# Introduction: Operations Research in the E-Business Era

This special issue of *Interfaces* on operations research (OR) in e-business carries a simple message: OR has a key role to play in the emerging digital economy. The message may be simple, but giving it substance as a collection of articles was not. We knew it was true from our many years of interest in the Internet's professional and business applications, from our long-term activities at the intersection of information technology with OR, and from teaching many e-business courses. Yet few of our colleagues and industry friends—even ones who shared our interest in e-business—were able to cite any OR applications in this area.

This set off an intensive, year-long search for such applications and an inquiry into the nature of the opportunities for OR. With the help of students, staff, and research assistants—which we gratefully acknowledge—we queried scores of friends, acquaintances, and experts in academia and industry, culled through innumerable articles and books, posted queries to several online lists, probed hundreds of Web sites (companies, conferences, e-commerce courses at other universities, and OR societies around the world), scanned the recent issues of many OR and e-commerce publications, culled through all of the software surveys published in *OR/MS Today* looking for Web-enabled products, wrote to INFORMS members at many of the leading Internet companies, wrote to most of the OR software vendors that advertise in *OR/MS Today*, and queried INFORMS' searchable databases (annual comprehensive index, conference papers, presentations, and working papers). We accumulated our findings as we went along in a shared document that now exceeds 150 pages, which we consulted and revised almost daily.

These findings indicate that the opportunities for OR are numerous and important. Bona fide, nonconfidential OR applications were somewhat slow in getting started but are now coming in greater numbers.

We hope that this special issue will help to narrow the seeming gulf between opportunity and achievement by helping OR professionals to better appreciate what could be done and what has been done. Each of the papers we commissioned contributes to this aim in its own way.

## The Papers

"Prospects for Operations Research in the E-Business Era" by A. M. Geoffrion and R. Krishnan sets the stage for most of what follows. In this portrait of the whole e-business landscape, we identify where OR has been most active: information goods and services (especially online financial and travel-related services), supply-chain management, e-business network infrastructure (especially quality-of-service topics), and packaged OR software that is Web-enabled or oriented toward e-business. We point out further opportunities for OR to contribute, and we close

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with some suggestions for OR professionals who wish to work on e-business applications.

In "E-Commerce and Operations Research in Airline Planning, Marketing and Distribution," B. C. Smith, D. P. Günther, B. V. Rao, and R. M. Ratliff begin by describing how the airline industry pioneered an early version of e-commerce about four decades before the present era of Internet-based e-business. American Airlines and its Sabre Inc. spin-off have been near the center of these developments from the beginning, and their experience is instructive in several ways even beyond the airline industry. Of particular interest are (1) the story of their multichannel, multivendor, global distribution system for reservations (compare with today's vertical Web portals), (2) how low-fare search engines had to be rebuilt to accommodate popular access via the Web (producing low-price search functionality similar to that in comparison-shopping engines), (3) OR's role in helping airlines develop revenue-maximizing countermeasures when display bias in computer reservation systems led to new regulation (similar results-display design optimization problems lurk behind almost all Web search engines), and (4) OR's role in yield (or revenue) management, a technique that is propagating rapidly as other industries realize the dramatic opportunities for dynamic pricing that the Internet presents.

"Applications and Opportunities for Operations Research in Internet-Enabled Supply Chains and Electronic Marketplaces," by M. S. Sodhi, is an essay on one of the areas most heavily impacted by the advent of the digital economy. Sodhi begins by surveying the important legacy of the last decade of enterprise resource planning (ERP), which is really about transaction processing rather than planning, and of advanced planning and scheduling (APS) systems. He provides a detailed example showing the use of ERP and APS in a Web-enabled supply-chain environment for an electronics company. He explains how Internet-enabled supply chains and electronic marketplaces help coordinate supply and demand for manufacturing capacity, materials, and logistics across the supply chain. A highlight of this essay is the detailed explanation of why supply-chain models for e-business need, by comparison with most past models, (1) longer decision horizons for supply-chain management processes, (2) broader physical scopes that take account of manufacturers' increasing collaboration with customers and vendors, and (3) broader functional scopes that include product design, sales, and customer-relationship management. To capture these emerging research and application opportunities, OR practitioners must invest heavily in staying abreast of Internet-based technologies and e-business processes.

In "Quantitative Analysis for Internet-Enabled Supply Chains," P. Keskinocak and S. Tayur go deeply into business-to-business spot markets, auctions, and exchanges. This is an important area, since electronic markets are forecast to become on the order of half of all e-commerce trade within a few years. The focus is on the complex dynamics that arise as the Internet causes supply-chain management to become more collaborative. They consider

supply-demand matching between multiple suppliers and buyers participating in a business-to-business exchange, spot markets for capacity and inventory, dynamic pricing, online negotiations, and many kinds of auctions. They demonstrate the value of math programming in supply-demand matching and make use of stylized economic models—sometimes including game theoretic elements—as a basis for solving strategic problems, such as bidding behavior, capacity reservation, and pricing, that arise in the context of auctions and spot markets. Their examples illustrate the need for more strategic analysis to complement the kinds of planning and operational applications that have been OR's forte. The authors believe the e-business era creates a major opportunity for the too-long separate modeling traditions of economics and OR to mate and produce techniques that carry economic insights and qualitative results much farther toward computable solutions to practical problems.

Next we turn to Internet marketing, which has become a major focus of interest in business schools owing to its many potential applications to business-to-consumer e-commerce. Texts have started to appear, including Ward Hanson's *Principles of Internet Marketing* [2000], and focused issues of leading journals are also starting to appear, notably the winter 2000 special issue of *Marketing Science* on "Marketing science and the Internet." Although few papers on real-life Internet marketing applications have been published so far, industry professionals are quietly using existing tools, and many university researchers are working with real data.

In "Applying Quantitative Marketing Techniques to the Internet," A. L. Montgomery advances the thesis that a lot of mileage remains in the known theory and techniques of marketing science for those able to make the connections between the apparently new problems of Internet marketing and those already studied. The author illustrates this convincingly with his discussion of diffusion models applied to viral marketing, conjoint analysis for purchase prediction, models for estimating price sensitivity in such a way as to inform online (real-time) pricing and coupon decisions, and clickstream (Web-site navigational) data analysis for profiling Web-site visitors.

To elaborate briefly on the third item above, Montgomery discusses the issue of brand equity using the example of an online bookstore. Using a comparison shopping engine, consumers can retrieve offers from multiple vendors for the same book. Given data from these engines and data on the offers users choose for purchase, an analyst can use a standard multinomial logit model to estimate the probability that a consumer will accept an offer from a branded store. This provides information on the premium that a branded store may be able to charge over a nonbranded store, thereby measuring brand equity and informing pricing strategy.

E-business is having a big impact on OR-software vendors, many of whom are Web-enabling their software and seeking to exploit some of the digital economy's new business opportunities. We turned to one of the largest such vendors for an account of this impact on its products and services: SAS Institute, which for more

than two decades has provided software for data management, OR, statistical analysis, and related functions.

In "Decision Support with Web-Enabled Software," M. D. Cohen, C. B. Kelly, and A. L. Medaglia focus on three of SAS's extensive efforts to exploit Web technology. The first uses an application server architecture to deploy mathematical-programming applications over the Web. The authors give examples from procurement, production, inventory, and distribution planning. The second effort is to facilitate data visibility using the Web. Model solutions can be treated very much like data; the Web is a nearly ideal medium for internally publishing data and solutions. SAS's tools for supporting this are advanced, including drill-down, drill-up, and dynamically created Web pages. The Lockheed Martin example shows that these tools can be combined effectively with analytical methods, such as an algorithm for calculating $n$th longest paths in a CPM context for the purpose of cycle-time reduction. The third effort has to do with applying data-mining techniques to data describing users' Web-navigational paths. All Web servers generate such data, which can shed light on consumer behavior and Web-site design. Data mining is of great interest to management these days. OR professionals have the background to easily understand most data-mining techniques, and therefore are in a good position to advise on and benefit from data-mining tools like those fielded by SAS.

The final paper in this issue is a comprehensive guide to online resources of potential value to anyone who needs to solve optimization problems.

In "Optimization as an Internet Resource," Robert Fourer and Jean-Pierre Goux provide a state-of-the-art survey of how the Internet can facilitate optimization. Building on their experience with the NEOS (Network Enabled Optimization System) project, the authors thoroughly discuss how the components that make up the usual monolithic desktop optimization system can be distributed and made available as services over the Internet. (This move to conceive of software-system components as services is in line with recently announced thrusts, such as Hewlett Packard's e-speak.) The paper covers optimization servers (modeling language only, solver only, and integrated), optimization clients (client-server, Java applets, and metacomputing for solving very large problems on networks of workstations), and application service providers. Thus, for example, a user armed with a favorite modeling-language tool can design, instantiate, and then solve a model by sending it (for example, using HTML forms) to a chosen solver for execution. This is all free for now, and many real problems can be solved conveniently in this manner, but this is not an industrial-strength approach. In the future, we can expect that application service providers (ASPs) will provide enhanced services of this sort on a commercial basis, but they must overcome some problems first. As the authors explain, a triple fusion must occur between (1) IT expertise in the Internet and distributed computing, (2) resource management and allocation expertise, and (3) an economic understanding of the role of Internet intermediaries. It should then be possi-

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ble to create scalable servers that can handle the likely demands for solver and modeling services at attractive prices.

## Complements and Compliments

A companion Web site for this special issue contains all of the papers in this issue in a form that, in exception to standard policy, will be free to all indefinitely. We thank the INFORMS board for granting this exception so that, as a service to the profession, OR professionals who are not yet INFORMS members can have ready access. We invite you to visit this site and to contribute your ideas and pointers to current work in its discussion areas.

Finally, we want to express our gratitude, first to all the authors for their outstanding cooperation. They were a pleasure to work with as they wrote and rewrote their papers on the Internet five to six times in response to an average of seven reviewers and *Interfaces*' excellent managing editor, Mary Haight. Fewer reviews and drafts would have sufficed, but our theory is that authors can never have too much feedback. Our thanks go second to our reviewers, acknowledged by name below. They, too, worked unselfishly on Internet time and produced quality work. And third to Editor-in-Chief Terry Harrison for his strong encouragement and support for this special issue, and his ready agreement that the fast-moving nature of the e-business revolution required publication as soon as the papers were in final form.

Our next project is a special issue of *Management Science* on the same topic, this time with research rather than practice in mind. We invite your assistance.

## Online References

Underlined terms in the papers indicate online references.

Companion Web site (www.informs.org/ebiz/interfaces/)

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