crossings. The mean frequency of threshold crossings is then obtained as the solution of a partial differential equation.

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## **7. Publications**

### **2010**

Arrow, K.J., A. Bensoussan, Q. Feng, and S.P. Sethi. *The Genuine Savings Criterion and the Value of Population in an Economy with Endogenous Fertility Rate*. Optimal Control of Age-structured Population in Economy, Demography, and the Environment, Series: Routledge Explorations in Environmental Economics, R. Boucekkine, N. Hritonenko, and Y. Yatsenko (Eds.), Routledge (Taylor & Francis, UK), Routledge, New York (September 2010) pp. 20-44.

Asunur, C., H. Cavusoglu, and S. Raghunathan. Outsourcing Information Security: Contracting Issues and Security Implications. Proceedings of the Ninth Workshop on the Economics of Information Security (WEIS) (June 2010). <http://weis2010.econinfosec.org/program.html>

Bandhopadhyay, T., V. Jacob, and S. Raghunathan. Information Security in Networked Supply Chains: Impact of Network Vulnerability and Supply Chain Integration on Incentives to Invest, *Information Technology and Management*, 11(1), (2010) pp. 7-23.

Bensoussan, A., T. Basar, and S.P. Sethi. Differential Games with Mixed Leadership: The Open-Loop Solution, *Applied Mathematics and Computation*, 217(3), (online January 2010) October 2010, pp. 972-979.

Bensoussan, A., M. Çakanyildirim, J.A. Minjarez-Sosa, S.P. Sethi, and R. Shi. An Incomplete Information Inventory Model with Presence of Inventories or Backorders as Only Observations, *Journal of Optimization Theory and Applications*, 146(3), (September 2010) pp. 544-580.

Bensoussan, A., M. Çakanyildirim, and L. Moussawi. Inventory Control with an Order-Time Constraint: Optimality and Uniqueness, *Annals of Operations Research*, 181(1), (September 2010) pp. 603-640.

Bensoussan, A., K. Chandrasekaran, and J. Turi. Optimal Control of Variational Inequalities, *Communications in Information and Systems*, 10(4), (October 2010) pp. 203-220.

Bensoussan, A. and N. Farhi. *Uncertainties and Risks in Water Resources Management*. The Economics of Sustainable Development, H, J. Lasry, D. Lautier, D. Fessler (Eds.) Economica, pp. 163-179.

Bensoussan, A., Q. Feng, and S.P. Sethi. Achieving a Long-Term Service Target with Periodic Signals: A Newsvendor Framework, *Manufacturing & Service Operations Management (MSOM)* (May 2010).

Bensoussan, A., J. Frehse, and J. Vogelgesang. Systems of Bellman Equations to Stochastic Differential Games with Non-Compact Coupling, *Discrete and Continuous Dynamical Systems- Series A*, 27(4), (August 2010) pp. 1375-1390.

Bensoussan, A., C. Hoe, and D. Diltz. Real Options Games in Complete and Incomplete markets with Several Decision makers, *SIAM J. of Financial Mathematics*, 1(1) (online September 2010) pp. 666-728.

Bensoussan, A., C. Hoe, and M. Kantarcioglu. *A Game-Theoretical Approach for Finding Optimal Strategies in a Botnet Defense Model*. Decision and Game Theory for Security First International Conference, GameSec 2010, Berlin, Germany, November 22-23, 2010. Proceeding, T. Alpcan, L. Buttyan, and J. Baras (Eds.), Vol. 6442, pp. 135-148.

Bensoussan, A., C. Hoe, and M. Kantarcioglu. *When Do Firms Invest in Privacy-Preserving Technologies?* Decision and Game Theory for Security First International Conference, GameSec 2010, Berlin, Germany, November 22-23, 2010. Proceeding, T. Alpcan, L. Buttyan, and J. Baras (Eds.), Vol. 6442, pp. 72-86.

Bensoussan, A., J. Liu, and J. Yuan. Singular Control and Impulse Control: A Common Approach, *Journal of Discrete and Continuous Dynamical System*, 13(1) (January 2010)

Bensoussan, A., J. Liu, and J. Yuan. *Singular Control and Impulse Control with Application to Mutual Insurance Optimization, Decision and Control*, Joint 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference Shanghai, P.R. China, December 16-18, 2009 (January 2010).

Bensoussan, A. and J. Turi. *On a Class of Partial Differential Equations with Nonlocal Boundary Conditions*, Applied and Numerical Partial Differential Equations: Simulation, Optimization, and Control in MultiApplications, W. Fitzgibbon, Y. Kuznetsov, P. Neittaanmaki, J. Periaux, and O. Pironneau (Eds.) ECCOMAS Springer Series, (January, 2010) pp. 9-24.

Cavusoglu, K., B. Koh, S. Raghunathan. An Analysis of the Impact of Passenger Profiling for Transportation Security. *Operations Research*. (September/October 2010) 58 (5). pp. 1287-1302  
<http://or-journal.informs.org/cgi/content/abstract/58/5/1287>

Cheng, T.C. Edwin, Choi, Tsan-Ming, Feng, Qi, and Suresh P. Sethi. *Procurement Flexibility under Price Uncertainty: Innovative Quick Response Programs in Logistics and Supply Chain Management*. International Handbooks Information System (Springer Berlin Heidelberg) 2010, pp. 63-90.

Haoya Chen, Youhua (Frank) Chen, Chun-Hung Chiu, Tsan-Ming Choi and Suresh Sethi. Coordination Mechanism for the Supply Chain with Leadtime Consideration and Price-Dependent Demand, *European Journal of Operational Research*, 203(1), (May 2010) Pages 70-80.

Janakiraman, Ganesh, Seshadri, Sridhar and Anshul Sheopuri. New Policies for the Stochastic Inventory Control Problem with Two Supply Sources, *Operations Research*, 58(3), (May-June 2010) pp. 734-745.

Li, Xiao-Bai and Sumit Sarkar. *Data Clustering and Micro-perturbation for Privacy-Preserving Data Sharing and Analysis*. ICIS 2010 Proceedings, Paper 58, (2010),  
[http://aisel.aisnet.org/icis2010\\_submissions/58](http://aisel.aisnet.org/icis2010_submissions/58).

Mai, Bin, N. Menon, and Sumit Sarkar. No Free Lunch: Price Premium for Privacy Seal-Bearing Vendors, *Journal of Management Information Systems*, 27(2) (2010) pp. 189 – 212.

## 2011

Bensoussan, A., M. Çakanyildirim, and S.P. Sethi. Filtering for Discrete-Time Markov Processes and Applications to Inventory Control with Incomplete Information, *Handbook on Nonlinear Filtering*, D. Crisan and B. Rozovsky (Eds.), Oxford University Press (April 2011) pp. 500-525.

Bensoussan, A., S. Hoe and M. Kantarcioglu. When Do Firms Invest in Privacy-Preserving Technologies? *E-Letter of Multimedia Communications Technical Committee (MMTC), IEEE Communications Society*, 6(4), April 2011, pp. 15-17.

Bensoussan, A., M. Çakanyildirim, J.A. Minjarez-Sosa, S.P. Sethi, and R. Shi. Computation of Approximate Optimal Policies in Partially Observed Inventory Model with Rain Checks, *Automatica*, 47(8), (27 July 2011 online), pp. 1589-1604.

Bensoussan, A., R. Mookerjee, V. Mookerjee and W.T. Yue. When Hackers Talk: Managing Information Security under Variable Attack Rates and Information Dissemination, *Information Systems Research*, (online 2010), doi: 10.1287/isre.1100.0341 22(3) pp. 606.

Bensoussan, A. *Dynamic Programming and Inventory Control* (IOS Press 2011) Vol. 3 Studies in Probability, Optimization and Statistics.

Huh, W.T., G. Janakiraman and M. Nagarajan, Average Cost Single-Stage Inventory Models: An Analysis Using a Vanishing Discount Approach. 2011. *Operations Research*. 59: 1: 143-155.

Huh, W.T., G. Janakiraman, A. Muharremoglu and A. Sheopuri, Optimal Policies for Inventory Systems with a Generalized Cost Model. 2011 *Operations Research*. 59: 4: 1040-1047

Menon, N., H. Ögüt, and S. Raghunathan. Cyber Security Risk Management: Public Policy Implications of Correlated Risk and Imperfect Ability to Prove Loss. *Risk Analysis*. (March 2011) 31(3), pp. 497–512.

#### Accepted

Bensoussan, A. and L. Benkherouf. Discrete-Time Inventory Problems with Lead Time and Order Time Constraint, D. Hernandez and A. Minjarez-Sosa (Eds.), Birkhauser. Forthcoming.

Bensoussan, A., M. Bulicek and J. Frehse. Existence and Compactness for Weak Solutions to Bellman Systems with Critical Growth, *AIMS' Journals (DCDS-B)*, Forthcoming.

Bensoussan, A., A. Cadenillas, H-K Koo and J. Sung. *Credit Risk with Selection of Effort and Volatility*, Hyeng Kuen Koo and Jaeyoung Sung (Eds.), IOS Press. Forthcoming.

Bensoussan, A., M. Çakanyildirim, M. Li and S.P. Sethi. *Existence and Uniqueness of Solutions for a Partially Observed Stochastic Control Problem*, World Scientific. Forthcoming.

Bensoussan, A., M. Çakanyildirim, S.P. Sethi, M. Wang and H. Zhang. Average Cost Optimality in Inventory Models with Dynamic Information Delays. *IEEE Transactions on Automatic Control*. Forthcoming.

Bensoussan, A., S. Hoe and D. Diltz. Real Options and Competition, *Stochastic Analysis, Stochastic Systems, and Applications to Finance*. D. Nualart and G. Yin (Eds.), World Scientific. Forthcoming.

Bensoussan, A., S. Hoe and M. Kantarcioglu. Impact of Security Risks on Cloud Computing Adoption, *Proceedings of Forty-Ninth Annual Allerton Conference*. Forthcoming.

Bensoussan, A., S. Hoe and M. Kantarcioglu Investment in Privacy-Preserving Technologies under Uncertainty, *GamSec 2011, LNCS Vol 7037*. Forthcoming.

Bensoussan, A., S. Hoe and H-K Koo. *Real Options and Variational Inequalities*, Hyeng Kuen Koo and Jaeyoung Sung (Eds.), IOS Press. Forthcoming.

Bensoussan, A., J.L. Lions and G. Papanicolaou. Asymptotic Analysis for Periodic Structure, Elsevier, Reprint online <http://www.sciencedirect.com/science/bookseries/01682024>. Forthcoming.

Bensoussan, A., R. Mookerjee, V. Mookerjee and W.T. Yue. Managing Information Security Under Continuous Drift and Sudden Shocks, *CIST 2011*. Forthcoming.

Çömez, N., K. Stecke, and M. Çakanyildirim. In-Season Transshipments among Competitive Retailers. *Manufacturing and Service Operations Management*. Forthcoming.

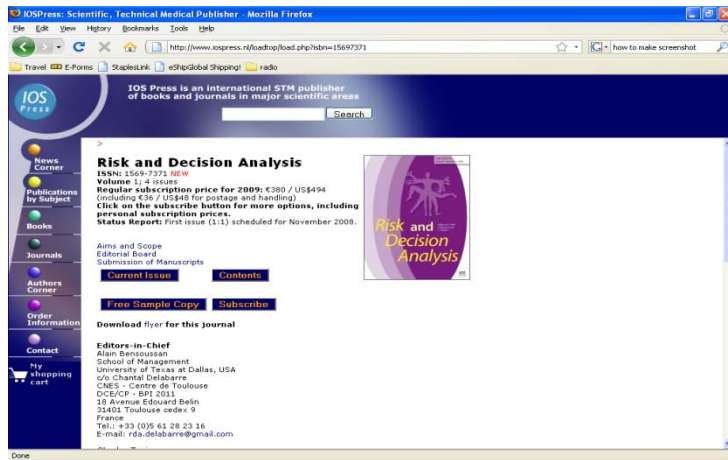
Çömez, N., K. Stecke, and M. Çakanyildirim. Multiple In-Cycle Transshipments with Positive Delivery Times. *Production and Operations Management*. Forthcoming.

Li, Xiao-Bai and S. Sarkar. Protecting Privacy against Record Linkage Disclosure: A Bounded Swapping Approach for Numeric Data. *Information Systems Research*. Forthcoming.

Moussawi, L. and M. Çakanyildirim. Optimal Overbooking Limits for a Two-Dimensional Cargo Problem. *Journal of Revenue and Pricing Management*. Forthcoming.

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