

E-Business and Management Science: Mutual Impacts (Part 1 of 2)

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This begins a two-part commentary on management science and e-business, the theme of this two-part special issue. After explaining the topical clusters that give organization to both parts, we pose two key questions concerning the impact of the emerging digital economy on management science research: What fundamentally new research questions arise, and what kind of research enables progress on them. We sketch the papers appearing in this part from the perspective of both these questions, and offer summary comments on the first question based on the papers in both parts. The principal conclusion is that the digital economy is giving birth to new research questions in three main ways (not all independent): by enabling and popularizing several types of technology-mediated interactions, by spawning large-scale digital data sources, and by creating recurring operational decisions that need to be automated.

(E-Business; Information Infrastructure; Online Markets; Management Science)

1. Introduction

Before, during, and after the dot-com bust, many have wondered whether there is really anything new about the emerging digital economy from a research perspective. Does it impact researchers and practitioners in any *fundamental* way? Or is it just one of many current developments that we need to know something about in order to stay up to date? In other words, does the digital economy require the management science community to change in order to thrive, or does it mean business as usual?

This issue and its companion to follow next month (*Management Science* 2003) aim to shed light on this subject.

An earlier special issue of *Interfaces* (2001) addressed the digital economy from the perspective of practice rather than research. Our experience with that issue helped shape our thinking because it helped us to understand both the potential and the reality of how management science is contributing as the

digital economy unfolds. The new call for papers was influenced considerably by that experience in terms of most-wanted topics, and went out shortly after we completed work on the *Interfaces* issue.

It was not a conventional Call. We invited not papers but rather *proposals* for papers. We especially encouraged survey papers as a way to organize and provide perspective for broad swaths of research. Of the 120 that arrived, we selected 27 for development into full papers. The 16 survivors (10 surveys and 6 original research contributions) went through many rounds of triple refereeing and editorial scrutiny by us and by six *pro tem* associate editors, and appear in not one issue as originally planned but two.

The topical span of the sixteen papers is quite broad, with two natural clusters.

The first cluster springs from the transformation of the digital economy's information infrastructure by unrelenting technological progress in computers and communications (especially the Internet, which

we almost always take to include extranets and intranets). Year by year it becomes easier to collect, store, process and communicate data, and to interconnect individuals and organizational units in various ways. Three general topics emerge from this progress.

The first concerns exploiting data sources—often voluminous—so as to move along the data → information → decision chain. Elmaghraby and Keskinocak (2003) have this focus in the context of pricing; Spann and Skiera (2003) have it in the context of demand forecasting; and Padmanabhan and Tuzhilin (2003), Murthi and Sarkar (2003), and Boyd and Bilegan (2003) have this focus in a customer-centric context (customer relationship management, personalization, and revenue management, respectively).

The second general topic concerns the strategic behavior of individuals, organizations, or more generally agents owing to the new technology-mediated interactions that can arise with the new information infrastructure. Here game theory is the approach of choice. Papers that deal with this topic are Swaminathan and Tayur (2003) in various supply chain contexts (procurement, excess inventory markets, inventory allocation, information sharing, and competitive pricing between traditional and Internet channels), Dellarocas (2003) in the context of online feedback mechanisms relating to reputation, Murthi and Sarkar (2003) in the context of personalization (in particular, the introductory discussion of the strategic role of personalization with respect to a firm's customers, competitors, suppliers, complementors, and intermediaries), and Elmaghraby and Keskinocak (2003) in the context of dynamic pricing with strategic buyers.

The third general topic concerns the network infrastructure of the digital economy. The special challenges associated with designing, building, operating, and managing this infrastructure lead to many opportunities for management science (Geoffrion and Krishnan 2001). Datta et al. (2003) survey the problem of when, where, and what digital content to cache in order to improve content delivery over the Web.

The second cluster of papers centers on a direct consequence of the new information infrastructure, online markets, whose level of use continues to

increase at the time of this writing. Here there are four general topics.

The first is mechanism design for auction markets, among the most visible developments of the digital economy and widely deployed in business-to-consumer (B2C), business-to-business (B2B), and consumer-to-consumer (C2C) settings. Pinker et al. (2003) focus on noncombinatorial single and multiunit auctions with an emphasis on bidder behavior and lot sizing issues in B2C and C2C settings, Pekeč and Rothkopf (2003) on the theory and design of combinatorial auctions, Snir and Hitt (2003) (and the accompanying note by Carr 2003) on reverse markets for procurement with high bid preparation and bid evaluation costs, and Beil and Wein (2003) on a new mechanism for multiattribute procurement auctions.

The second general topic concerns the study of other specific price discovery mechanisms in online markets. Anand and Aron (2003) address group buying as an alternative to conventional posted prices, and Hann and Terwiesch (2003) address name-your-own-price retailing.

The third topic is how to estimate the various benefits of online markets. Brynjolfsson et al. (2003) develop a method for estimating the consumer surplus gains from increased product variety.

The fourth general topic is e-procurement. Kleindorfer and Wu (2003) survey this topic from a novel and highly integrative vantage point that stresses risk management.

In summary, the papers fall into the natural thematic groupings of Table 1. We choose to place the first cluster in this issue and the second cluster in the next, in the order shown (ignoring the second occurrence of the two papers that appear twice in the first cluster).

The thematic groupings shown are not intended to be more generally exhaustive than for the papers in this two-part special issue.

The next section presents a process view of management science research and uses it to restate the important topics raised in the very first paragraph as two key questions. Section 3 then sketches the papers in this issue in terms of those questions. Section 4 presents our summary comments on the first key question based, not only on the papers in this issue,

Table 1 Thematic Organization of Parts 1 and 2

Theme	Article
Information infrastructure (Part 1)	
From voluminous data to decisions	Elmaghraby and Keskinocak (2003)* Spann and Skiera (2003) Padmanabhan and Tuzhilin (2003)* Murthi and Sarkar (2003)* Boyd and Bilegan (2003)*
Strategic interactions	Swaminathan and Tayur (2003)* Dellarocas (2003)* Murthi and Sarkar (2003)* Elmaghraby and Keskinocak (2003)*
Network infrastructure	Datta et al. (2003)*
Online markets (Part 2)	
Auctions	Pinker et al. (2003)* Pekeč and Rothkopf (2003)* Snir and Hitt (2003) Carr (2003) Beil and Wein (2003)
Other price discovery mechanisms	Anand and Aron (2003) Hann and Terwiesch (2003)
Estimating online market benefits	Brynjolfsson et al. (2003)
E-procurement	Kleindorfer and Wu (2003)*

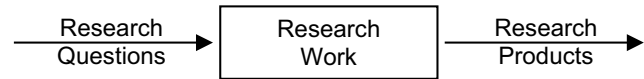
Note. Survey articles are indicated with an asterisk.

but also on those in next month's companion and in *Interfaces* (2001). It describes three new research question wellsprings that largely "explain" why the digital economy is giving birth to so many new research questions. Our comments on the second key question will appear next month. Section 5 concludes, and §6 extends our thanks to the many people who contributed to these special issues.

2. The Research Process and Two Key Questions

We take a simplified process view of management science research (Figure 1): *research questions* arise, *research work* is done on those questions, and the result is *research products*, both intermediate and final.

Some research questions arise in the real world from managerial challenges and issues. Others arise internally within management science from the desire to build a stronger body of knowledge. Both sources lead to a great variety of questions of general interest, but our concern is mainly with the first.

Figure 1 A Process View of Research in Management Science

The research work done on these questions is of many kinds. It includes *empirical* work with real-world data or experimentally generated data, *methodological* work aiming to design or develop or improve a tool or method that facilitates performing some class of tasks, and *theoretical* work aiming to elucidate (descriptively, predictively, or normatively) some aspect of reality or to enable methodological advances. Not to be neglected is the *precursive* or generative work that aims to bring significant research contributions closer by careful observation and description, improving conceptual foundations, assimilating or adapting the content of neighboring fields of study, acquiring and organizing data, formulating good questions, generating plausible conjectures and hypotheses, doing field tests, crafting stimulating survey papers such as appear in this special issue, and the like.

The resulting intermediate and final research products are equally varied in kind: archived *data* (field, survey, or experimental), *hypotheses* (untested, inconclusively tested, or convincingly tested), *algorithms, insights and findings from models* (symbolic or fully instantiated with data), widely applicable *modeling paradigms, software* (experimental, custom, or packaged), *theoretical results, tools/methods* for particular tasks, and more.

We could have labeled the output "answers" rather than "research products," but we chose the latter term because the emphasis here is on the process of research. The means that research generates for answering questions as yet unasked is a legacy of enduring value.

Interdisciplinary dynamics can be very important, particularly when—as is the case with management science during this developmental phase of the digital economy—evolutionary opportunities are great. Think of the great impact that operations research had on industrial engineering starting about

half a century ago; that statistics had on economics (leading to econometrics); or that economics had on political science (the “public choice” school), law (the “law and economics” movement), and sociology (the “rational choice” school). We take pains to point out interdisciplinary influences in our sketches of the papers in these special issues. They impact not only research work, but also research questions and research products.

From this process view of management science research, two main questions emerge from the first paragraph of this paper:

Q1 (Research Questions). What fundamentally new or revitalized research questions of importance to managers are arising from the emerging digital economy?

Q2 (Research Work). What kind of research work is being done to make progress on the research questions just identified?

The first question focuses on the challenges that the digital economy poses to management science, and the second focuses on how researchers in the vanguard are responding to these challenges.

3. The Papers: Information Infrastructure Cluster

We comment below on the papers published in this issue, with special reference to Q1 and Q2. For each paper, after a brief introduction, we sketch the fundamentally new or revitalized management-oriented research questions that it provokes. We then sketch the kinds of research work that it exhibits, with particular attention to contributions from other disciplines.

3.1. “Dynamic Pricing in the Presence of Inventory Considerations: Research Overview, Current Practices, and Future Directions” (Elmaghraby and Keskinocak 2003)

Posted prices are, of course, the usual case both on and off the Internet. How to vary them in response to changing inventory and forecast demand—e.g., markdown pricing—is an everyday concern of many firms. The Internet channel permits prices to be changed quickly, globally, and much more cheaply than has been the case in traditional brick-and-mortar

stores, leading to great interest in dynamic pricing in the online sales environment. This interest and associated decision technology probably will spill over to the offline setting with the emergence of electronic shelf labeling systems (which, together with point-of-sale data, are improving opportunities for offline dynamic pricing). Such systems, which must connect to other systems that supply the intelligence for setting prices, can be viewed as bringing aspects of the digital economy to the brick-and-mortar world.

Research Questions. The online environment has some distinguishing features that raise important new research questions. For example, it has the unique advantage of enabling the collection of click-stream data about online consumers’ selection and purchasing behaviors. It also enables inexpensive real-time price testing and permits customizing the assortment of products, prices, and offers for each online customer based on up-to-the-second data about the customer’s online behavior. There is much yet to be learned about how best to do these things to effectively support price discrimination and demand/inventory/promotion management. Finally, there are potential synergies between the Internet and brick-and-mortar channels. For example, a retailer may make excess (and out of style) inventory available on an Internet channel rather than resort to one of the usual clearance tactics. How best to exploit these synergies remains an open question.

Research Work. This paper discusses mathematical models and operational software for dynamic pricing (for price discrimination) and demand/inventory/promotion management. Often this includes the need for real-time or near-real-time execution. This may influence the kind of research work, possibly empirical, that is most likely to be ultimately useful. Solutions will have to scale well, since the volume of data and the number of customers can be quite large in real applications. Final computations often will need to take place in a very short amount of time, which raises both algorithmic and implementation challenges. Sections 3.3 and 4.3 are quite specific about some of the disconnects between theory and current operational software, and shed light on future research directions to enable progress on the research questions that truly derive from the needs of managers. The extensive

literature surveys in this paper make it plain that much research work must incorporate results from pricing theory and game theory (from marketing science and industrial organization), while taking into account the special characteristics of inventory management as developed in operations management.

3.2. "Internet-Based Virtual Stock Markets for Business Forecasting" (Spann and Skiera 2003)

A virtual stock market (VSM) brings together a group of participants via the Internet and lets them trade shares of "stocks," each share representing a bet on a specific future outcome (e.g., the future sales during a specified period of some product or service). Once the outcome is known, each share receives a cash dividend according to a formula that depends on the outcome. The promise of VSMs is that they provide a new way to forecast demand or uncertain events of interest to management.

Research Questions. VSMs raise new research questions concerning the effectiveness of these markets as a forecasting method and how best to design them.

Research Work. This paper demonstrates through Internet-based experiments that VSMs hold clear promise for demand forecasting for some kinds of products and services. These experiments illustrate the convenience and power of the Internet as an experimental medium. It presents an extended discussion of design issues, but on that topic this paper is best described as precursive in the sense defined in §2. The fields of experimental economics, behavioral economics, and financial market design are useful for studying effectiveness and design questions.

3.3. "On the Use of Optimization for Data Mining: Theoretical Interactions and eCRM Opportunities" (Padmanabhan and Tuzhilin 2003)

Online environments permit the collection of vast amounts of customer-related data at low cost. For example, click-stream data from users' navigational paths on the Web can be gathered during all phases of the online shopping process: browsing, choice, purchase, and post-purchase. In contrast, scanner data in physical retail environments sheds light only on

the purchase phase, and not on the others. Moreover, experiments can be conducted on the Web at low cost to learn about consumer behavior in response to price, personalization, and other marketing decisions. This paper focuses on ways to process such data in support of personalization, customer relationship management, and determining lifetime customer value.

Research Questions. The most important new research questions in this area revolve around how to exploit the new online data sources to improve marketing through improved information about the previously invisible phases of the shopping process. This gives rise to many technical questions. For example: How can models for customer lifetime value leverage the detailed customer data tracked online? How should click-stream data be optimally preprocessed to build data-mining models? What are the best k products to recommend when recommendations are wanted? How can optimization and statistical methods be used in tandem with data-mining methods to improve one another's capabilities?

Research Work. This paper surveys methodological and empirical work with an emphasis on the former. It draws from the marketing, data mining, and optimization literatures. Marketing science provides the business context and the modeling framework for exploiting better and more timely information concerning customers. Data mining, which is mainly at the interface of computer science (especially knowledge discovery and very large databases) and statistical data analysis, provides the most popular methods for obtaining such information from massive data sources. Optimization supplies additional methods. This paper demonstrates in detail how data mining and optimization can contribute to each other. The research challenges mentioned make it clear that this is a fertile area for management scientists with a strong interest in methods for large-scale data analysis.

3.4. "The Role of the Management Sciences in Research on Personalization" (Murthi and Sarkar 2003)

Personalization is the ability of the seller to *learn* customer preferences, to *match* offers (products, messages,

prices) to customer preferences and segments, and to *evaluate* the learning and matching processes for the purpose of improving them. This paper principally addresses the learning stage. While the growth of bar coding and scanner data has enabled great progress in personalization in the physical environment, the data-collection and real-time computational opportunities of the online environment provide dramatic new opportunities for all three stages of personalization.

Research Questions. On a strategic level, what is the business value of personalization that exploits the new online opportunities? Research needs to examine the role of personalization in providing competitive advantage and in affecting market structure. When does it make sense for a firm to adopt an online personalization program? Here it is important to consider the role of strategic customers, privacy and trust, and the role of competitors and partners. From a tactical and operational perspective, the important questions pertain to learning consumer preferences and response functions in an online setting. This involves properly integrating data from multiple sources, understanding the pros and cons of inference methods about customer preferences, and developing new models that exploit the interactive nature of the online environment. Having learned preferences, matching becomes the important task. Given the attributes of products, messages, and deals, what methods permit the best matching to preferences of users? What are good feedback mechanisms or metrics for evaluating the learning and matching processes?

Research Work. The research on strategic issues is theoretical and primarily draws on the industrial organization literature. The research on tactical and operational issues is methodological and empirical, drawing on the literatures of operations research, econometrics, and marketing.

3.5. "Revenue Management and E-Commerce" (Boyd and Bilegan 2003)

When question Q1 refers to "the emerging digital economy" and "fundamentally new" research questions, the implicit frame of reference is the period beginning about 1996 when e-commerce passed

\$1 billion for the first time, or perhaps three years earlier when the first graphical Web browser was released, or five years earlier still (1991) when NSF lifted its restrictions on commercial use of NSFNET. But the digital economy actually began to emerge long before that. Electronic data interchange (EDI) matured to the point of acquiring its first interindustry standard in 1979. SITA, the first worldwide packet-switching network dedicated to business services, began in 1969, and the first computer reservation system dates back to 1962: SABRE at American Airlines, said to be the first large-scale, real-time, networked business application of computers (Smith et al. 2001). These early IT developments led to important managerial issues that were researchable. The most prominent example is revenue management, which tracks historical demand for different products that use the same underlying resource, and establishes future product availability based on demand forecasts in an effort to maximize revenue with product prices taken as given.

Research Questions. Optimization-based revenue management, developed by the early 1970s, can be construed as supplying the earliest context for Q1 if the frame of reference is lengthened to include pre-Internet e-business. This linking of the sales and inventory management processes has famously produced enormous benefits for some airlines. But surprisingly, the airline industry does not yet jointly optimize prices as part of its revenue management applications. The Internet creates a rich contemporary context for Q1 with the adaptation of airline revenue management applications to the novel features of the online setting. Of particular importance here are the ability to rapidly communicate prices (e.g., through the Web and e-mail), both posted and individualized to potential customers, and the emergence of the Internet channel and Internet-based intermediaries as channel partners—some independent of the airlines (e.g., Expedia) and others owned by them (e.g., Orbitz).

Whereas the airlines had to spend enormous sums to build proprietary networks to support reservations and related business processes, the Internet now places a comparable infrastructure at the disposal of almost any company. This is enabling the gradual

spread of revenue management applications throughout the hospitality industry and beyond. Variants of familiar revenue-management research questions arise in connection with Internet-enabled applications in these new domains, since each industry poses its unique challenges.

Research Work. Applied research in airline revenue management has made extensive use of operations research, and also of econometric methods for modeling and forecasting demand. To the extent that revenue management succeeds in penetrating other industries, whether or not in an Internet-enabled way, management scientists will continue to need econometric methods. As pricing and inventory management begin to be studied and applied jointly, as they have been in other settings (Elmaghraby and Keskinocak 2003), researchers will need to understand the literatures on pricing from economics (industrial organization) and from marketing science. Clearly, traditional methods that analyze static databases will need to be supplemented by experimental methods designed to exploit opportunities for dynamic interaction with online markets.

3.6. "Models for Supply Chains in E-Business" (Swaminathan and Tayur 2003)

This is a survey of the state of the art of analytic modeling-based research in supply chain planning and execution. It emphasizes procurement and supplier management, the increased visibility and information sharing enabled by developments in information technology, pricing and distribution problems in the presence of multiple channels, the manufacturing implications of Internet-enabled product customization, and trends in enterprise software and decision technologies that exploit the real-time data made available by the Internet.

The Internet has led to increased use of enterprise-wide information systems. Firms and their trading partners operate with much more information about each others' orders and inventory position than they did previously, thereby enabling greater efficiency in coordinating interfirm supply and demand processes. This change in the information infrastructure and associated decision-making scope applies within a firm's boundaries as well, and has resulted in

the need for cross-functional enterprise-level decision making such as the integration of pricing and demand management with supply chain management. Thus, the digital economy is revitalizing old questions and raising new ones.

Research Questions. The Internet can facilitate frequent forecast exchanges between supply chain partners and help create shared forecasts that are increasingly accurate. How should firms use these forecasts to efficiently manage their inventory and production plans? The emergence of e-markets has given firms a larger set of alternatives for procurement. While procurement through auctions can result in lower costs due to competition among bidders, procurement through a long-term supplier can provide lower costs over time through learning. What is the optimal combination of these procurement options, taking into account product characteristics, relative costs, and other considerations? (Kleindorfer and Wu 2003 address an expanded form of this question.) As firms move from traditional retailing to also selling online, pricing the same product across multiple channels becomes an important problem. How should a monopoly firm price its product? How does pricing change when a multichannel retailer competes with a monopoly e-tailer? The online "make-to-order" model is popular with consumers, and companies want to preserve economies of scale while still supporting customization. This has spawned variants such as the "assemble-to-order" model. Given the relevant costs, what is the optimal product architecture that best balances economies of scale and the sales impact of customization?

Research Work. The surveyed literature, mostly from operations management sources but drawing also from information systems and marketing, exhibits a growing use of game theoretic machinery to study incentive and strategic interaction problems. Most of the work emphasizes theoretical development based on stylized analytical models. At the interface of computer science and economics there is also an emerging literature on distributed decision support systems that take advantage of better data availability along the supply chain to improve supply chain planning and coordination. An important open issue is how game theoretic models can be combined with

large-scale distributed systems technology to create decentralized real-time supply chain decision support tools that could be implemented in practice.

3.7. “The Digitization of Word of Mouth: Promise and Challenges of Online Feedback Mechanisms” (Dellarocas 2003)

Trust is a key ingredient for successful commerce of all types. Word of mouth has long played a key role in helping people decide whom to trust. Since the advent of the Internet, word of mouth has reached a new level of importance, thanks to websites that systematically collect reports of experience and opinions on various goods and services, and on the companies and people who participate in transactions (cf. Snir and Hitt 2003, who discuss a software services market that compiles vendor ratings). At the same time, the legal system is being undermined as a trust-building institution by certain characteristics of online commerce.

Research Questions. The ascendance of online word-of-mouth feedback mechanisms raises new questions about their design and application. Three aspects are central in this problem context: the consequences of the unprecedented scale inherent in the Internet, the ability to use information technology to exert control over the type and ways in which feedback propagates to participants, and the relative ease with which online feedback can be contaminated by dishonest anonymous postings or rendered useless by identity-altering pseudonyms. Some of the questions pertaining to design are: Should a system release the entire feedback history of sellers in an eBay-like market or should the system only report recent behavior? What mechanisms should be put in place to detect dishonest feedback or to provide incentives to tell the truth? More generally, what are the equilibrium strategies of sellers in the presence of these feedback mechanisms? Some of the questions pertaining to applications are: How does online feedback affect marketing and product development? What will be the consequences of large-scale feedback forums for established trust-building institutions such as the legal system? Which constituencies gain and who loses from the introduction of such mechanisms?

Research Work. Game theory plays an important role in answering many such research questions. This follows from the large number of self-interested and presumably rational agents involved, their financial interdependencies, and the ease with which online feedback mechanisms can be manipulated. Other applicable approaches include experimental economics, empirical research using econometrics (for which rich data sources are potentially available), and algorithmic OR methods for inferring reputation.

3.8. “World Wide Wait: A Study of Internet Scalability and Cache-Based Approaches to Alleviate It” (Datta et al. 2003)

The Internet provides the infrastructure for the delivery of digital content from producers to consumers. In this context, the Internet can be viewed as a digital supply chain in which processing and transmission latencies result in delivery delays. These delays can be routine (as when a Web page takes more than several seconds to load) or occasional (as when a “flash crowd” of requests arrives and swamps a server). Given the autonomous nature of the Internet’s components, there is little coordination among them to address the performance challenges. Caching (or storage)—be it static content or content that results from computation—is the solution technology of choice.

Research Questions. What objects should be cached, where and when they should be cached, and how caching services should be priced are important questions with tantalizing similarities to familiar inventory questions. Given a content delivery network and a content request, which is the best server to deliver the content given the load on the servers and the various time delays involved? The quality of service that a cache can provide is based on whether an object is available in storage when requested. Due to limited capacity, caching service providers use various rules to determine how long to keep an object in storage. Differentiated quality of service results from providers determining how long an object will stay in storage by taking into account the level of service the object owner has contracted for. Given different segments of customers (content owners who value performance benefits differently), how

should differentiated quality-of-service-based caching services be provisioned by a caching service provider and how should these be priced? How can marketing science and/or decision analytic methods be used in this context to elicit preferences of customers and content owners?

Research Work. This survey draws primarily on the systems and performance evaluation literature in computer science to model the operational aspects of caching. This literature addresses optimization problems using various heuristic methods and data analysis techniques. The paper highlights opportunities to bring management science (particularly work on supply chain management) to bear on caching problems in online environments. The discussion relating to questions on pricing caching services draws on the industrial organization literature, particularly the literature on the economics of telecommunication and information systems. Addressing these questions requires knowledge of both information technology underlying content delivery and certain analytical tools from operations research and economics.

4. New Research Questions: Genesis

We present our summary comments on Q1 from the vantage point of the papers in this issue, in its companion, and in our earlier special issue of *Interfaces* (which is freely available online). We shall see that the new research questions have three main sources. Next month we discuss Q2.

Earlier we noted the transformation of the digital economy's information infrastructure: the increasing ease of collecting, storing, processing, and communicating data, and of interconnecting individuals and organizational units. The seminal consequence is that parties involved in commerce interact with each other more frequently and in more complex ways, and the same is true of many of the artifacts of commerce (business processes, business software, etc.). It is these interactions that, together with two important byproducts, produce most of the new or revitalized research questions.

Interactions are of several types:

Intermediaries. Some interactions occur through intermediaries. For example, Anand and Aron (2003)

list about two dozen Web-based, group-buying intermediaries in the B2B, B2C, and nonprofit sectors. A more technology-intensive example is the subject of Datta et al. (2003), who examine the intermediate caches so crucial to the commercial performance of the Internet.

Internet Channel. Other interactions occur through the Internet channel that now directly connects many B2B trading partners to each other and consumers to a vast number of companies that sell retail. This immediately raises new questions about how to exploit the ease of changing prices in this channel (Elmaghraby and Keskinocak 2003), pricing innovations that would otherwise be impractical (Anand and Aron 2003, Hann and Terwiesch 2003), the impact of this channel on consumer surplus (Brynjolfsson et al. 2003), and how to price by comparison with brick-and-mortar channels (Swaminathan and Tayur 2003), among others. An impediment to Web-based consumer-to-consumer commerce is the need for adequate trust between transacting parties, which raises new questions concerning the design and management of online databases for word-of-mouth feedback (Dellarocas 2003). Several important questions concerning the opportunities and dislocations caused by the advent of the Internet channel in the airline industry can be found in Smith et al. (2001).

E-Markets. Still other interactions occur through e-markets for procurement or sale that, as noted, raise important design and management issues (Pekeč and Rothkopf 2003, Pinker et al. 2003, Snir and Hitt 2003 together with Carr 2003, Swaminathan and Tayur 2003, Beil and Wein 2003). With a commercial history dating back only to 1995, Internet-based B2B e-markets are still a recent innovation. Even so, the deep implications of procurement e-markets for contracting, operational decisions (capacity, technology choice, and production) and risk management are already well recognized (Kleindorfer and Wu 2003) and deserve much more attention. See also Keskinocak and Tayur (2001).

Collaboration. Collaboration is another important kind of interaction enabled or facilitated by the digital economy's infrastructure. Examples include data sharing between a manufacturer and supplier, vendor-managed inventory in a retail setting, and

most strategic alliances. Collaboration has been a major trend in supply chain management for some time; Swaminathan and Tayur (2003) pose many questions in this area that are either new or revitalized by the commercialization of the Internet. Collaboration can be intra- as well as interfirm: Sodhi (2001) discusses how firms can use management science to improve planning and execution in Internet-enabled supply chains, not only through an expanded physical scope that includes vendors and customers, but also with an expanded functional scope that includes product design, marketing, and customer-relationship management. Kleindorfer and Wu (2003) illustrate well how expanding the usual functional scope of e-procurement can take a firm much closer to the goal of enterprise-wide decision making. Elmaghraby and Keskinocak (2003) discuss models that combine dynamic pricing and inventory management, functions not yet treated in an integrated way by current commercial software for optimization-based dynamic pricing. This sort of integrated modeling of pricing and inventory management is relevant in other settings as well, in particular the revenue management applications discussed by Boyd and Bilegan (2003). See also Keskinocak and Tayur (2001).

Other. Many other kinds of Internet-enabled interactions take place, not all within the e-business world, for such purposes as community, discussion, e-government, gambling, HR (employee portals), and recreational multiplayer game play. These too spawn research questions for management science. The virtual stock market idea (Spann and Skiera 2003) is a nice example of how to organize Internet-based interactions with experts, consumers, and others for the purpose of eliciting knowledge or predicting the future.

A natural by-product of these and other kinds of interactions is the generation and capture of much more data in digital form, often in massive quantities: bidding data from auctions, click-stream data, customer profiles, reputation data from online feedback systems, data shared for collaborative purposes, data from a proliferating variety of fixed and mobile scanners and from bots that mine websites, price histories, many kinds of transaction data generated by ERP systems, and more. Thanks to data storage

technology that has been advancing even more rapidly than Moore's Law, an ever increasing amount of such data is being stored and treated as an asset. However, much of this data ends up entombed—stored but not analyzed—since in addition to being massive, it also tends to exhibit more complex interrelationships among its parts, thereby creating the need for more powerful types of data-mining methods (Fayyad and Uthurusamy 2002). Some of the papers that extract useful knowledge from such data sources include Padmanabhan and Tuzhilin (2003) (click-stream data mining for customer relationship management), Pinker et al. (2003) (modeling grounded in auction data), and Murthi and Sarkar (2003) (a variety of model-based methods for learning customer preferences from customer data). See also Cohen et al. (2001, pp. 126–128) and Montgomery (2001, pp. 100–104) on taking advantage of click-stream data.

Another natural by-product of many digital-economy interactions is the need to automate recurring operational decisions, often in near real time. Automation becomes increasingly desirable as decision frequency increases, a common consequence of the Web's inherent potential for rapid scaling. It is appropriate both for Web-based interactions between software applications, which benefit greatly from XML-based standardization (the core of Web services), and for human-computer interactions. When a person is on the other end of an interaction, the legendary impatience of consumers and even of many business people often requires a response within seconds, to avoid dissatisfaction or loss of business. Adding intelligence to recurring decisions through decision technology is a natural for management science, and the usually tiny compute windows for adding this intelligence add to the challenge. See Boyd and Bilegan (2003), Datta et al. (2003), Elmaghraby and Keskinocak (2003), Padmanabhan and Tuzhilin (2003), and Swaminathan and Tayur (2003) for research questions with a real-time context, Geoffrion and Krishnan (2001, pp. 28–29) for further discussion of real-time applications, and of Geoffrion (1992, pp. 438–440) for commentary on embedded applications.

Thus arise throughout the digital economy many research questions that are either new or greatly revitalized in managerial importance. The papers in this

two-part special issue add chapter and verse to the sketch given above.

5. Conclusion

This issue continues the project begun with our *Interfaces* (2001) special issue. Where that one surveyed the state of practice and opportunities in the context of the digital economy, this one and next month's companion survey the state of research. We are particularly concerned in this pair of issues with (1) the nature and origins of the fundamentally new or revitalized research questions of managerial interest that are raised by the digital economy, and (2) the implications of the answers for the training and self-renewal of management scientists who wish to work on these questions.

Contrary to a suspicion voiced repeatedly over the years with respect to (1), these special issues reveal a plentitude of significant research questions and opportunities arising from three wellsprings:

- proliferating technology-mediated interactions among the parties participating in the digital economy,
- proliferating large-scale digital data sources, and
- an increasing number of recurring operational decisions that need to be automated.

Next month's completion of this commentary will include a discussion of the digital economy's implications for the conduct of management science research. We shall see that ideas from certain of management science's neighboring disciplines are becoming considerably more important. We shall also see that the research enterprise of management science itself is being reshaped by the very same technological advances which are giving rise to the digital economy.

6. Acknowledgments

We are most grateful to all of our authors for their diligent, prompt, and invariably cheerful efforts no matter how many revisions we requested (as many as 7), and for crafting such careful and individualized responses to the many detailed reports they received from the associate editors, the referees, and us.

Our associate editors likewise performed to a high standard. We count ourselves fortunate to have had

the services of Professors Eric Bradlow, Scott Carr, Paulo Goes, ManMohan Sodhi, Jan Stallaert, and Rakesh Vohra, and extend our sincere appreciation to them.

Thanks go also to approximately 75 referees for their indispensable advice; to Professor Hau Lee, who commissioned these issues, and to Professor Wally Hopp who inherited them—we could not have asked for more support or encouragement; to Pamela Price Klebaum, the freelance copy editor we engaged to help with more than half of the manuscripts; and to the production staff at INFORMS, who handled the manuscripts and our special requests with competence and grace.

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Accepted by Wallace J. Hopp.