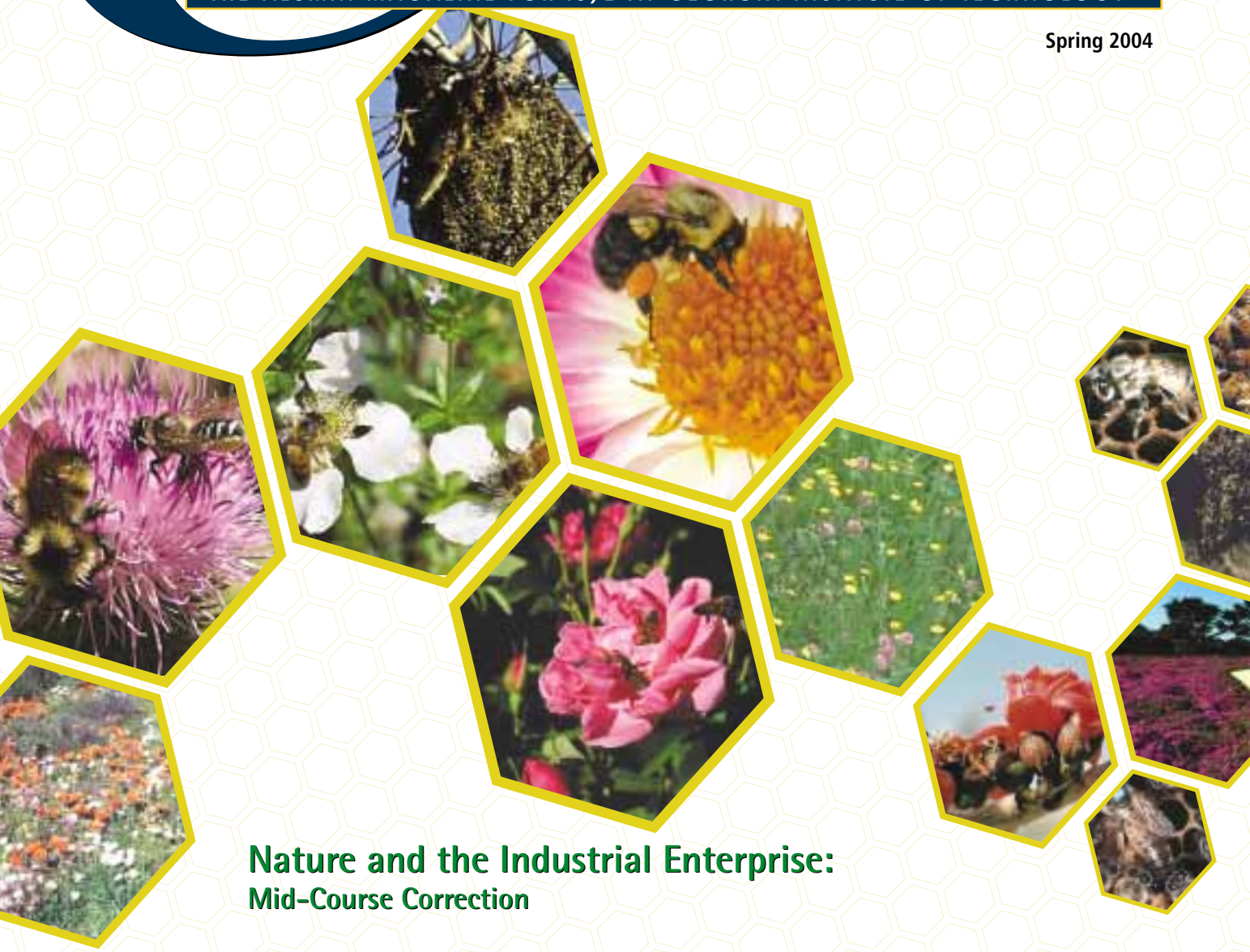
Engineering ENTERPRISE

THE ALUMNI MAGAZINE FOR ISyE AT GEORGIA INSTITUTE OF TECHNOLOGY

Spring 2004

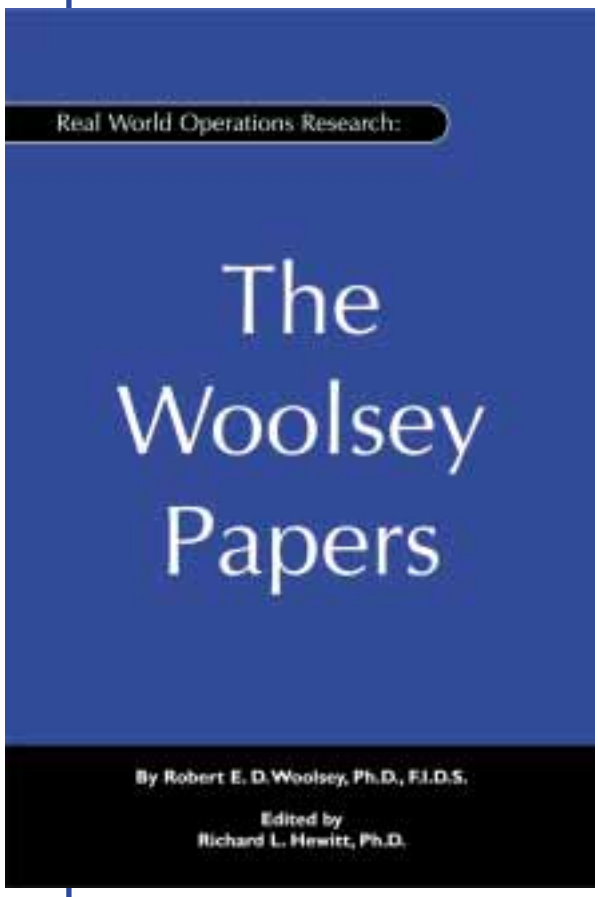


Nature and the Industrial Enterprise:
Mid-Course Correction

The Honey Bee Algorithm:
A Biologically Inspired Approach to Internet Server Optimization

Nature's Assembly Line:
Bucket Brigades

Real World Operations Research:
The Woolsey Papers



Edited by Richard L. Hewitt, Ph.D.

Real World Operations Research: The Woolsey Papers is a collection of the diverse writings of one of OR's most outspoken and controversial figures, Gene Woolsey. Whether he's the man you love to hate or hate to love, Woolsey's humorous and practical writings leave little wonder as to his venerable status in the field.

This collection contains 33 articles published from 1972 to 2003, covering a broad spectrum of subject matter relevant not only to OR/MS professionals, but also educators, managers and corporate administration. To accompany his writings on operations research, chapters also cover topics from communication in the corporate world to handling labor disputes, getting promoted to getting fired. Through creative storytelling and down-to-earth advice, Woolsey provides readers with the knowledge and philosophical mindset to conquer operations and management situations in all settings.

"Gene Woolsey is unique, provocative, insightful and entertaining. This collection of some of his articles is an important and thought provoking read for anyone in the field of OR. Hopefully, this book will motivate and guide the behavior of those in the profession to successfully apply OR to resolving real problems that matter and to insure that the solutions are actually used."

– Tom Cook,
Chairman and CEO,
CALEB Technologies Corp.
President (2003), the Institute for Operations Research
and the Management Sciences

Real World Operations Research: The Woolsey Papers
By Robert E. D. Woolsey, Ph.D., F.I.D.S.
Edited by Richard L. Hewitt, Ph.D.

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Natural Systems

by William B. Rouse

This issue marks the beginning of the second year of *Engineering Enterprise.* Themes to be addressed this year include natural systems, health systems, knowledge mining, and supply chain management. And, of course, there will be lots of news regarding the activities and accomplishments of our students, alumni, and faculty.

The field of "natural systems" considers what should be learned from nature that can guide the design and deployment of engineered systems. In the interview in this issue with alum Ray Anderson, CEO of Interface, Inc., you will learn how the new carpet in my office at Georgia Tech was designed on the basis of how nature designs floor covering in a forest. When you are on campus, stop by the ISyE Chair's Suite to see the best-selling Entropy floor covering that resulted from Interface's trips to the forest.

This issue also provides a fascinating glimpse into studies of ants and bees by John Bartholdi and Craig Tovey. Ants and bees can provide great insights into how best to handle logistics and supply chain management.

Natural systems can provide important insights into sustainable design and development. This is of broad interest at Georgia Tech, as evidenced by the many activities of the Institute of Sustainable Technology and Development (ISTD), led by Bert Bras of the Woodruff School of Mechanical Engineering. This issue highlights the roots, formation, and accomplishments of ISTD.

Why is all this of interest? Engineers are great at designing solutions to problems in both private and public sectors. However, these solutions often consume considerable non-renewable resources and produce significant wastes. Nature is often better at evolving solutions that consume renewable resources (e.g., sunlight) and produce biodegradable by-products (e.g., cellulose). Efficiency is a hallmark of natural solutions.

As an example of such efficiency, consider the carpet in my office, designed by studying the forest. Like nature, the pattern of the carpet does not repeat. Any panel can go any place. Any piece cut from one panel to fit an edge can be deployed to another place to fill an edge. Thus, waste is minimized. Best of all, the name is Entropy. Can you think of a better name for the floor covering in a faculty member's office?

William B. Rouse is the H. Milton and Carolyn J. Stewart Chair and Professor of the School of Industrial and Systems Engineering at the Georgia Institute of Technology.

EMIL Research Fellowships to Break New Ground in International Logistics

By Terri Herod, *EMIL Managing Director*

Georgia Tech's EMIL (Executive Master's in International Logistics) program launched its newly created ***EMIL Fellows*** program in November 2003. The EMIL Advisory Board named seven doctoral students from the School of Industrial & Systems Engineering as the first recipients of EMIL research fellowships. The EMIL Fellows were selected based on their abilities to both support the EMIL curriculum and industry-initiated research projects.

EMIL is a master's degree program that helps the world's leading companies develop creative, global logistics solutions by grooming their supply chain executives.

EMIL is a master's degree program that helps the world's leading companies develop creative, global logistics solutions by grooming their supply chain executives. Over the years, EMIL has collaborated with many industry leaders. Now, with the EMIL Fellows program, Georgia Tech continues this collaboration by integrating EMIL's industry focused, real world problem solving program and its more traditional graduate programs. Specifically, the Fellows program allows doctoral students to interface with and impact the real world of global logistics by engaging in research that has immediate business relevance. At the same time, it provides EMIL with the intellectual "horsepower" of the world's brightest, up-and-coming researchers to advance the EMIL curriculum and the supply chain field overall.

The EMIL Fellows program is designed to enhance the EMIL program in one of three areas. First, the Fellows can provide analytical support for one of the **EMIL Global Supply Chain Projects**. To participate in EMIL, class members must complete an 18-month, global supply chain project, handpicked by their sponsoring organization. Through the Fellows program, Georgia Tech now provides additional resources to increase the analytical strength of these global project solutions. Secondly, the Fellows can participate in **EMIL Infrastructure Projects** that enhance EMIL course content and are compatible with Ph.D-level research. Some examples include the development of an Internet-based supply chain game and the improvement of returns management algorithms and practices. Lastly, EMIL Fellows can address **EMIL Research Projects** by examining supply chain problems that are of common interest to both Georgia Tech faculty and EMIL sponsor companies.

EMIL Fellows Announced

Recipients of the 2003-2004 EMIL Fellowships, their project areas, and advisors are:

EMIL Fellow	Faculty Advisor	Topic
Gorkem Bedir Turkey	Dr. Jane Ammons	The Future of Returns Management
Ralph Mueller Germany	Dr. Christos Alexopoulos	Internet-based Supply Chain Game
Nan Li China	Dr. Leon McGinnis	Distributed Supply Chain Model (Intel Corporation)
Jinpyo Lee China	Dr. Amy Ward Dr. Anton Kleywegt	Contract Manufacturing Study (BAX Global)
Ni Wang China	Dr. J.C. Lu	China Logistics Study
Melda Ormeci Turkey	Dr. John Vande Vate	Variability in the Supply Chain
Deniz Dogan Turkey	Dr. Mo Bazaraa	General Motors Global Supply Chain Project

SPOTLIGHT:

THE FUTURE OF RETURNS MANAGEMENT

EMIL Fellow: Gorkem Bedir
Faculty Advisor: Dr. Jane Ammons

Reverse logistics is a growing concern for most corporations with an estimate of $137 billion spent annually worldwide. Although much research has already been focused in this area, Gorkem Bedir and Dr. Jane Ammons look to launch seminal research on the less understood topic of returns management, which ranges from 3 to 50 percent of all U.S. shipments, depending on the industry.

Bedir's initial research will explore current returns management approaches with an eye to developing industry recommendations for future best practices.

Bedir's initial research will explore current returns management approaches with an eye to developing industry recommendations for future best practices. Furthermore, Bedir expects to form a research collaboration team consisting of industry partners and Georgia Tech faculty to develop analytical models that will improve insight and understanding of the returns management process. Companies interested in participating on the research team should contact Terri Herod, EMIL Managing Director at terri.herod@isye.gatech.edu.

As output, Bedir will develop a report on returns management best practices and opportunities, available to all EMIL sponsors and participating companies. She will also formulate a case study for use in EMIL's Reverse "Green" Logistics course taught during the program's European Residence.

SPOTLIGHT:

CONTRACT MANUFACTURING

EMIL Fellow: Jinpyo Lee
Faculty Advisor: Dr. Amy Ward and Dr. Anton Kleywegt

Jinpyo Lee's planned study of Contract Manufacturing, sponsored jointly by EMIL and BAX Global, is an example of a proposal in the EMIL Research Projects category. Lee's research will take an unbiased look at the Contract Manufacturing (CM) industry and its relationships with third-party logistics providers (3PLs), now and in the future. In addition, the study will shed light on the factors impacting the expectations that Original Equipment Manufacturers (OEMs) have for CMs and 3PLs with an eye to defining effective strategic relations between the two groups.

SPOTLIGHT:

CHINA LOGISTICS STUDY

EMIL Fellow: Ni Wang
Faculty Advisor: Dr. J.C. Lu

Another key EMIL Scholar's project is aimed at gleaning vital information about the logistics environment of one of the fastest growing and most challenging markets in the world: China. With an annual economic growth rate topping 10%, the importance of this unique market to businesses worldwide is tremendous. Ni Wang's China Logistics Study is an Infrastructure Project designed to provide U.S. corporations with a reference for starting new logistics business ventures in China. It will include an overview of federal governmental organizations that impact logistics corporations, as well as provincial and municipal governmental structures. The study will also detail procedures and documents required to operate in China, outlining steps that a start-up third-party logistics provider must follow when entering the Chinese marketplace as its example. Finally Ni Wang's research will provide predictions of the changing role of government involvement in the logistics environment of China. The initial study will focus on one logistics services company located in one province as the basis for creating a research model that can be applied throughout China in future EMIL research studies. The wealth of information gained from this project will serve as an invaluable resource for EMIL sponsors, and enhance the EMIL curriculum during the Asia Residences.

With China's annual economic growth rate topping 10%, the importance of this unique market to businesses worldwide is tremendous.

The EMIL Fellows program has been welcomed enthusiastically by both industry and academia, according to EMIL Executive Director Dr. John Vande Vate. "As students at the premier school for Industrial & Systems Engineering, these doctoral candidates are some of the smartest people in the world," said Vande Vate. "With the EMIL Fellows program, we can now offer them funding for vital research, while tapping their brainpower to build the EMIL program curriculum and advance industry's knowledge base."

Engineering Projects in Community Service

By Dr. Faiz Al-Khayyal, *Associate Professor and EPICS Program Director*

A team of senior design students is spending the academic year working closely with Hands On Atlanta (HOA), a volunteer-recruitment agency that assists nonprofit groups throughout Metro Atlanta. Team members Jessica Holmes, Carla Bryce, Faith Hyman, Dayton Shuman, Mark Rogers, and Tim Sweeney, under the supervision of Professor Augustine Esogbue, are helping the agency make better use of its partner, the Atlanta Community ToolBank.

HOA, an EPICS partner, is traditionally a good source for senior design projects. The nation's largest single-day volunteer event is Hands On Atlanta Day, held every October. This day is the largest and most demanding event for both HOA and the ToolBank. In 2003, approximately 16,000 volunteers were assigned to more than 200 projects. These typically involve the clean up of buildings and grounds, including repair and painting.

Up to this point, HOA has been using a non-automated paper system to request materials from the ToolBank, an organization that stores tools for community efforts. This manual process is prone to error. The senior design team's EPICS program is creating a robust automated system for HOA and the ToolBank.

HOA has grown so rapidly that the ToolBank's current warehouse facility can no longer handle the traffic. Volunteers are often confused while hunting for tools. The ToolBank is now undergoing a $350,000 remodeling. With the students' assistance in automating ToolBank functions, the new ToolBank will soon be efficiently managed.

The goal of this EPICS project is to develop a system that improves the operation of HOA's tool allocation process. This will be accomplished by addressing three opportunities for improvement:

a) reduce the number of HOA staff hours needed to complete the tool allocation process, which takes staff away from their normal daily duties;
b) reduce the number of errors made during the tool allocation process, which are largely due to the manual nature of the task; and
c) redesign the layout of tools in the warehouse to provide for more efficient storage, more timely retrieval, and more accurate replacement of tools.

The design team is accomplishing their goal using the follow methods:

a) modeling in AutoCAD the current ToolBank layout, including the space requirements and placement of each tool;
b) determining the quantity of each tool needed for Hands On Atlanta Day;
c) ranking the tools by usage over the last two years in descending order. A recommendation was made to locate the tools used most frequently in the most accessible area in the warehouse, close to the loading/unloading bays.

The results of the data collection and analysis phase of this project, completed Fall Semester, are listed below. Further analysis is being performed during the Spring Semester.

1) Current ToolBank Layout
   a) Aisles are not properly labeled.
   b) Some of the bigger and heavier items are stored on the higher shelves or in the back of a shelf with no forklift available for retrieval. This causes hazardous conditions for volunteers. Larger items, including ladders and wheelbarrows, are stored in another warehouse, which adds to the inefficiency of the picking process.
   c) The paper sheet used by volunteers to pick tools does not facilitate locating items in the warehouse.
   d) Items are not stored in the ToolBank according to picking frequency, which causes congestion in the areas of high use items.
   e) Insufficient space allocation for plentiful tools results in like tools being placed in different locations throughout the warehouse. Logistically, the placement results in confusion for volunteers and a loss of inventory control.
2) Process Documentation issues include inconsistent writing format, lack of documentation for some key processes, and the need for more technical and professional language in documentation.
3) The Automation process lacks functionality for projects to be requested or researched online. When HOA decides on the nature and scope of the desired functionality it to enhance its website, the EPICS team will provide detailed specifications for necessary webpages and links to implement the vision.

Tony Chan, an ISyE graduate and the Hands On Atlanta client representative, says that "Hands on Atlanta wants to grow more aggressively," and the completion of this EPICS project will "significantly impact its progress by providing a sustainable infrastructure for the future." Chan adds that implementation of the project will improve the efficiency of Hands On Atlanta Day by 15-20 percent.

If you are interested in working with EPICS, you are invited to visit our website at www.isye.gatech.edu/epics/.

Wally Buran Newest Edenfield Executive-in-Residence

Wallace "Wally" P. Buran, BIE 1975, MIE 1978, is the latest person to become an Edenfield Executive-in-Residence with the School of Industrial and Systems Engineering at Georgia Tech.

Buran, most recently employed with IBM, has a quarter century of consulting experience. He has worked with companies in a multitude of industries, including aerospace, automotive, beverages, building products, chemicals, consumer products, defense, electronics, food processing, household products, industrial products, machine tools, medical equipment, paper, plastics, tire and rubber, transportation, and utilities. While at IBM, he served as Global and Americas Practice Leader for Operations Strategy Consulting in Business Consulting Services.

Prior to joining IBM, he was the chief executive officer of WorldCrest Group, an independent procurement shared services company started by Kohlberg Kravis Roberts. Buran was also a partner and National Director in the Strategy, Consumer Business, and Manufacturing Practices of Deloitte Consulting. He authored and directed Deloitte's annual research on Consumer Business issues, led the development of the firm's Supply Chain Methodologies, built Deloitte's relationship with i2 Technologies in the Consumer Business Sector, and served on the Strategic Planning Committee of Deloitte Consulting.

"Wally's wealth of experience, both in consulting and executive positions, will be of great value as ISyE plans and pursues its enterprise-oriented initiatives," says School Chair Bill Rouse.

Buran is a member of the ISyE Advisory Board. He lives with his wife Betty and their two children in Marietta, Georgia.

Alumni News

Don Aldworth, BIE 1971, as been appointed vice president of Quality for KEMET, a preferred supplier of passive component solutions. In this capacity, he will lead the company's Lean Six Sigma initiative. Aldworth has been with the Greenville, South Carolina, based company for 19 years.

Garrick W. R. Bauer, BIE 1972, has been named MD-11 captain at the new Federal Express crew base in Los Angeles.

Jeff Greenbaum, BIE 1993, is president of Bins Corp., a $100 million conglomerate that owns and operates a 15-unit restaurant division, five retail liquor stores, and approximately 600,000 square feet of industrial real estate. He and his wife Sonja live in Atlanta with their son Maxwell, age three. They are expecting their second child in June.

Kristine Kennedy, BIE 1993, is celebrating her 15th anniversary with NASA. Kennedy began working with NASA at Kennedy Space Center in Florida as a co-op student. She currently works as a quality engineer in the Safety and Mission Assurance Directorate, specializing in biomedical systems, at the Johnson Space Center in Houston, Texas.

Tiffany N. Legington, MSIE 1999, has been promoted to manager at Kurt Salmon Associates, a retail and consumer products consulting firm headquartered in Atlanta.

Dr. Fay Cobb Payton, BIE 1989, of North Carolina State University, was recently honored and inducted into the Raleigh-Wake Forest YWCA Academy of Women in the category of Science and Technology.

George Rabstejnek, BIE 1954, has been elected chairman of the board of the Massachusetts Eye and Ear Infirmary, a Harvard Medical School Hospital with a clinical, research, and teaching mission. He has also been elected chairman of the board of the Center for Technology Commercialization, an organization dedicated to technology transfer and public safety. Rabstejnek resides in Cohasset, Massachusetts.

David Riviere, BIE 1987, has been named national service director for the North American Consumer Products IT practice at Kurt Salmon Associates. Riviere and his wife Gretchen have three children and live in Atlanta.

Randal Rupert, BIE 1987, MSIE 1989, has been named vice president for Customer Success at Workbrain, Inc.

Girish Vengurlekar, MSIE 2003, is now an industrial engineer with TSI Logistics in Stockbridge, Georgia. He is currently working on his APICS certification and is interested in hearing from anyone else who is working on or has achieved certification at girishvengurlekar @yahoo.com.

(continued on page 19)

Nature & the Industrial Enterprise

Mid-Course Correction

AN INTERVIEW WITH RAY C. ANDERSON

Ray Anderson, BSIE 1956, is the founder and chairman of Atlanta-based ***Interface, Inc.,*** one of the world's largest interior furnishing companies. For the last decade, he has been committed to making Interface a sustainable enterprise that consumes no non-renewable resources and produces no waste – taking nothing and doing no harm. In this interview, he speaks about the circumstances of his conversion to these beliefs, the resulting products and profits, and how he hopes to radically influence the practices of modern industry.

EE: Give us some sense of the genesis of your thinking in this area of natural systems and sustainability. Was there some key event, or driving force?

Anderson: It came out of my own life changing mid-course correction. Once I had my eyes opened by [business writer] Paul Hawken, I began to read voraciously. One thing I learned is that a forest is a very complex, self-organizing system. In fact, nature is filled with self-organizing systems. Through billions of years of evolution, nature has evolved very efficient, effective, self-organizing systems that meet all of its needs with abundance and no waste.

EE: What's the time frame for when you began your readings?

Anderson: All of this began in the summer of 1994, and evolved over the next year or two as I got myself up to speed on what was already known about sustainability and the path to sustainability. I first formed the impression that nature is a model, and then I realized that is not so – nature is the real thing, and we have, in the industrial system, a very poor artifice that needs changing. We can look to nature for the inspiration, the guiding principles to make the changes needed in the industrial system to make it as effective as nature is – waste free, resource-effective and resource-efficient, benign, operating on sunlight the way nature operates on sunlight; taking nothing and doing no harm.

I had a conversation with [former ISyE School chair] John Jarvis somewhere along the way. I said. "John, if you can figure out how a forest works, you will have a pretty good idea of what the industrial system ought to look like." At least, metaphorically you have it there. In the midst of Georgia Tech's capital campaign, I was persuaded to make a contribution, and this sort of sprang out of my head: Why not create a Chair of Natural Systems and dedicate somebody to studying nature and how to emulate nature in a sustainable, effective, efficient industrial system?

EE: Were you applying these ideas at Interface in that same timeframe?

Anderson: In a way, yes. We recognized a few of those organizing principles. In nature there is no waste, so we set out on a quest, literally QUEST – Quality Utilizing Employee Suggestions and Teamwork – to eliminate waste. When you look at a manufacturing operation, you know there is going to be a certain amount of off-quality, so you build in cost allowances for these, and you have a standard cost system that allows so much expected waste and so much off-quality and so forth. Interface has manufacturing operations all over the

world, and every one had a different idea of what was standard. You couldn't compare one operation with another without getting into the question of, "How did you establish your standard?" So one day we said, "Let's just measure everybody against perfection. Let's take all the waste out of the cost, and see what our cost would be if we had no waste and no off-quality. If we did it right the first time, every time." We found 10 percent of the sales dollar was going to waste, most of it allowable under the standard cost system. So we thought, if we measure ourselves against perfection, and go after all waste, we will get further than we can ever get with a standard allowance.

EE: It is easy to imagine that practically doubling your profits.

Anderson: During the nine years we've been measuring it, the elimination of waste – the savings – represents 28 percent of our operating income, and we still have two-thirds of it yet to go. We've already captured about one-third. It gets close to doubling your profit if you can eliminate waste.

EE: We're here in the ISyE Chair's office with our feet on your Entropy carpet. Can you tell us the inspiration for this product?

Anderson: Entropy is a wonderful example of looking to nature for inspiration. Our head of product development, David Oakey, read Janine Benyus's book, *Biomimicry*, and he was inspired. He decided to send his entire design team into the forest. He told them, "Go, and see how nature would design a floor covering. And don't come back with leaf designs; that's not what I mean. Come back with design principles. What are nature's design principles?"

They spent a day in the forest, looking at the forest floor, looking at the streambed, and finally it dawned on them, there are no two things alike on the forest floor, or in the streambed. Each stick and every leaf is different. Yet, there is a uniformity to that chaos. Sort of organized chaos. You can pick up a stick here and drop it there, and you can't tell you've changed anything. They came back realizing that nature's design principle is basically organized chaos and total diversity. And they designed a carpet tile where no two were alike. That's what you have in Entropy.

Aside from being a very pleasant aesthetic that emulates the forest floor, it turned out to be practically waste-free in the production process. You cannot find a defect. If there is a defect, it's camouflaged by the design. The installation process has practically no waste. When the installer gets to the edge of the room and cuts the last piece to fit, the scrap from the last piece can be used somewhere else. And you can't find it; you won't recognize it as a cut carpet tile.

EE: People sometimes come into this office just to see the carpet.

Anderson: There is a woman on the speaker circuit – I can't remember her name – who begins every speech by asking her audience to close their eyes and imagine that perfect place where they feel safe and secure, creative, and totally at ease. Totally comfortable. She lets them think about it, and then she asks, "How many of you were someplace indoors?" Hardly anyone ever raises a hand. That perfect place we gravitate to is in nature. It is somewhere outdoors. I really think part of the appeal of Entropy is that it brings part of the outdoors indoors on a subliminal level. After it was introduced, it became the number one seller in the product line, faster than any other product has ever made it to the top of the league tables.

You asked me if Interface was in any way patterned after nature. When I first read Janine Benyus's book, I came to the chapter on the industrial organization and how it could be organized to simulate nature. And as I read it, it described Interface. She didn't know Interface when she wrote the book. But what she described as the industrial enterprise that is modeled after nature is Interface: the idea of cyclical processes, doing no harm to the biosphere, taking nothing from the earth that is not naturally and rapidly renewable, and producing no waste. Ultimately that is the objective, even though we have a long way to go. We want to drive the whole thing with sunlight, renewable energy, closing the loop on material flows so that you have not only the basic organic cycle we're all familiar with—the dust to dust cycle—but in an analogous way, a technical cycle that takes used-up products and gives them life-after-life through the recycling process, so that no molecules are

lost; everything stays in the flow, the material loop. All of that is basically emulating nature in an industrial system, and that remains our goal. We're one-third of the way there, not only on the waste front, but in other respects, too.

One measure is carbon intensity, the amount of petroleum extracted from the earth, processed through the entire supply chain to produce a dollar of revenue for our company. Not just the material, but the energy, too. The carbon intensity of Interface is down one-third in nine years. We've managed to shut down 39 percent of our smokestacks, and 55 percent of our effluent pipes. In a number of cases, this has been done by simply eliminating processes altogether or designing around the processes to produce a waste-free, emission-free, effluent-free production line.

EE: Does Interface just happen to be naturally oriented this way, or did you have to go through some sort of transformation?

Anderson: Oh, it was a total transformation. It was a burst of insight, followed by a couple of years of really digging in and studying the literature and thinking. We drew a schematic (see Diagram X) of a typical company of the twentieth century. Then we created a series of schematics that showed the evolution to the prototypical company of the twenty-first century. We made that first schematic of our company, showing the linkages to the lithosphere (the crust of the earth), the biosphere, the supply chain, the community, the supply chain's dependence on the earth's crust, on the biosphere, and so forth. And we asked ourselves, what's wrong with this picture? Out of that came the plan for pursuing sustainability. We call it climbing Mt. Sustainability, identifying the seven faces of the mountain, and figuring out how to climb each of those seven faces to meet at the top, at that point where environmental impact, or footprint, is zero. We imagined the kinds of initiatives that would be necessary to make it to the top of each of those faces, to become the prototypical, sustainable company of the twenty-first century (See Diagram Y). All of that developed over the course of a year or two.

EE: When you announced this to your management team and your colleagues, did everybody buy in immediately?

Anderson: People thought I was nuts. We had to go through a total cultural transformation. The culture shift still goes on, we still have people asking why, and it is nine years later. Of course, new people come and people leave, so we're constantly renewing the process of inspiring people to see the world a different way.

EE: Is it easier now, when you hire people, to get the people you want?

Anderson: My goodness, yes, it has now become a huge magnet for people who never would have thought of going to work for a carpet company. The carpet industry has a pretty poor reputation, frankly, but Interface has been able to rise above that and attract people we never would have attracted, and keep people that we never would have been able to keep

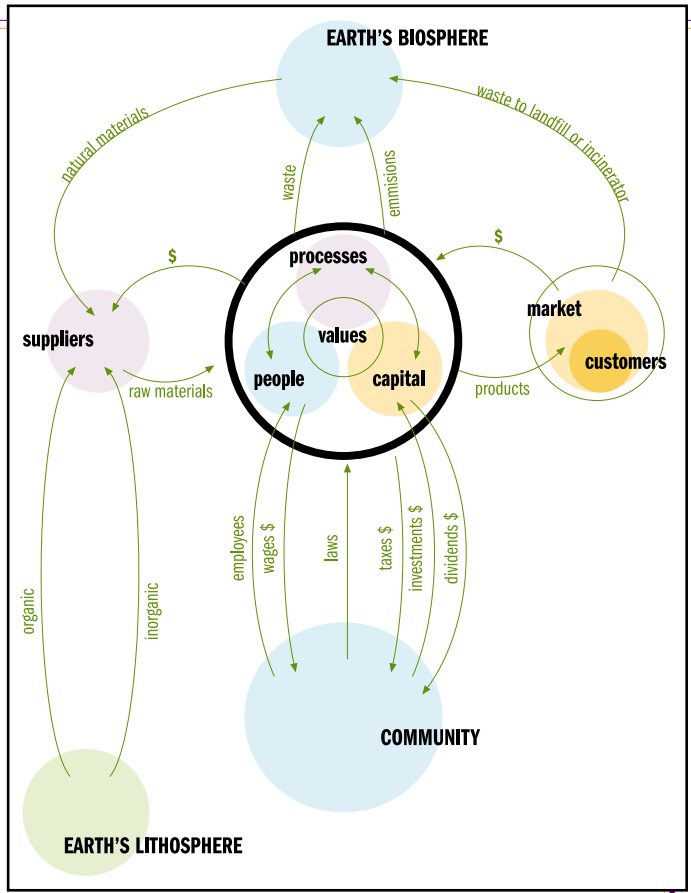

Diagram X: Typical Company of the 20th Century

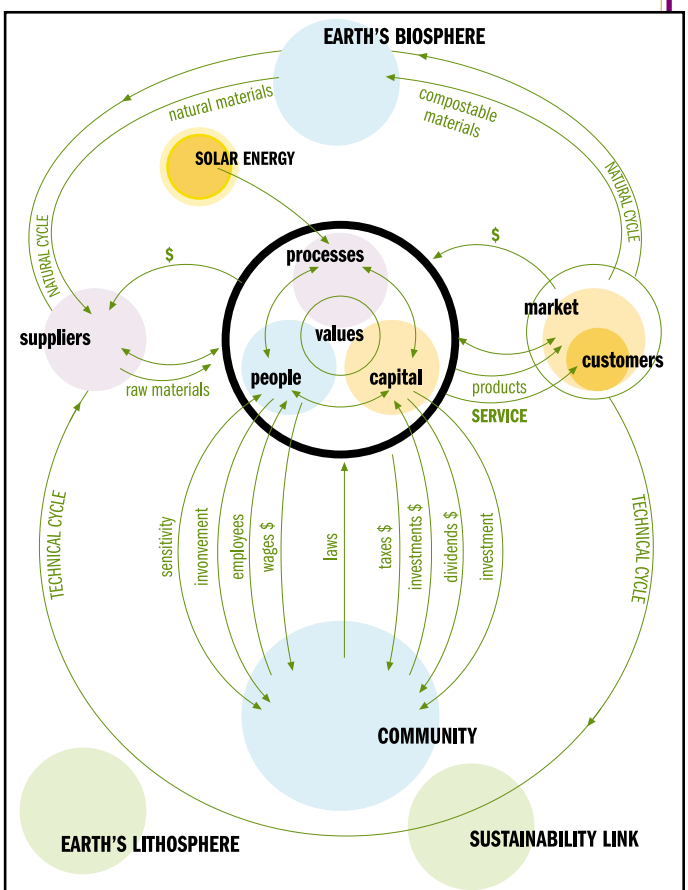

Diagram Y: Prototypical Company of the 21st Century

involved and motivated. People want to be identified with a higher purpose.

EE: What would you say were the toughest one or two things in that transformation effort?

Anderson: It took about 50 speeches by me before we really got a lot of buy-in from our people. The toughest challenge was really to be sure that we stayed on the drum beat, the consistent, persistent message. This is where we've been, this is where we're going, and we have got to do this. Unless somebody leads, nobody will. Why not us? That was the message.

EE: You're constantly selling the idea.

Anderson: Constantly, constantly. It became my mission, my personal mission, to bring our people along, share the vision, and put it out there so clearly that they would grasp it. It requires a different way of thinking.

EE: How long did it take until it got a little easier?

Anderson: I'd say two or three years. And it was a watershed event. I was invited in August of 1995 to speak to the U.S. Green Building Council at its annual conference. I put a lot of myself into that speech; it was only my second public speech on the subject. I worked really hard on it, and it was well received, so I had it published in a tiny little booklet, which you can read in 20 minutes or less. It described my own conversion, and my vision for our company to lead the whole industrial system toward sustainability. It was distributed all through the company. Some people read it, and others didn't, I'm sure.

About six months later, I was invited to Scotland to an environmental conference to make a speech. My management team in Europe – and that's about a third of our company – found out I was coming to Scotland and asked if I'd stop and spend a day with them. They said, "We want to understand what you are really thinking." This was a year and a half into this process. They were sitting there in Europe not believing that any American company could be serious in what I was saying, because they see America, and the way we live, and they didn't believe we were serious. So they asked to see me, and I agreed to stop in London. I told them, "Yes, I mean it, this is where I want Interface to go."

Two of them wanted to go along to Scotland to hear my speech. After I spoke there was a break. The hall was vacated when I came back in. There was one person who had come with me sitting in this big room, like a cathedral. I came up behind him and looked over his shoulder, and he was reading that little pamphlet. And he looked up, and there were tears streaming down his face. He said, "You know, I've read this before, but now that I've heard you say it, I'm reading it again, and I just want you to know that I get it" After that, the European team really came aboard. And because Europe is so far ahead of us in their thinking [about the environment], it gave us a real shot in the arm back here in the U.S., to have them fully engaged, and in a way, showing us the way.

EE: You contrast human practices with nature's practices, but given that we're part of nature, why aren't our practices natural in some sense also?

Anderson: We are different from any other organism on earth in the way we take more than our share and give back our poison. The rest of nature can't handle it. We set ourselves apart from nature. We're at war with the rest of nature. You could call it a civil war. It is a war where if we win, we lose. Of course we are winning; therefore, we are losing. We're losing the biosphere at a rapid rate, in an instant of evolutionary time.

EE: I've often wondered about how much effort goes into maintaining lawns, and why? It just strikes me that there is a huge amount of effort to make the lawn look like carpet. Why do we invest all that energy?

Anderson: (laughs) So we can cut it, fertilize it and let it grow, and cut it again. I think civilization is at war with nature; since civilization is humankind's creation, that puts us at war with nature.

EE: Whereas a colony of beavers doesn't war with nature, they use nature…

Anderson: The give and take all balances out with them; it doesn't balance out with us.

EE: Who in this whole effort are your heroes?

Anderson: People primarily from the non-governmental organization (NGO) community who have been out there for years and years gaining an understanding of what is going on, sharing that understanding with us, not only finding the problems, but trying to develop the solutions. Paul Hawken, Amory Lovins, Janine Benyus, Karl-Henrik Robèrt, Daniel Quinn, Donella Meadows. They are my heroes. Lester Brown, who has been writing for the World Watch Institute all these years and producing the State of the World Report every year. He's basically been a voice in the wilderness for years, but the stuff he's saying is true. And there is an economist by the name of Herman Daly who has been saying for years that our economic system is upside down.

The Anderson/Interface Chair Natural Systems Speaker Series presents:

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Founder,The Natural Step
Thursday, April 29th, 5:30 PM

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For information, please visit
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EE: What happens next? You're one-third of the way there with Interface. I imagine the next pieces get tougher and tougher?

Anderson: There are some breakthroughs that will have to happen. And there are some that have happened, where we've not yet realized the total benefit. David Oakey's work with our products has only just begun to kick in, and our product line will evolve more and more in a sustainable direction, with recycled content and renewable energy.

Another breakthrough that we're on the verge of is the use of carbohydrate polymers as substitutes for hydrocarbons. Hydrocarbon coming from petroleum, carbohydrates coming from vegetable matter. Cargill, the big grain grower, and Dow Chemicals have created a joint venture, Cargill Dow. They are extracting the tiny bit of dextrose from a kernel of corn, and through a bio-engineering process, producing polyester, a synthetic fiber, derived directly from corn, rather than going through billion-year-old oil – ancient sunlight – to get there. Taking today's current solar income, if you will, corn, and going directly to the synthetic fiber. We're working with this in textiles and in carpet. That's a transition that lies before us. We're in the early days.

EE: You also had some ideas about leasing carpet?

Anderson: That's gone nowhere. The market is not ready for it. The economics don't quite make sense yet because we have not closed the loop on all the material flows. You still have oil subsidized to a terrific degree, so anything made from oil is basically subsidized. You have an artificially low market price for the virgin materials; consequently, you don't have the value in the recycled material that you would have if prices were honest. Instead, we have this basically blind and dishonest marketplace.

EE: What if we included a portion of the defense budget in the oil price?

Anderson: Well, yes, the portion that is protecting the oil at its source; together with a war in the Middle East every now and then. The cost of global warming is not reflected in the price of a barrel of oil, either. You have the externalities. This is Herman Daly's theme, that the externalities don't get priced by the market. They get externalized, so you have a blind market allocating resources. It's crazy.

EE: Is that primarily in the oil area, or are there other areas?

Anderson: That's probably the most flagrant of all – the billions of dollars that go to subsidize the oil industry, including the wars in the Middle East. There is a book by Norman Myers, *Perverse Subsidies: How Misused Tax Dollars Harm the Environment and the Economy*, that details the perverse subsidies that we have all around us.

EE: Cotton has been getting a lot of attention lately.

Anderson: Cotton is one. Cotton is what, two percent of the total fiber production of the biosphere, and uses 22 percent of the pesticides? And a huge amount of water. Norman Myers' book details that. It'll make you cry.

EE: If someone from your research staff, or Georgia Tech, could walk into your office and say "we've just discovered how to do x," and it is something plausible, what would help you most?

Anderson: Closing the loop on nylon type 6,6. Type 6,6 is the designation for the polyamide molecule that we know as nylon. There is another one, type 6 (and that has to do with the number of carbon atoms in the molecule). Nylon 6 is recyclable; nylon 6,6 is not. Nylon 6,6 is the better fiber in terms of durability and wear and all those good performance attributes. So the best product for its functional value is the hardest to recycle. Du Pont, who makes the type 6,6 nylon, has basically given up on the recycling of it.

EE: What are your thoughts about students' orientation toward this whole topic? Have you seen that change over the years?

Anderson: Not much, yet, because you guys are still teaching the wrong stuff. You go to the mechanical engineering school and your students are still learning about internal combustion engines instead of fuel cells. You go to ceramics, and people are still studying heat, beat, treat technology for

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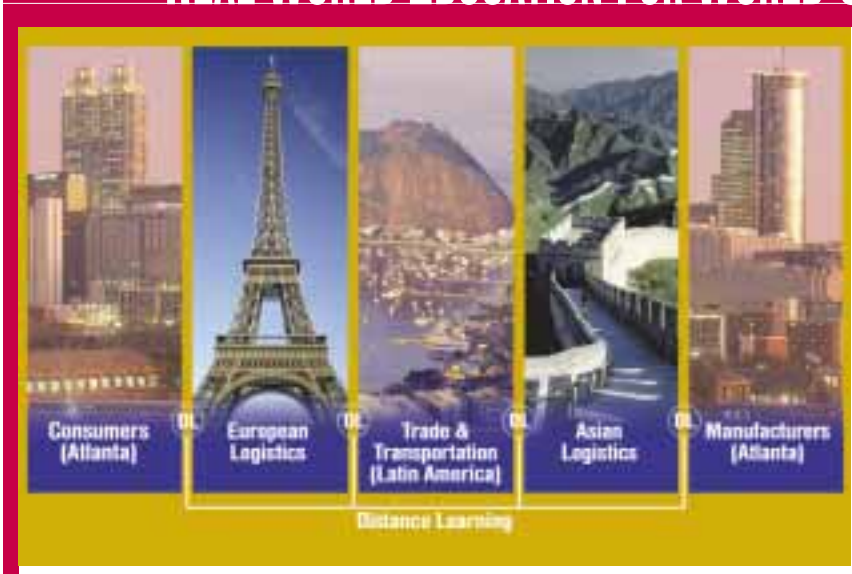

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producing ceramics, instead of studying how the abalone does it better out of commonly available minerals in the ocean at 40 degrees Fahrenheit. Economic students are still learning a system of economics that allows the externalities and ignores those subsidies as if they were deserved. The education system needs revamping. You're teaching the wrong stuff, which is why I'm on your case all the time. You're still teaching the system that is destroying the biosphere, and teaching the teachers to perpetuate it.

EE: Why do you think we do this? One reason could be that education is just an inherently conservative enterprise and changes very slowly. Or maybe there are other reasons?

Anderson: I think there is an entrenched commitment to the status quo. It is like there is a vested interest in the status quo. Why does education change so slowly? That's a really good question. It is the most ponderous of institutions.

EE: Yes, we got the basic disciplinary organization back in Bologna in 1119 and we're hesitant to change it.

Anderson: You've got a lot of silos, too. People don't want to look across the silos at what the other guy is doing because it might make doing what they do wrong.

EE: Another possibility is that you can't really appreciate this phenomenon unless you look at it from a multidisciplinary point of view.

Anderson: That's another point that Herman Daly makes in his book *For the Common Good*. It is an absolutely wonderful read. I recommend it to anyone in education.

EE: We've got various initiatives trying to enhance the multidisciplinary activities at Tech, but you really have to work at them to make them succeed. And that's true at all universities. Any other observations? Your thoughts now as compared to 10 years ago? Any surprises?

Anderson: When we began this initiative, we stumbled upon waste elimination as the first face of the mountain, the first priority, the initiative that, if we tackled it first, would pay the way for all the rest. That's still basically true. We continue to whittle away at this waste opportunity. We continue to generate savings that are paying for investments we are making in research and development. In more recent years, a couple of allies or partners have developed to help pay for this whole journey.

The first of these is the goodwill in the marketplace, which should not be underestimated. People are looking for authenticity in an artificial world. Our customers, particularly the interior design community and architects, are people who just want to do the right thing, if someone will only show them what that is. They have embraced what we have done, and that has translated directly into the good will of the marketplace and a predisposition to deal with Interface. That's not everybody, but it is unquestionably a segment of the market place, and it has cushioned our top line in a very bad recession.

Our industry is down 40 percent from five years ago. Our own sales are down 26 percent; but in a marketplace that's down 40 percent, we have gained market share in a recession. Just now, the products out of this pursuit of sustainability are beginning to emerge, products like Entropy. And now there is a family of products built on that basic principle of diversity. In our fabrics business, we are using more and more recycled content. Something like 87 percent of our raw materials in that business now come from recycled PET, primarily Coke bottles. The products have begun to kick in along with the customer goodwill, so you've got a positive feedback loop building.

EE: This is an example of doing well by doing good?

Anderson: This is doing well by doing good. As the resource efficiency improves, and we get some help from the economy, which finally looks like it is coming, I believe that we will become the example that the whole sustainability community has been waiting for. Finally a company emerging that is really doing well at the same time. I think that example will attract other companies. I know it has moved our whole industry already. Every competitor is on our heels.

EE: Are they pushing for the same sustainability issues, or are they doing it different ways?

Anderson: They are all reacting to our initiative in their own way. Typically, it is a product here and a product there. We've not seen anybody else take the whole, broad, seven-faces-of-the-mountain approach to this. But everybody is doing something, and consequently you have an industry that is moving toward…glacially, but moving toward…sustainability. If we could do that to the whole industrial world, by setting the example for others to emulate, that would really be significant.

Toward Sustainability:
Ray Anderson's Suggested Bibliography
for the Enlightened Industrialist

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Those interested in reading more about Mr. Anderson's philosophy and how it applies to Interface may wish to read his book, *Mid-Course Correction*, 1998, distributed by Chelsea Green, and available at Barnes & Noble and amazon.com.

The HONEY BEE Algorithm:

A Biologically Inspired Approach to Internet Server Optimization

By Dr. Craig A. Tovey

DR. CRAIG A. TOVEY is a professor in the College of Computing and the School of Industrial and Systems Engineering at Georgia Tech. His principal research and teaching activities are in optimization, probabilistic analysis, and natural systems. His current research concerns the effectiveness of valid inequalities in integer programming, classical and biomimetic algorithms for robots and web-hosting, the formation of social dominance hierarchy structures, and sustainability measurement. The following article details one of his current research projects in natural systems.

When Sunil Nakrani knocked on the door, ISyE Professor Craig Tovey didn't know that a 15-year old dream of his was going to be realized. Nakrani, a visiting scholar in the School of Electrical and Computer Engineering at Georgia Tech and a doctoral student at the University of Oxford, was searching for a method to allocate computers among different clients at a web-hosting facility. He approached Tovey based on the professor's reputation for algorithm heuristics. He did not know that Tovey had studied how honey bee colonies allocate foragers among different flower patches and had been searching for an industrial application of the bees' method. But that all changed as a result of this meeting. The two researchers began working together to model the dynamic server allocation problem and proposed a biologically inspired approach to the optimization problem in a managed Internet server colony. Within the past two years, Nakrani and Tovey have developed an algorithm that mimics the behavior of honey bee foragers, with very promising test results for a simulated web-host center.

In ISyE, Tovey explains, "we learn about natural systems, and we learn from natural systems. This project has some of both." Years ago, Professors John Bartholdi, John H. Vande Vate, and Tovey used Operations Research (OR) techniques to help explain how bees allocate foragers among flower patches in order to bring a lot of nectar into the hive. Now, Nakrani and Tovey have imitated the bees to allocate computers among web clients in an effort to bring a lot of money into a web-host center. And the test results give new insight as to why the bees' strategy helps them survive.

To provide some background, Nakrani first encountered the web-host allocation problem while working at IBM. Web-hosting is now a $30 billion/year and growing industry. Every time you check the weather, buy merchandise, or pay your bills online, chances are the computer you connect to is not actually run by the weather station, retail store, or bank. Instead, you most likely connect to a computer at a facility which runs several web-applications, or web-apps for short, on a large bank of computers. By aggregating the different and highly variable demand patterns of its various web-app clients, the hosting center can achieve an economy of scale, as shown in Figure 1. (The same computer which provides weather reports in the morning can serve shoppers in the evening.) Web-app clients pay a small fee for each customer serviced, but for security reasons, only one web-app may be loaded onto a computer at a time. Therefore in order to maximize its revenue, the web-host facility must decide how many computers will serve each web-app, while adapting to the changing levels of customer demand.

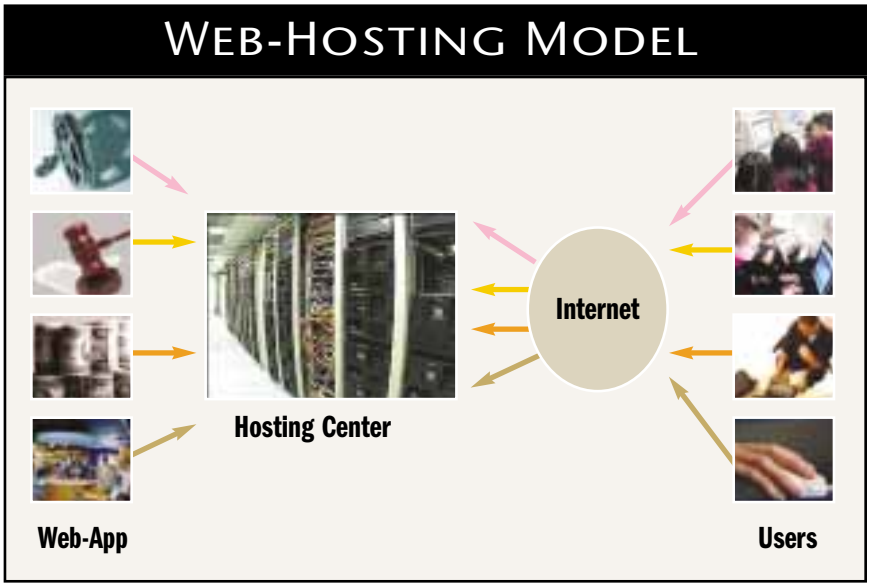

Figure 1

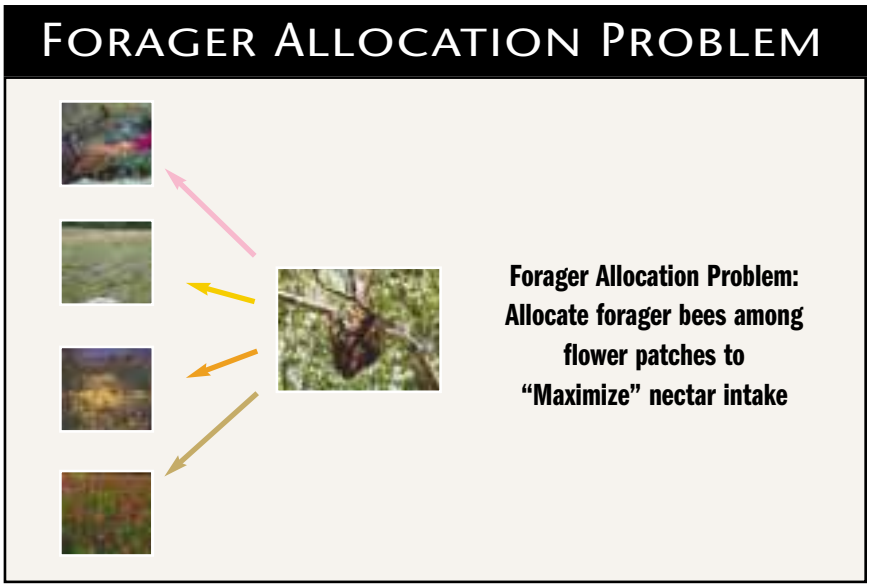

Figure 2

In turn, honey bee colonies operate using the same basic principle. Each colony must collect extra nectar during the warm season to make and store enough honey – usually 20 to 50 kg – in order to survive the winter. Efficient nectar collection is thus crucial to colony survival. It is inefficient, in general, for all of the colony's foragers to collect from the same flower patch. A large number of bees at one patch can "swamp out" the flowers' capacity to generate nectar. On the other hand, some flower patches are richer or more productive than others. To maximize nectar intake, the honey bee colony must "decide" in some decentralized but intelligent fashion how many bees will forage at each flower patch. (Figure 2).

As Nakrani described the web-host problem to Tovey, the apparent resemblance to the honey bee problem was obvious. In fact as he moved to the next level of detail, Tovey says, "I got very excited about the potential, because at the deeper level, the problems continued to match up beautifully." For example, when a computer is switched from one web-app to another, it incurs a 5 to 7 minute downtime (to be scrubbed and reconfigured) for security reasons. A honey bee who is switching patches usually requires several attempts to successfully find the new patch, incurring a similar downtime in effect. As another example, the time to serve a web-app customer has both a fixed-cost component, depending on the web-app, and a variable cost, which increases as the number of computers assigned to the web-app increases. Similarly, the time a forager requires to collect a stomach-full of nectar has a fixed-cost component, the round-trip travel time, depending on the patch location, and a variable cost, the collection time, which increases as the larger number of assigned bees swamps out the patch's nectar production. After these and other similarities revealed themselves, Tovey presumed that he had finally found the appropriate application of the honey bee method.

"I got very excited about the potential, because at the deeper level, the problems continued to match up beautifully."

First, the researchers devised a careful test of the honey bee method. They implemented it and three other algorithms in order to assess performance. One of the other algorithms was a standard myopic/greedy algorithm, a traditional optimization method. The second was an optimal static algorithm, which provides an upper bound on current-day practice at many facilities, which only reset their allocation once a month. The third calculated a theoretical upper bound on revenue collection, as if the web host center knew the future customer arrival data in advance. They ran a battery of tests on both real trace data from a service provider (NDA) and simulated web traffic.

Like many biologically inspired heuristics, the method has advantages over many other types of algorithms.

As the tests began, the researchers were hoping that the honey bee method would be on par with traditional methods and current usage. Like many biologically inspired heuristics, the method has advantages over many other types of algorithms. It is simple, less centralized, and robust under even undetected breakdowns. If its revenue performance were competitive, these other features would give it an edge. However, the results were better than Nakrani and Tovey had hoped. The honey bee method earned more revenue than either the greedy or static methods over a range of data parameters.

When web traffic was not very variable (real web traffic is), the honey bee heuristic no longer performed so well. This gave a new insight into the bees themselves. Earlier work of Bartholdi, Vande Vate, Tovey and Seeley (building on work of von Frisch, Seeley, and others) showed what the allocation pattern is, and that while not optimal it is a good heuristic method. It is not optimal in the sense that if you look at the bees at any one particular time, a different allocation would get more nectar, given the way things are at the present moment. A different way to say this is that if the environment were static, unchanging, then the bees' allocation pattern does not maximize nectar influx to the hive.

The reason is that to achieve static optimality, the derivatives, i.e. the marginal revenue at each patch, must be equalized. If one extra bee is more valuable at patch A than at patch B, then it would be better to switch a bee from B to A. The honey bee colony does not do that. Instead, the colony equalizes the average return per bee. Nakrani and Tovey suggest that the colony would have to switch allocations one bee at a time, in order to be able to manifest the value of the derivative of nectar influx. Instead, the colony permits many bees to switch at the same time, but it can only manifest the value of the average nectar influx. The colony seems to have traded off optimality in-the-moment for rapid adaptability to change. This may be a very good lesson for human optimizers.

For additional information about the honey bee algorithm, please contact Dr. Craig Tovey at craig.tovey@isye.gatech.edu.

Bucket Brigades

Since the dawn of the Industrial Age, humans have used engineers to organize the workers on the line. But ISyE research led by John Bartholdi, Manhattan Associates Chair of Supply Chain Management, indicates that nature may have a more powerful method of balancing the work.

Bartholdi and then-doctoral student Don Eisenstein, now a professor at the Graduate School of Business at the University of Chicago, worked together to harness nature's technique in a system that has revolutionized order picking in warehouses around the world. Known as "bucket brigades," the system mimics the behavior of ants, whose methods of foraging food are designed to give the colony its strongest chance of survival.

Bartholdi's work on bucket brigades was born out of the same impetus as Dr. Craig Tovey's work with honey bee colonies (see article page 13). They were inspired by biologist Tom Seeley, a professor at Cornell and an expert on bees, as was another research partner, ISyE Professor John Vande Vate. "We were all attuned to the issues of self organization and decentralization in the emergence of behavior," says Bartholdi.

Bucket Brigades in Industry

Studying nature was an interesting break for a professor who normally concentrates on industrial issues. But duty called, and Bartholdi was asked to work on a project for the Defense Logistics Agency. The agency was looking for a better way to operate the assembly lines that sew military uniforms. He soon learned of the Toyota Sewing System, a Japanese method which allows workers to move around from machine to machine during production – an assembly line, but not a strictly defined one. "There is little bit of freedom in their movements, but not much," he says. "We looked at this for about a year, and realized it could be improved by sequencing the workers from slowest to fastest, allowing them to move any place on the line, completely cross trained."

In modeling, the extended idea worked well. "We applied the theory of dynamical systems to show that such lines, which we called 'bucket brigades', had the properties to self organize. Once you set them up correctly, they will spontaneously configure themselves so that they are the most productive that they can possibly be. That seemed like a great idea, because if they spontaneously organize themselves in the best way, that means that an engineer doesn't have to do it." Another benefit: if there are disruptions, the system reorganizes itself.

"Another way of thinking about this is that you've set up a force, like the force of gravity, that pulls the assembly line to the very best organization. Like gravity, that pull is always there. Even if something goes wrong, like the machine breaks and throws the line out of balance, once fixed, it will be pulled right back to balance." A sick worker can leave the line to go home, and the remaining workers will keep the line in balance. The workers don't even have to understand the principle, he says. "All they have to do is keep following the simple rule, much as a line ant or a bee follows a simple rule."

Bucket brigades, as used by the ant species *Messor barbarus*

J. L. Reyes and J. Fernandez Haeger, in their published paper "Sequential co-operative load transport in the seed-harvesting ant Messor barbarus," describe the ant as using bucket brigades to carry seeds back to the colony. The smallest, slowest ants forage out farthest. When carrying a seed back toward the nest, such an ant may be interrupted by a larger, faster ant, who wrests the seed from the first ant and continues carrying it towards the nest. After the largest ant leaves the seed at the nest, she goes back out to get another.

This raises an interesting question: How do bucket brigades arise? Bartholdi, with C. Anderson and J. J. Boomsa, offer an explanation in their paper, "Task partitioning in insect societies: bucket brigades." First we make the following assumptions, which are consistent with the observations of Reyes and Fernandez Haeger (and others).

Assumption 1: Larger ants are faster.

Assumption 2: An ant can take a food item from a smaller ant but not from a larger ant.

Now under Assumptions 1 and 2, bucket brigades arise spontaneously if each forager follows this simple, myopic rule:

The Foraging Rule: *If you are without a food item, run out along the foraging trail until you encounter one and then take it if you can, even if you must wrest it from another ant, and carry it back toward the nest.*

Consider the experience of a large forager. As it leaves the nest, it is likely that the first returning forager it encounters is smaller, and so our ant will successfully wrest the food item away and return to the nest. It is unlikely to meet a still larger ant on the way back. Subsequent trips are likely to repeat this experience.

Similarly, consider the experience of a smaller ant. It is likely to have to travel for a long time before it encounters an even smaller forager that is returning with a food item; in fact, it may have to travel all the way out to the food source to get a food item. As our small ant returns with a food item, it is likely that any forager it encounters will be larger and will take the food item, after which our small ant will return to the food source. Again, subsequent trips are likely to repeat this experience.

The result is that the ants will sort themselves from slowest (smallest) to fastest (largest) along the direction of seed movement towards the nest.

After a few effective simulations, the researchers were confident enough to approach Revco Drug Stores (now CVS) and asked for the opportunity to test the method at Revco's national distribution center in Knoxville, Tennessee. "The director of logistics for Revco had been trained in operations research, so he understood exactly what we were talking about it," says Bartholdi. On a slow Monday morning, they explained the procedure to those responsible for order picking. "Total implementation time was about 15 minutes. They tried it, and we saw almost immediate improvements. We didn't have to buy any new equipment, didn't have to change any software – we just sequenced the workers from slowest to fastest and told the industrial engineer to stop assigning the work. Let them move to where the work is spontaneously, just like the social insects."

Revco soon discovered the method was 34 percent more productive than its own system. "That's a huge cost savings for companies like Revco, which have enormous seasonalities. They're a retailer, they're very busy at the end of the year. They have to supplement their staff with a lot of new and untrained people, and that's not very productive. They also have to pay a lot of overtime, so getting a 34 percent improvement in the pick rate (the rate at which people send product out of the warehouse shelves to be sent to customers) is a huge savings. And it cost them nothing to achieve," he continues.

"I think it's safe to say that most of the big retailers now use this or some adapted form of it for coordinating their order pickers. All of the software systems, warehouse management systems, and similar systems have been adapted to integrate with the bucket brigade style of order picking."

Bucket Brigades in Nature

While Bartholdi and Eisenstein were formatting their ideas around bucket brigades, they continued their study of social insects. "A friend of mine e-mailed me that two Spanish biologists had found a species of ant in the high plateau of Spain which appeared to carry seed back to the nest by bucket brigade," says Bartholdi. "It was the oddest thing. The seed would be picked up by the smallest and slowest ant, carried back, passed over to a larger and faster ant, who speeds it back toward the nest, where it is taken by a bigger and faster ant, until the biggest and the fastest ant of all races back to the nest. The slowest guy goes back to get another one."

Bartholdi was fascinated. The ants don't even have an engineer to issue the basic commands. "They just do it. It turns out that you can explain it very simply. If each ant simply grabs whatever seed it can, the bigger ants are able to grab the seeds from smaller ants, because they are bigger and faster. The biggest ants tend to work at the end of the line. The smallest ants, who can't take anyone's seed, have to walk all the way out to the end of the path and pick up the seed off the ground, because it's the only way they can get a seed."

"The allocation of work emerges spontaneously," he continues. "In the industrial environment, we had to tell people to sequence themselves from slowest to fastest. The ants do it automatically. Everywhere we've been with our research, the workers always know who is slowest and who is fastest. In the world of social insects, even the bucket brigades emerge spontaneously. Once they've emerged, they balance themselves."

For ants, the system has other good qualities. "As the ant carries the seed back to the nest, she is subject to predation, capture by a spider, or to another species of ant stealing the

Bucket Brigades: How They Work

By John Bartholdi and Don Eisenstein

What are 'bucket brigades'?

"Bucket brigades" are a way of organizing workers on a flow line so that the line *balances itself*.

Here is how it works. Products on a flow line are progressively assembled as they move down the line toward completion. An assembly line is a familiar example from the realm of manufacturing; but flow lines are found in all types of industries, wherever "products" may be imagined to move along, from worker to worker.

A classic difficulty in the management of flow lines is to balance the line so that it will be maximally productive. This requires precise and time-consuming identification of the work elements and estimates of standard work-content. For example, assembly lines are balanced by teams of engineers, who define task elements and then conduct time-motion studies so that the work can be divided equally among workers. Because bucket brigades are *self-organizing*, the need for centralized planning and management is reduced.

This idea may be found in the social insects, such as ants or bees, which are highly effective at organizing themselves even though without blueprint or management. Instead, global coordination emerges spontaneously, through the multiple interactions of many simple components. Similarly, when workers on a flow line are organized into bucket brigades, they can function as a self-organizing system that spontaneously achieves its own optimum configuration, without special equipment, time-motion studies, work-content models, management, or control systems.

The operation of bucket brigades is simple: Each worker carries a product towards completion; when the last worker finishes his product he sends it off and then walks back upstream to take over the work of his predecessor, who walks back and takes over the work of his predecessor and so on, until after relinquishing his product, the first worker walks back to the start to begin a new product. If, in addition, workers are sequenced from slowest to fastest, then we call the system a *bucket brigade* and the workers will, we have proven, spontaneously gravitate to the optimal division of work so that throughput is maximized.

Notice that workers must maintain their sequence: No passing is allowed and so it can happen that one worker is blocked by his successor, in which case we require that he simply wait until he can resume work, after his successor has moved out of the way. (This waiting is not necessarily bad because it is the means by which the workers migrate to their optimum locations.)

Benefits

- There is a reduced need for planning and management because bucket brigades make the flow line self-balancing.
- Production becomes more flexible and agile because bucket brigades "tune" themselves, without time-motion studies or the other cumbrous endeavors of assembly-line balancing.
- Throughput is increased because bucket brigades spontaneously generate the optimal division of work.
- Secondary labor is reduced and quality improved because bucket brigades operate with the absolute minimal work-in-process.
- Training and coordination are simplified because it is easy for workers to know what to do next.

Who is using bucket brigades?

Bucket brigades are used mostly in distribution warehouses to organize order-pickers, in the apparel industry to organize garment-sewers, and in simple assembly processes.

We believe bucket brigades to be more widely applicable but feel that the greatest economic significance is in order-picking, which is very labor-intensive. A typical high-volume distribution warehouse employs hundreds of workers to pick orders and the work must be rebalanced daily, and sometimes more often.

For more information, as well as a web-based demonstration of the bucket brigade concept, visit http://www.isye.gatech.edu/~jjb/bucket-brigades.html.

seed. So you can imagine, as the seed gets closer to the nest, it increases in value. You've already invested work in it. At the same time, as it gets closer to the nest it is being carried by bigger and faster ants, so it is more likely to be safe. In addition to being an efficient way of gathering seeds, in the ant context it makes economic sense."

The Work Continues

Bartholdi and Eisenstein continue their work on bucket brigades. "We've found additional uses for bucket brigades, adapting them slightly for different kinds of environments. It appears to be very robust behavior that balances itself strongly, as long as you're careful about how you set it up. If you set it up incorrectly, you induce chaos. Even though your system is very predictable, even mechanical, it can behave as if it were effectively random, which means that there is a high variability in the time to complete a product."

The next stop for bucket brigades is the military. Bartholdi, Eisenstein, and former ISyE doctoral student Kevin Gue are in discussion with the Pentagon to adapt some of these ideas for what they refer to as "sense and respond" logistics, Bartholdi says. "In the military exercise, the effort would function almost like an organic creature. Social insects again are a good metaphor here. We know that ants fight wars with other ant colonies, for example. And there is clearly no general in charge. What we would like to do is find some context in military activities in which one can embed this form of self-organization, so that a colonel doesn't have to enforce it. We'd like to have individuals make decisions right there at the front, in a way that this coordination emerges spontaneously."

(continued from page 5)

Stewart Winn, BIE 1958, MSIE 1963, is an associate with Carter & Burgess, Inc., in Williamsburg, Virginia, where he says he is in transition to retirement. He consults on the construction of transit projects in Philadelphia and Baltimore, and looks forward to the day he can improve his golf game.

Correction from Winter 2003: **Randy J. Thayer, MSIE 1980,** received his BSME from Kettering University (formerly GMI). He began his General Motors career as a college co-op student at Oldsmobile in Lansing, Michigan in 1973. We apologize for the error.

Marriages

Nicole Stout, BIE 2003, and Shawn Montague, BIE 2002, were married on September 23, 2003, in San Antonio, Texas. The couple now resides in Windermere, Florida, where Nicole has started a new position as a Labor Maintenance Analyst with Walt Disney Corporation.

Births

Karin Anderson Quigley, MSIE 1998, and her husband Scott announce the birth of a baby girl, Julia, born October 7, 2003.

Vicki Estrin, BIE 1986, and her husband David announce the birth of Ryan Seth Estrin on October 13, 2003. Estrin is vice president of HMD-The SmartHospital Company in Nashville, Tennessee.

William N. McQueen III, BIE 1994, and his wife Robyn announce the birth of a son, William Northington McQueen III, on September 16, 2003. In August 2004, McQueen will begin the master of divinity program through the School of Theology at the University of the South in Sewanee, Tennessee.

Justin Whitfield Wiechart, BIE 1998, and her husband Matthew Wiechart, ME 1997, announce the birth of a son, Keith Whitfield Wiechart, on October 20, 2003. He joins his big brother John, age three and a half.

Deaths

Marshall Spieth, BIE 1948, on January 14, 2004, in West Hartford, Connecticut. Spieth retired in 1985 after a 37-year career with Combustion Engineering (now Alston). He is survived by his wife, Georgia.

Faculty News

ISyE faculty members **Sigrun Andradottir** and **Brandi Vidakovic** have been promoted from associate professor to full professor.

Assistant Professor **Julie Swann** has been selected for a National Science Foundation Career Award. The Faculty Early Career Development (CAREER) Program are NSF's most prestigious awards for new faculty members. The CAREER program recognizes and supports the early career-development activities of those teacher-scholars who are most likely to become the academic leaders of the twenty-first century. CAREER awardees are selected on the basis of creative, career-development plans that effectively integrate research and education within the context of the mission of their institution.

Jeff Wu, the ISyE Coca-Cola Chair in Engineering Statistics, has been elected to the National Academy of Engineering for his work conceiving and building modern systems of experimental design based on contemporary methods for parameter estimation to provide quality improvements.

Election to the National Academy of Engineering is among the highest professional distinctions accorded to an engineer. Academy membership honors those who have made important contributions to engineering theory and practice, including significant contributions

Exploring the Business of Sports

No question about it – sports today mean big business. Members of the Georgia Tech Business Network heard from a number of experts in the business of sports at the Network's December meeting.

The evening was kicked-off with a keynote speech from Wayne Luke, executive vice president of People and Organizational Development with the Atlanta Falcons. Luke began by comparing the similarities between the business and sports world, including the use of metaphors such as "team" and "coach." Sports customers, like any consumer, are looking for a quality product, Luke said.

"The Falcons are going through a catharsis, now that they are being run by a successful businessman [Arthur Blank]," said Luke. "You have to find out what people want and then deliver," he continued, noting, "Arthur listened intently when he started." Because of that, the Falcons have added 18,0000 more parking spaces and improved traffic flow around the Georgia Dome. They've also discounted ticket prices with the aim to fill the Dome, so that more games can be televised, allowing the team to build up a stronger fan base.

There are differences between sports and business, as well. Most notably, said Luke, is the pace. "The schedule is excruciating, and everything is played out in front of an audience, all of whom are experts."

After Luke spoke, his concepts were batted around by a panel moderated by Doug Konkel, editor of *Georgia Sports Monthly* and host of Friday Night Football and the Pigskin Review/Preview Show on 680 The Fan. Panelists included Evan Appel, vice president of Strategic Development for Career Sports Management, Inc.; Drew Barry, professional basketball player and former star Yellow Jacket point guard; Paul Connell, director of Marketing for BACE Motorsports; and Bob Herrfeldt, executive vice president of Horrow Sports Ventures.

to the literature of engineering theory and practice; and those who have demonstrated accomplishment in the pioneering of new fields of engineering, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education.

Student News

Monique Gupta, BIE, 2004, has been awarded the Churchill Scholarship for one year of study at the University of Cambridge in the United Kingdom. The Winston Churchill Foundation of the United States, which only considers candidates from 75 universities, funds the scholarship. Gupta, who was awarded the prestigious Goldwater Scholarship last year, plans to use her scholarship to get a Masters of Philosophy in genetics before going to medical school.

E-Waste Update

Researchers and officials in the state of Georgia can now make informed decisions on environmental recycling policy guided by a modeled solution approach developed by Jane Ammons, ISyE's NSF ADVANCE Professor of Engineering.

Dr. Ammons is chair of Georgia's Computer Equipment and Disposal Recycling Council. Using her model, the Council – which advises the Governor and legislature – has an objective and quantitative basis to simulate the effectiveness of environmental actions before policies are issued.

Assisted by Chemical Engineering professor Matthew Realff and a team of graduate students, Dr. Ammons, operating on a National Science Foundation grant, continues to expand the model that was developed in 1998 for the design of infrastructures to recycle electronic equipment, or e-waste.

E-waste, the most rapidly growing waste problem in the world, develops

The History of Sustainability at Georgia Tech

No one will be surprised if the business students in the Georgia Tech College of Management show increased academic performance after moving to the new Management building in Technology Square. In fact, the expectation is that not only will they perform better, but that they will be more enthusiastic as they learn.

This expectation is not related to any new developments in the business curriculum, but instead is linked to the indoor air quality, filtration systems, carbon dioxide monitors, and other energy management features that were incorporated into the construction of the building that serves as the new home for the business school.

The design materials, features, and processes earned the environment-friendly building a prestigious Silver certification under the Leadership in Energy and Environmental Design (LEED) criteria, a nationally recognized rating system launched in 1998 by the U.S. Green Building Council. Besides offering environmental benefits, studies show that LEED school buildings contribute to higher test scores for students.

As one of only two LEED-certified buildings in Georgia, the Technology Square structure is literally a monument to Georgia Tech's commitment to creating a more prosperous and sustainable society. It is an example of "putting your money where your mouth is" and represents a significant milestone in the evolving history of the sustainability movement at Georgia Tech.

Preventative Medicine

Although difficult to define, the commonly accepted description of sustainability is in terms of a high-level objective: "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs..." (Report of the United Nations World Commission on Environment and Development, 1987). Unlike the post-Earth Day (1972) focus on correcting ecological ailments resulting from past activities, the sustainability movement focuses on preventative methodologies for living today that avoid future impairment of global systems.

For Georgia Tech, a commitment to sustainability means researching and developing technologies that not only protect or renew limited material and energy resources; but that also promote new practices and renovate existing processes in ways that reduce future risk to the stability of the ecosystem. This entails establishing a multi-faceted strategy that integrates discovery in the research laboratory with learning in the classroom and practice in the stewardship of the campus environment, and beyond to Georgia Tech's myriad partners through local, regional, and global outreach projects.

Planting the Seed

Sustainability began at Georgia Tech in the early 1990s as an offshoot of the extensive environmental research conducted at the Institute during that period. With more than 200 faculty members identifying themselves as involved in green or environmental-relevant research, Georgia Tech leaders helped create the Georgia Research Alliance/Georgia Environmental Technology Consortium (GETC) to provide funding for endowed chairs and research infrastructure in Georgia. The consortium, a partnership among Georgia's research universities, industry, and government, was created in 1991 to foster environmentally responsible economic growth.

Under the leadership of Dr. Jean-Lou Chameau, then chair of the School of Civil and Environmental Engineering, Georgia Tech established the Center for Sustainable Technology (CST), with a grant from the General Electric (GE) Fund, in order to develop curricular materials on sustainability for the College of Engineering. This effort provided a foundation for campus-wide education on the principles of sustainability and coalesced a critical mass of faculty capable of introducing these concepts into the institution's curricula.

Concern for sustainability issues expanded beyond the classroom and laboratory into Institute operations in 1995, by way of the first Institute Strategic Plan. Presented by Georgia Tech President, Dr. G. Wayne Clough, the plan included Georgia Tech's vision statement affirming the institution's commitment to a sustainable society.

The commitment moved from vision to reality in 1996 when Dr. Chameau, then vice-provost for research and CST founder, formed the Sustainability Task Force. Now as provost and vice president for academic affairs, Dr. Chameau continues to promote the sustainability initiatives on campus.

Dr. Chameau was inspired to ensure that resources would be available for faculty members and students to advance education and research in

from discarded computers, televisions, VCRs, electronic games, cell phones, and other electronic equipment. Although aggressive computer recycling efforts delay the ultimate disposal of these electronics, the products eventually become e-waste materials – glass, wire, certain plastics, and metals such as lead, copper, aluminum, and gold.

Ammons' solution lies in "reverse production" systems – infrastructures designed to recover and reuse materials contained in e-waste. The recycling part of the process entails re-distribution of equipment to new or extended uses before resorting to the recovery phase, which involves collection of raw materials. Scientists are concerned with the high amounts of contaminants that pose a threat to groundwater and eventually affect drinking water.

The original Georgia Tech case study determined a successful model of an economically effective reverse production system. After solving the model over numerous 'what-if' scenarios, the results showed that the most effective recycling systems occur as a result of increasing collection and usability percentages. An overview of the original case study appears in the Spring 2003 issue of *Engineering Enterprise.*

According to Dr. Ammons, in the last year, "the model has been extended to include brand new methodology and robust optimization that is promising for large scale systems." The model, with improved data, includes explicit design of collection systems and is being expanded to represent each collector and processor as an independent agent.

It also considers economic factors such as distance, cost of fuel, and labor used in transporting materials and parts.

The modeling process has captured the interest of national and international researchers. With this effort, Georgia Tech continues to set the agenda to deal with e-waste in an effective and environmentally responsible manner.

sustainable technologies. Consequently, he challenged the interdisciplinary Sustainability Task Force to understand the level of sustainable-related activities at Georgia Tech and to make recommendations to the administration on what was needed to foster a culture of sustainability. After a year of monthly meetings, the group developed a list of recommendations which defined the strategic approach to embracing sustainability.

One of the recommendations was that "the Institute establish processes for integrating campus master planning and facilities management with research and educational activities that focus on the long-term campus environment." From this, the CST was elevated to the Institute for Sustainable Technology and Development (ISTD) and has ultimately become the umbrella and campus-wide coordinator for sustainability related projects, courses, and initiatives.

"The vision and momentum provided by the 1996 faculty task force has served Georgia Tech and led to the strong programs and activities we now have in sustainability. This vision and commitment has enhanced Tech's overall reputation," said Dr. Chameau.

Sustainability at Georgia Tech Today

Sharing space in the new LEED-certified Management building in Technology Square, ISTD promotes the incorporation of sustainability into new and existing research programs; and supports efforts to include sustainability concepts into required and elective courses.

Functioning as a warehouse for sustainable-related resources for faculty, researchers and students, ISTD also develops tools that educate and link the sustainability community together.

Examples of ISTD-created resources include *A Primer on Sustainable Technology and Development*, written by Carol Carmichael, former director of ISTD, used in several courses at Tech. In addition, *Georgia Tech Courses with Sustainability Content*, compiled under the leadership of Nancy Jones, program manager at ISTD, is a reference for students who desire to enhance their program of study with courses containing sustainability concepts. *The Green Purchasing Guide* was written by Nancy Jones and Cindy Jackson, manager of the Office of Solid Waste and Recycling. In addition to developing publications, ISTD has catalogued known sustainable-relevant researchers and projects. Links to this and other vital sustainability information are available at the ISTD website: www.sustainable.gatech.edu

The history of sustainability at Georgia Tech continues to evolve with frequent milestones that show a significant shift in the technology paradigm. Keeping track of the entire Institute's sustainable technology developments is difficult these days as the rapidly occurring stories on this topic seem to indicate that early visionaries have been successful in affecting a change in social thinking that considers the needs of the future. The ISTD website provides numerous links to local and global headlines that point out the technological community has developed sensitivity to environmental and sustainable awareness in many aspects of research, design, and operations.

Paradigm shifts, however, are notoriously slow processes. Nevertheless, it will take a corporate change in mindset to overcome the resistance to fully envelop sustainable processes and technologies – which invariably add extra costs to projects. A global perspective that accounts for benefits that occur over a period of time helps to justify the additional investments of time and money that are typically required on the front end of sustainable projects.

According to Dr. Bert Bras, Professor of Mechanical Engineering and Director of ISTD, a major barrier for introducing new courses exists because curricula are full and do not leave room for students to take extra courses. Dr. Bras adds that attempts to change existing core courses can lead to stalemate. Overcoming the curricular obstacles will also require time as some schools are reviewing their programs for change and are also investing in young faculty who are more eager to participate in curriculum innovation.

Dr. Bras shares that "We are currently working on some new undergraduate certificate programs that address sustainability from a number of cross-cutting themes. For example, sustainable energy systems and sustainable manufacturing systems." Dr. Bras says that a long term goal has been to integrate some courses with Campus Management, revealing there are opportunities to use the campus as a research and education test-bed.

From the viewpoint at Technology Square, where the new Management building serves as a model for future campus growth that supports the sustainability vision, this looks promising, Dr. Bras.

ALUMNI NEWS

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