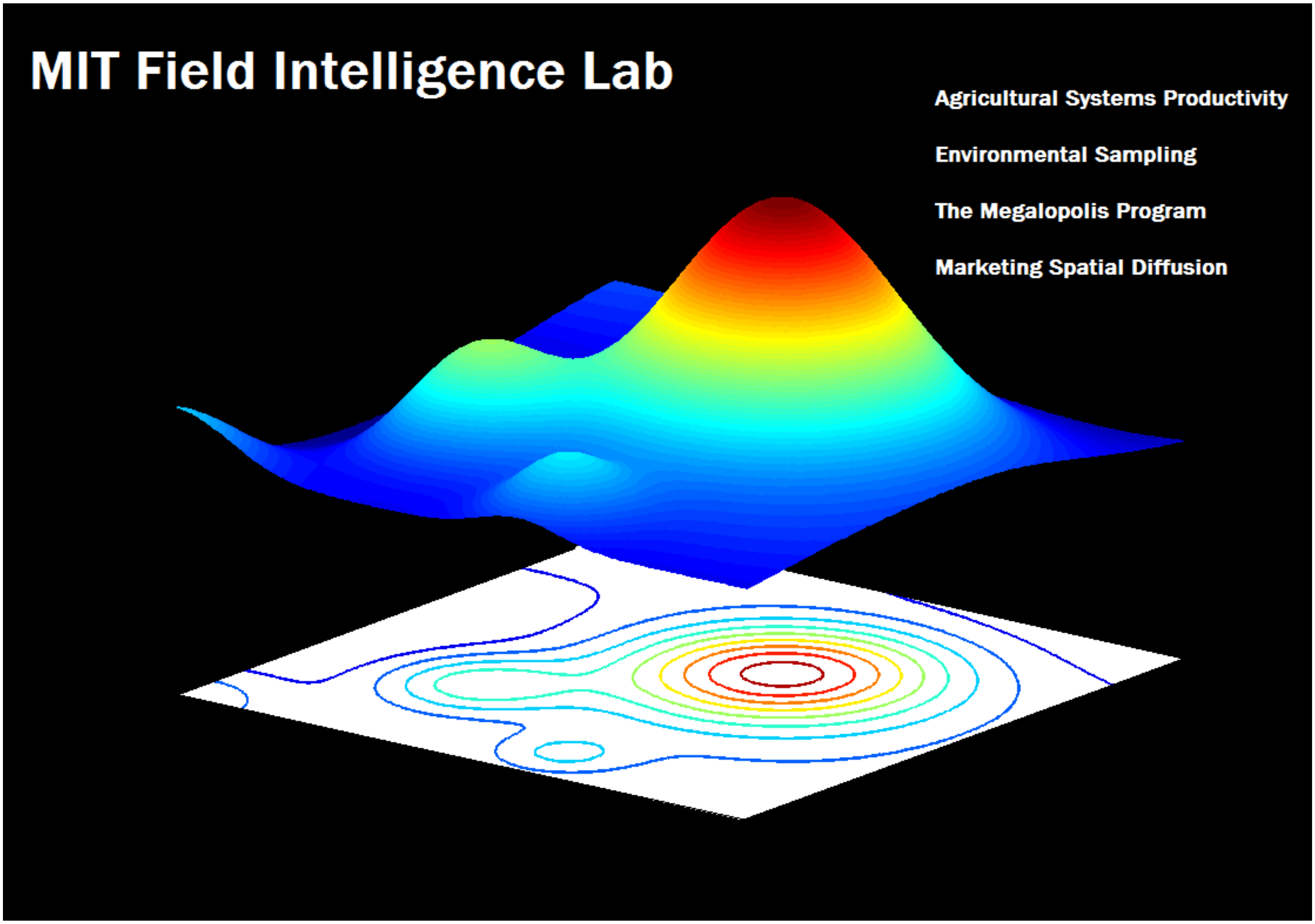
MIT Field Intelligence Lab
Agricultural Systems Productivity
Environmental Sampling
The Megalopolis Program
Marketing Spatial Diffusion

SPECIALTY CROP RESEARCH

Edmund W. Schuster

Field Intelligence Lab

Massachusetts Institute of Technology

Historically, the various segments of the specialty crop industry have taken independent paths to address critical research issues. Since each segment represents a small portion of the total specialty crop industry, many important research issues do not receive the proper attention in national programs funded by Federal Agencies. This has created a sub-optimal environment for innovation in US specialty crops agriculture as compared to program crops, which have traditionally received the bulk of research attention.

To meet a number of emerging challenges, the specialty crops industry must have modern tools and technologies that can address labor concerns, improve production efficiency and product quality, optimize the post-harvest supply chain, and reduce the environmental impact of agricultural chemicals. Given these broad objectives, existing technologies both internal and external to the agricultural industry might provide effective solutions. Further, a need exists to conduct research in new technologies that have no previous precedent. The most useful inventions often do no resemble anything that currently exists. Perhaps the greatest challenge for the specialty crop industry is to create a balance between incremental improvement and break-through innovation.

The purpose of this report is to provide an analysis of the April 24 – 25 meeting titled *"Engineering Solutions for Specialty Crop Challenges"* and to develop a research plan for the future. Held in Washington D.C., the meeting sponsors included the USDA, NSF, NASA, CSREES, and ARS. Constituencies from all areas of agriculture participated (growers, government agencies, suppliers, and Universities). The goal was to identify industry needs through a series of group discussions and to match with University research capacity and governmental funding opportunities. Besides industry-oriented presentations, there were two full days of discussions organized by specialty crop category (day 1) and engineering topic (day 2).

Day 1 - Industry break-out sessions: Wine and Grape, Tree Fruits and Nuts, Citrus and Subtropicals, Ornamentals, and Berries and Brambles.

Day 2 - Engineering Topics: Sensors and Sensor Networks, Precision Agriculture, Education and Workforce, Information Technology and Decision Aids, Automation/Robotics/Mechanization, Socio-Economic and Enterprise

Prior to the workshop, a great deal of planning took place to maximize the impact of the meetings. This included formulation of a detailed set of objectives, including:

1. Convey to the engineering and R&D community the labor productivity and production efficiency needs of the specialty crop industries and how technology solutions would fit into current operations.

2. Highlight some current R&D activities and technologies that could have application to specialty crop labor and efficiency problems.

3. Develop an agenda for short, medium, and long-term engineering R&D activities to aid specialty crop industries (the expectation is that some of this R&D will be supported at the Federal level).

4. Foster an ongoing dialog among workshop participants and expand options for future networking.

During conference, several important topics dominated discussion. The following describes macro themes that form a context for examining the research needs of the specialty crop agricultural industry.

Since the value of specialty crops in the United States now surpasses the value of “program” crops (corn, wheat, soybeans, cotton, and sorghum), there needs to be more research emphasis on the practical problems associated with the grape, tree fruit and nut, citrus, berry, and nursery industries. A common issue expressed by nearly all meeting attendees relates to the shortage of labor and the prospects for automation using robotics. Another focus involved the application of “systems” ideas as a way of developing effective technological solutions.

Beyond specific industry issues such as the availability of labor, attendees noted that the forces of globalization are forming a new competitive environment for many high margin specialty crops. This creates a need for better methods of determining production costs (and projected profit) for domestic growers along with improved understanding of supply chain dynamics and global economic systems. Many growers stated that increasing the yield of specialty crops was the best way to meet competitive challenges from overseas.

With the prospect of global climate change, the possibility exists that a shift in optimal growing areas will take place across the United States. Slight changes in average temperature (and climate) might also cause new patterns of plant disease and pest concentration.

While potential climate shift is a longer-term factor, there exist short-term trends that will have an immediate impact of United States agriculture. Urbanization has caused a significant loss of productive land and has increased the competition for water. Demographic shifts and the general increase in American population will have uneven impacts across the country, with Southern states like Florida experiencing rapid grown as baby-boomers retire. Given continued economic expansion, ever-increasing amounts of land will be needed for the construction of dwellings, roads, shopping centers, and businesses.

RESEARCH PROCESS

To begin to understand how technology and research might play a role in dealing with the needs of the specialty crop industry, a process needs to be in place that would guide governmental and university research efforts in solving practical problems of value. To extend this line of thought, a process might be comprised of three parts:

1. Identifying research and existing technologies, both within and external to the agricultural industry, that hold potential for a significant engineering break- through.

2. The formation of multi-discipline teams, including cooperation between universities, to address specific problems.

3. Integration of all stakeholders, including growers, Governmental agencies, Universities, and suppliers into a formalized community of practice. The goal is to speed communication and to increase the rate of diffusion for new technologies. An outgrowth of this integration effort would be select standardization of processes and technology within the specialty crop industry. Through-out the history of commerce, standards have been a significant factor in stimulating economic growth.

Based on the April 24-25 discussions, it appears that research needs for the specialty crop industry comprise three main areas; a. *mechanical/electrical*, b. *quantitative technologies* including modeling and data analysis for decision making, and c. *supply chain* related issues.

The next three sections outline specific research problems within these three areas based on the notes from the group discussions.

MIT Field Intelligence Lab
Published Jan. 11, 2008
Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)

CATEGORIZATION AND RESEARCH PRIORITIES

Mechanical/Electrical Technologies

a. sprayer technology

The traditional "air blast" sprayer for applying pesticide is old technology that needs to be replaced with new engineering approaches that do a better job of targeting application and reducing drift. This is true for all chemicals used in agriculture. Besides being a significant environmental issue, the over application of agricultural chemicals represents an excess cost to the growers.

Improving sprayer technology also raises important engineering issues such as the properties of aerosols and airflow. For example, the mechanics of airflow within an orange grove, grape vineyard, or field of tomatoes also affects pollination and patterns of frost damage.

b. sensors

An important area for future research, agricultural sensors exhibit important differences as compared to traditional industrial sensors that measure temperature, light, humidity and vibration. Though the use of sensors in agriculture is in an early stage, there seems to be several type basic types; 1) fixed sensors that are placed in a distributed manner, covering many acres of orchards, vineyards, vegetable fields, or orange groves, or 2) sensors attached to agricultural machinery to measure yield per area or the density of foliage. In all cases, cost will be an overriding factor in the deployment of sensors.

There are many ideas for developing agricultural sensors. Some include:

- A sensor placed on a tree or grape vine to measure internal water uptake for irrigation planning purposes.

Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)

• Development of a new family of sensors designed to analyze the internal quality of fruit. This might also include measuring maturity of fruit and vegetables in the field (sugar and starch content and the rate of growth).

• From a food safety perspective, sensors are needed to measure pathogens and other chemical contaminates in the field.

• In terms of the efficiency of agricultural production, sensors could measure the concentration of pests and perhaps various plant diseases that appear in the field. This would provide better information on when and where to apply chemicals.

• Forecasting crop size and timing presents an interesting opportunity for sensors relating to the measurement of maturity rate and weight. This might include detection of certain chemicals such as phenols that have significant pharmacological properties.

• Nanotechnology offers some opportunities for creation of agricultural sensors.

In all applications of sensors, there is concern about making the data interoperable and applying various means such as mathematical models to analyze the data. The M Language being developed at MIT might offer a solution to this problem.

c. robotics

With the shortage of agricultural labor, innovative applications of robots, and other types of mechanization holds the promise of solving important problems in agriculture. Historically, it has been difficult to apply automation approaches in agriculture because of the considerable variability inherent in agricultural systems.

From the April 24 – 25 meeting, several applications of mechanization were identified. These include:

- Pruning
- cane cutting
- crop regulation (leaf thinning, shoot thinning, fruit thinning)
- canopy management
- harvesting

A final application involves using robots to take various samples from a large area. For example, some growers in Florida have as much as 20,000 acres of orange groves. It is a massive job to walk the entire grove looking for possible contamination such as citrus canker or greening. A robot could perform this task in a much more efficient way.

d. food processing

Though the focus of the April 24 – 25 meeting was on agricultural operations, there was mention of the need for a new method of pasteurization. This process is an important area that influences quality and energy consumption.

e. energy

A significant input, energy usage for all aspects of farm operations is likely to increase in cost. While not often considered, the cost of transporting supplies to farms and crops to markets will also significantly impact overall agricultural production costs. Potential research areas include internal combustion engine efficiency, farm practices, and improved supply chain coordination.

MIT Field Intelligence Lab
Published Jan. 11, 2008
Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)

Quantitative Technologies, Modeling, and Data Analysis

a. spatial risk in agriculture

Building on the work of Allen and Schuster (2004), this research area expands the measurement and mathematical modeling of risk from a point estimate to spatial observations. It also expands the types of risks considered (temperature, wind, and hurricane). This is an especially important issue for specialty crops, which are often very sensitive to frost damage and other risk factors. Beyond modeling risk, the goal is to incorporate a quantitative assessment of risk into supply chain planning and execution. With the prospect of global warming, this line of research is especially important in matching certain types of agricultural products to specific locations. Broadly speaking, this could be considered site selected for both annual and perennial crops.

Examples of the value of this research include:

- The selection of the best location to plant a crop while also optimizing the trade-off between harvesting schedules, quality, and the chance of weather related losses represents a difficult long-term problem for many types of specialty crops.

- The general area of using geospatial data for making better day-to-day decisions and the development of quality maps is also a very important area for research and application.

b. crop forecasting

Essential to the efficient functioning markets, crop forecasting represents a significant challenge for specialty crop agriculture because of a lack of data and appropriate mathematical models. The three typical areas that could benefit from improved forecasting include; yield, maturation, and quality.

c. pest modeling

Further refinement of models for pest and disease management is important for improving crop yields. During group discussions, several stated that the idea of making existing models for the spatial diffusion of pests interoperable might serve an important need in accelerating the research, development, and application of these approaches for other crops.

d. data and mathematical modeling infrastructure

One of the biggest issues in agriculture involves the application of mathematical models to data in a way that aids decision-making. For many agricultural situations, there is a lack of data. In situations where data is available, there is often no pre-determined mathematical modeling approach in mind.

If the future of United States agricultural productivity rests on the application of data to make better decisions, then there needs to be a national information technology backbone to make data interoperable with mathematical models. With this idea in mind, it makes sense to build an open system available at little or no cost to users.

Other computer related areas of importance to agriculture include the design of visual interfaces that are simple and intuitive along with answering the question “where does modeling make sense in agriculture?”

An overlooked opportunity in both the data and modeling areas involves the determination of “economic thresholds” for agricultural activities such as spraying or applying fertilizer. In many cases, these model outputs are obsolete because of a lack of updating. There is also a concern relating to an over reliance on empirical models. Though these models are effective, most require constant updating to remain valid. The future would appear to be in the area of modeling biological processes. This will require considerable refinement in modeling approach.

Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)

Supply Chain

a. integration

In general, there is a lack of supply chain orientation for specialty crop agriculture. Yet the link between growers and consumers is becoming stronger as improved information technologies become widespread. Though there are a number of different definitions, logistics and supply chain management generally covers forecasting, warehousing, inventory management, transportation, purchasing, and customer service; and sometimes marketing and finance. Many opportunities exist for specialty crop producers to achieve a greater degree of integration with upstream supply chain partners. This is especially important for such issues as quality, shrink, and profitability from the retail perspective along with what products sell the best is specific areas of the United States.

Relating to specialty crop producers, the operational elements of supply chain management that are important include forecasting, planning, and execution. Using these concepts as a base for management, a great deal of efficiency and cost reduction can result. For example, the coordination of transportation is a specific concern for many specialty crop producers. Increasing prices for transporting might ultimately constrain the optimal areas to plant specialty crops. Another example involves the use of sensors to provide information on crop maturity and projected picking schedules.

b.food Safety

An important research area is food safety and the ability to track and trace food products at any stage of the supply chain. This is a data intense area that requires substantial information technology infrastructure.

c. store kiosk

For some specialty crops like nursery stock sold in large outlets such as Wal-Mart or Home Depot, it makes sense to move more information to the point of sale. Informational kiosks are powerful ways to facilitate customer interaction and stimulate sales. The application of

Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)

this technology to agricultural supply chains is just beginning, however, as demonstrated in other countries there is great potential associated with this technology.

d. inventory control

Nurseries rank inventory control as a #1 priority. Based on knowledge of the operations management and agricultural literature, there does not appear to be any work ongoing in this area.

CURRENT STATE OF KNOWLEDGE

Quantitative Technologies, Modeling, and Data Analysis

MIT Field Intelligence Lab

---

a. Harvest Risk

Gathering the harvest represents a complex managerial problem for agricultural cooperatives involved in harvesting and processing operations: balancing the risk of overinvestment with the risk of underproduction. The rate to harvest crops and the corresponding capital investment are critical strategic decisions in situations where poor weather conditions present a risk of crop loss. This mathematical model has general application to a wide variety of crops, including grapes, oranges, and vegetables.

Allen, S.J. and E.W. Schuster, "Controling the risk for an agricultural harvest," *Manufacturing & Service Operations Management* 6, no. 3 (2004): pp 225 – 236.

http://www.ed-w.info/1526-5498-2004-6-3-0225.pdf

Allen, S.J. and E.W. Schuster, “Managing the risk for the grape harvest at Welch’s,” *Production and Inventory Management Journal* 41, no. 3. (2000): pp 31 – 36.

http://www.ed-w.info/P&IMJ%202000%20SJA%20EWS.pdf

b. M Language and Web Machines

This technology involves a means to achieve data interoperability using enhancements to existing XML standards. The technology also provides a framework for building a network of mathematical models using web services and other means. Applications in agriculture include integrating sensor data and making the use of mathematical models practical.

Brock, D.L., E.W. Schuster, S.J. Allen, and P. Kar, “An introduction to semantic modeling for logistical systems,“ *Journal of Business Logistics* 26, no. 2 (2005), pp 97 – 117.

http://www.ed-w.info/BrockSchusterAllenKar.pdf

Brock, D.L., Schuster, E.W., and Kutz, Sr., T.J., "An overview of the M Language," *The MIT Data Center*, Cambridge, MA: MIT-DATACENTER-WH-09 (January 2006).

http://www.ed-w.info/MIT-DATACENTER-WH-009.pdf

Brock, D.L., Schuster, E.W., and Thumrattranapruk, C., "Multi-lingual display of business documents," *The MIT Data Center*, Cambridge, MA: MIT-DATACENTER-WH-10 (May 2006).

http://www.ed-w.info/MIT-DATACENTER-WH-010.pdf

Schuster, E.W. and S.J. Allen, "The Data-Driven Economy: Applications of the M Language in Agriculture," University of Florida Citrus Research and Education Center: Lake Alfred, Florida, *MIT-DATACENTER-PR-026*, October 16, 2006.

http://www.ed-w.info/MIT-DATACENTER-PR-026.pdf

Schuster, E.W. and D.L. Brock, "The Data-Driven Economy: Applications of the M Language in Manufacturing and Supply Chain Management," University of Florida - Computer Science Department: Gainesville, Florida, MIT-*DATACENTER-PR-027*, October 17, 2006.

http://www.ed-w.info/MIT-DATACENTER-PR-027.pdf

Supply Chain

MIT Field Intelligence Lab

a. Integrated Capacity Planning for Agricultural Supply Chains

Optimizing capacity for agricultural supply chains is often difficult because there are a number of processing and transportation steps between the grower and end consumer. This technology uses various types of mathematical optimization to determine the optimal amount of capacity needed for harvesting and production operations.

Schuster, E.W., S.J. Allen and M.P. D'Itri, "Capacitated materials requirements planning and its application in the process industries," *Journal of Business Logistics* 21, no. 1 (2000): pp 169 – 189.

http://www.ed-w.info/JBL2000-CapMRP.pdf

Schuster, E.W. and S.J. Allen, “Raw material management at Welch’s,” *Interfaces* 28, no. 5 (1998): pp. 13 - 24.

http://www.ed-w.info/Schuster-Allen%201998.pdf

b. Scheduling Technology

Given the complexity of agricultural operations, developing schedules by had for various operations is a difficult task. This technology is a family of mathematical models that are capable of producing an optimized schedule in a wide range of real world situations. All of the references below were applied in real-world agricultural situations.

Schuster, E.W., C. Unahabhokha, and S.J. Allen, “Master production schedule stability under conditions of finite capacity,” Paper accepted for the poster session of The Proceedings of the 34th Annual Logistics Educators Conference: San Diego, CA (2005).

http://www.ed-w.info/LEC20054-14-05R1.pdf

D’Itri, M.P., S.J. Allen and E.W. Schuster, “Capacitated scheduling of multiple products on a single processor with sequence dependencies,” *Production and Inventory Management Journal* 40, no. 4 (1999): pp 27 – 33.

http://www.ed-w.info/ditri[1].pdf

Allen, S.J., J. Martin, and E.W. Schuster, “A simple method for the multi-Item, single level, capacitated scheduling problem with set-up times and costs,” *Production and Inventory Management Journal* 38, no. 4 (1997): pp. 39 - 47.

http://www.ed-w.info/P&IMJ%201997%20SJA%20JM%20EWS.pdf

Allen, S.J. and E.W. Schuster, "Practical production scheduling with capacity constraints and dynamic demand: family planning and disaggregation," *Production and Inventory Management Journal* 35, no. 4 (1994): pp. 15 - 21.

http://www.ed-w.info/P&IMJ%201994%20SJA%20EWS.pdf

Schuster, E.W. and B.J. Finch, "A deterministic spreadsheet simulation model for production scheduling in a lumpy demand environment," *Production and Inventory Management Journal* 31, no. 1 (1990): pp. 39 - 42.

http://www.ed-w.info/P&IMJ%201990%20EWS%20BJF.pdf

c. RFID and Supply Chain - Track and Trace

A new technology, Radio Frequency Identification (RFID) holds great promise as a replacement for the bar code. Already applied in the agriculture industries, RFID is an effective means of improving operations. There are also substantial applications in tracking and tracing agricultural produces moving through complex supply chains.

Schuster, E.W., S.J. Allen, and D.L. Brock (2007), *GLOBAL RFID: The Value of the EPCglobal Network for Supply Chain Management*, Berlin and New York: Spriger-Verlag.

http://www.ed-w.info/EWSwebpageGLOBALRFID.htm

Koh, R., E.W. Schuster, I. Chackrabarti, and A. Bellman, "Securing the pharmaceutical supply chain," *MIT Auto-ID Center*, Cambridge, MA (2003).

http://www.ed-w.info/MIT-AUTOID-WH021.pdf

MIT Field Intelligence Lab
Published Jan. 11, 2008
Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)

d. Simulating Warehousing Cost

Many specialty crops must undergo refrigeration prior to distribution to retailers. While warehousing fulfills important temporal and spatial functions within supply chains, it also represents a significant cost that must be minimized. This technology uses a computer simulation to determine the lowest cost billing system for refrigerated warehousing.

Canella, T and E.W. Schuster, “Simulating warehousing costs: a spreadsheet application,” *Production and Inventory Management Journal* 28, no. 4 (1987): pp. 1 - 5.

http://www.ed-w.info/P&IMJ%201987%20TC%20EWS.pdf

e. Fresh Food Supply Chain

Increasingly, American consumers are demanding fresh foods as a part of everyday life. This requires a complex supply chain to ensure a high percentage of availability. The technologies and organization involved to accomplish this task requires a high degree of sophistication. In case study format, this research explores current issues in Japan relating to the Sushi supply chain. Through study of this case, readers will gain greater insight into distributing fresh foods in the United States.

Schuster, E.W. and K. Watanabe, "The impact of e-commerce on the Japanese raw fish supply chain," Proceedings of the 32nd Annual Logistics Educators Conference (2003).

http://www.ed-w.info/Watanabe%20-%20Schuster,%20eCommerce,%203-22-03%20(final%20draft).pdf

Presentation

http://ed-w.info/LEC%202003%20pres..pdf

f. Marketing Science

The integration of marketing science, engineering technology, and supply chain management represents the next big innovation in business. Although this is a future technology, there are currently examples of applications in the consumer goods industries that use a wide range of computer science techniques.

Schuster, E.W., S.J. Allen, and D.L. Brock, "Marketing Science and Technology: Unique Identification and Spatial Diffusion" Executive Update (April 2007). (Published by the Cutter Consortium: Arlington, MA)

http://www.ed-w.info/CutterSpatialDiffusion.pdf

Schuster, E.W., Tsou, C., and Williams, J.R., "Improved new product forecasting though visualization of spatial diffusion," The MIT Data Center, Cambridge, MA: MIT-DATACENTER-WH-006 (July 2005).

http://www.ed-w.info/MIT-DATACENTER-WH-006.pdf

g. The Organic Supply Chain

Though it is at an early stage of development, organic food in the United States represents a growing business. Not much is understood concerning the characteristics of organic food supply chains. This study represents early survey research to gain understanding.

Chang, M.W. and E.W. Schuster, "Understanding the Organic Foods Supply Chain – Challenges and Opportunities from Farm Gate to End Consumer," Unpublished Manuscript (2002).

http://www.ed-w.info/Agribusiness,%206-7-02.pdf

h. Production Planning for Vegetables

Innovative companies are experimenting with taking the role of integrator within agricultural supply chains. This results in the need for new decision-making capabilities. A specific problem involves deciding how many acres to plant, and where to plant, to maintain a steady flow of vegetables to retailers year-round. This technology involves a two-stage production planning model that trades-off transportation cost and planting windows to arrive at the optimal pattern of planting within Eastern United States.

Merrill, J.M.,“Managing Risk in Premium Fruit and Vegetable Supply Chains,” unpublished Master of Engineering Thesis, *Massachusetts Institute of Technology* (2007).

Thesis Advisor: Edmund W. Schuster

i. Crop Yield Distributions and Crop Insurance

Agriculture is a business fraught with risk. Crop production depends on climatic, geographical, biological, political, and economic factors, which introduce risks that are quantifiable given the appropriate mathematical and statistical methodologies. Accurate information about crop yields helps farmers, agribusinesses, and government policymaking bodies and is an important modeling input to managing risk. Estimating yield is an important part of crop size estimation. Historically, crop yields are assumed to exhibit normal distribution for a statistical population and for a sample within a crop year. This thesis examined the assumption of normality of crop yields with data collected from India. Country yield data for India and state level yield data from Madhya Pradesh, Maharashtra states of India was collected for Sugarcane and Soybean crops. The null hypothesis of normality of yields was tested using Lilliefors test and results conclusively rejected the null hypothesis. This thesis concludes that crop yields of sugarcane and soybean exhibit non-normal and skewed distribution. The impact of skewed distribution of yields on crop insurance was analyzed and discussed. Strategies for effective risk management are suggested.

Gayam, N.R., "Risk in Agriculture - A Study of Crop Yield Distributions and Crop Insurance," unpublished Master of Engineering Thesis, *Massachusetts Institute of Technology* (2006).

Thesis Advisor: Edmund W. Schuster

FUTURE TECHNOLOGY

Quantitative Technologies, Modeling, and Data Analysis

MIT Field Intelligence Lab

a. The Three Risk Problem

This prospective model extends harvest risk to include supply and demand variability. The formulation of the model is consistent, however, after a great deal of searching it appears there is no analytics solution. We plan to solve this problem either through numeric methods or by reformulation. The difficulty in using numerical methods for this type of problem is that the solution might be different each time the model is run. Therefore, all that might be possible would be a bounded solution.

http://www.ed-w.info/AnalysisofThreeCropRisks%20(SJA%208-1-04).pdf

If solved, this is a very important problem in establishing the optimal size of an agricultural cooperative. There are many opportunities in the agricultural supply chain to put this technology into operational practice.

Stuart J. Allen and Edmund W. Schuster

b. The Jones Problem

The idea of risk in agriculture has a foundation in the work of Jones et al. The group worked with Syngentia to establish a two-stage model for dealing with hemispheric specialization of the production of seed corn in the US and S. America. The goal is to establish the number of acres to plant in each hemisphere so as to minimize the year-round risk of over or under supply.

More details can be found at the following link:

http://www.ed-w.info/Jones.pdf

We feel that more detailed analysis of hemispheric risk is an important first step in establishing optimal land use.

Stuart J. Allen and Edmund W. Schuster

NOTES

MIT Field Intelligence Lab
Published Jan. 11, 2008
Email: edmund_w@mit.edu
Phone: 603-759-5786 (c)