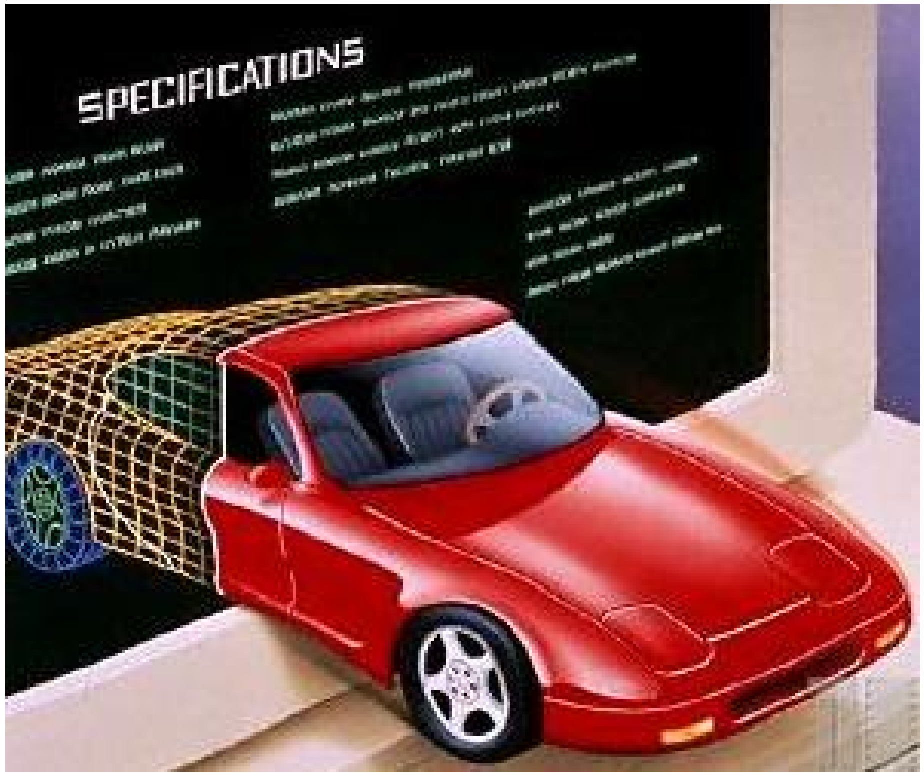
Mathematics in Industry and Government



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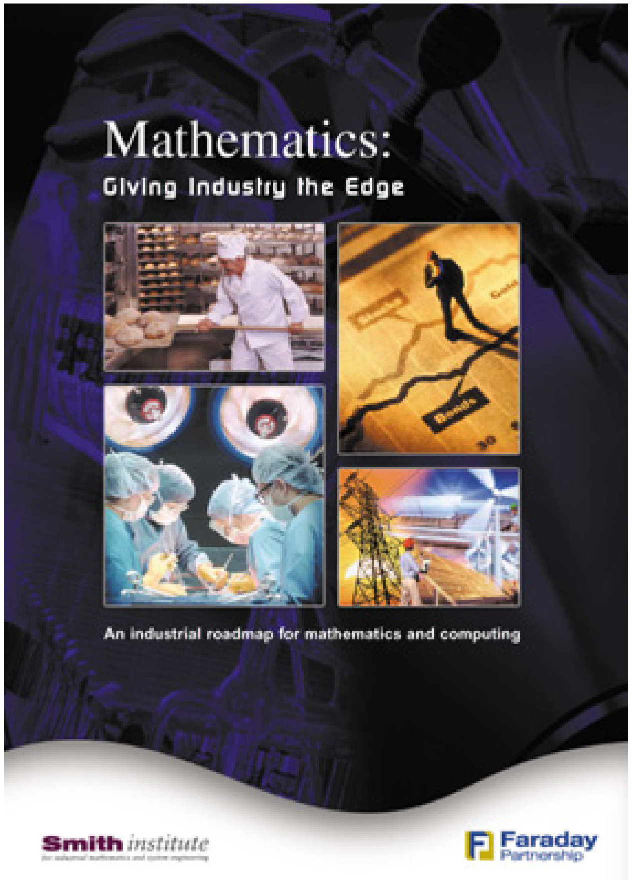
Institute for Mathematics and its Applications



Mathematics is the most versatile of all the sciences. It is uniquely well placed to respond to the demands of a rapidly changing economic landscape. Just as in the past, the systematic application of mathematics and computing to the most challenging industrial problems will be a vital contributor to business performance. The difference now is that the academic community must broaden its view of mathematics in industry and its expertise must be managed in more imaginative ways.

Mathematics now has the opportunity more than ever before to underpin quantitative understanding of industrial strategy and processes across all sectors of business. Companies that take best advantage of this opportunity will gain a significant competitive advantage: mathematics truly gives industry the edge.

Academic mathematics is insufficiently connected to mathematics outside the university. One of the greatest—and most difficult—opportunities for academic mathematics is to build closer connections to industry.

Academic mathematical science must strike a better balance between theory and application. At one extreme, a narrowly inward-looking community will miss both the opportunities that arise outside the mathematical sciences and the opportunities that are part of scientific and technological developments. At the other extreme, an exclusive concern with applications and collaborative research would severely limit the mathematical sciences and deprive the scientific community of the full benefits of mathematical inquiry. At present, the balance is tilted too far towards inwardness.

A narrow vision of mathematics in academic departments translates into a narrow education for graduate students, most of whom are orinted toward careers only in academic mathematics.

Observations and opinions

- The potential impact of contemporary mathematics on science, on technology, and on industry is vast.
- Unfortunately, the actual impact—though great—is no where near as large as it should be.
- In significant part, this results from the decision of many mathematicians to address themselves to internally generated challenges rather than to the challenges that arise from the complexities of the modern world.
- Industrial mathematicians almost always face problems coming from outside mathematics.
- Industrial managers are convinced of the power of mathematics. . . they hire 25% of mathematics doctorates.

A problem from outside mathematics

Planning for and responding to the deliberate release of infectious agents is a clear example of a problem that mathematics cannot solve, but to which it can contribute immensely.

For a smallpox attack for example, many critical decisions have to be made. Examples:

- who to vaccinate (direct contacts of infected, neighborhoods of infected, essential personnel, the city, the country,. . . , healthy, at-risk, young, old, . . .)
- prophylactic vaccination?
- quarantine policy
- value of early detection
- value of diagnostic testing
- dealing with uncertainty

Math can help!

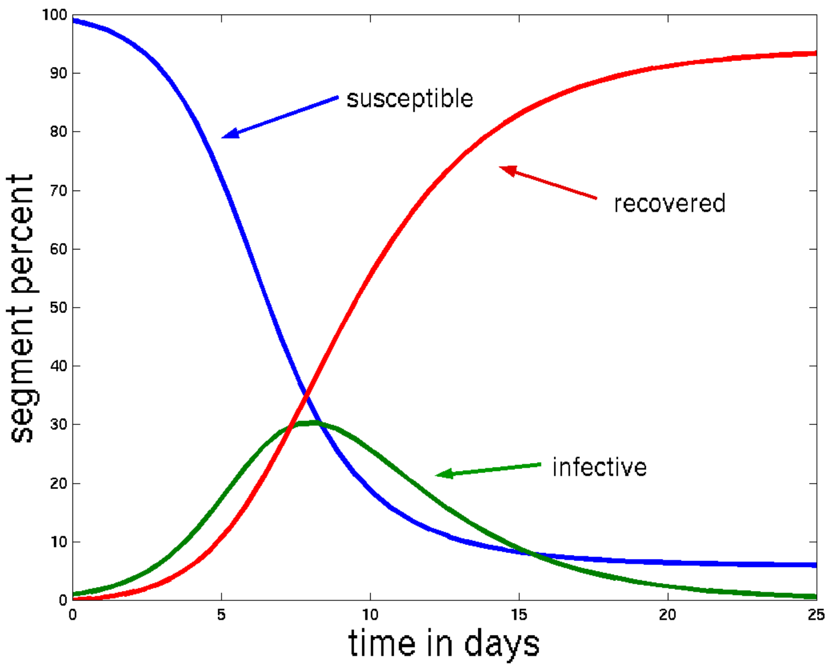
SIR model of mathematical epidemiology

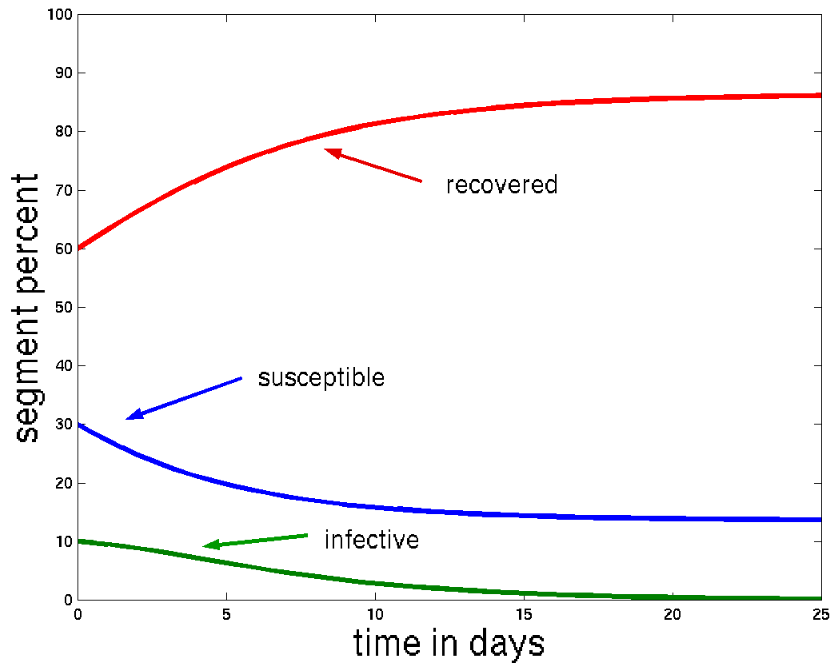
Daniel Bernoulli published a mathematical study of smallpox spread in 1760. In the 1920's Kermack and McKendrick formulated the SIR model:

$$\frac{dS}{dt} = -\beta SI, \quad \frac{dI}{dt} = \beta SI - \gamma I, \quad \frac{dR}{dt} = \gamma I,$$

where $S + I + R = 1$ give the division of the population into susceptible, infective, and recovered segments, $\beta > 0$ the *infection rate*, $\gamma > 0$ the *removal rate*.

Theorem. *Let* $S(0), I(0) > 0$, $R(0) = 1 - S(0) - I(0) \geq 0$ *be given. For the solution of the SIR model with* $S(0) > \gamma/\beta$, $I(t)$ *increases initially until it reaches its maximum value and then decreases to zero at* $t \to \infty$. *Otherwise* $I(t)$ *decreases monotonically to zero as* $t \to 0$.





herd immunity

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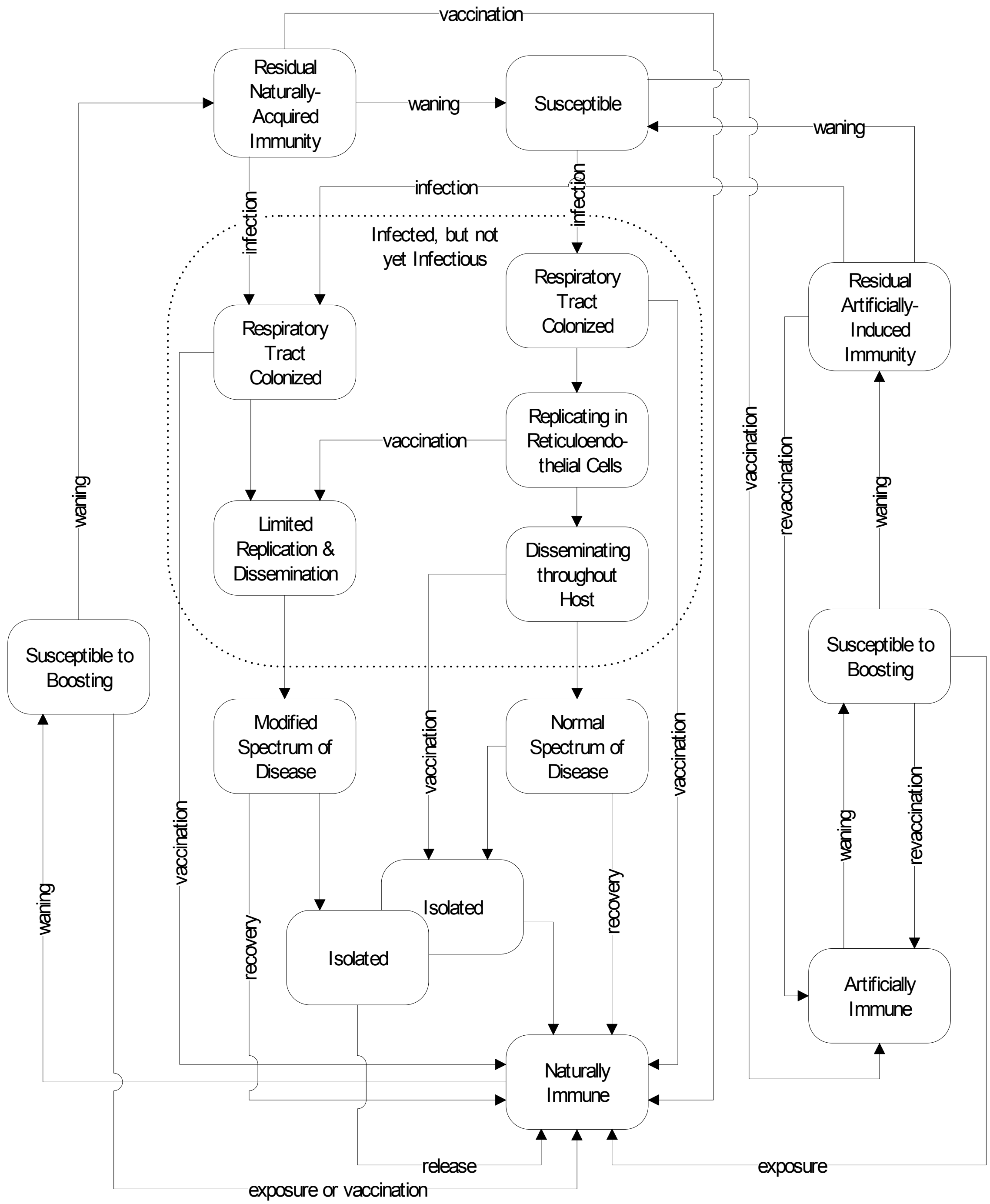
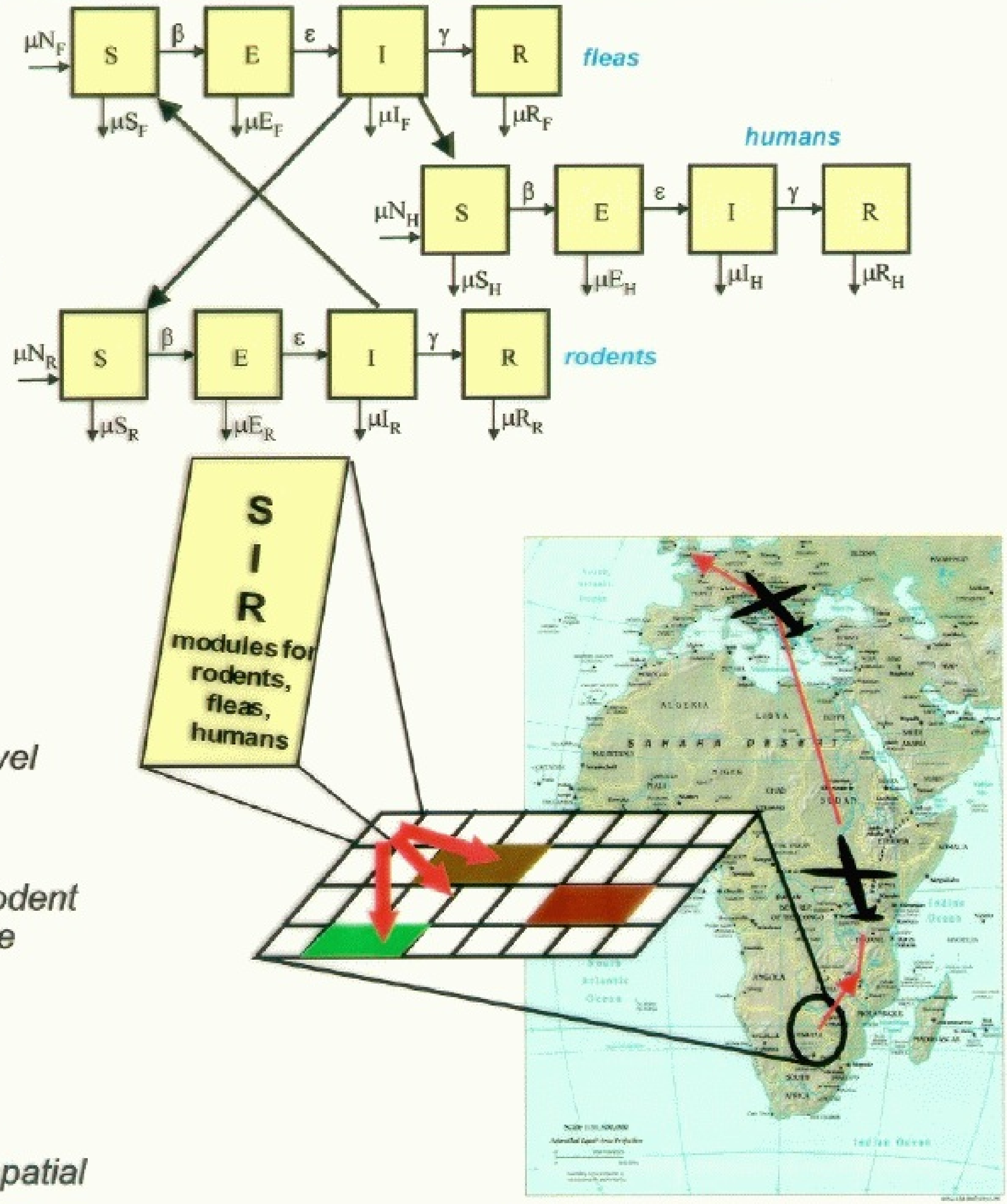
Smallpox modeling at the Center for Disease Control



Plague modeling at Dynamic Technology, Inc.

Multi-patch generalization of Keeling and Gilligan, 2000

- *Treating patch-patch heterogeneity by Lloyd and May's (1996) approach*
- *Incorporating spatial spread (city-city to transnational) by modeling transportation networks, rates via Rvachev et al. (1977) approach*
- *Including human pneumonic transmission term*



Includes essential dimensions of plague epidemiology

- *Human, rodent and flea interactions*
- *Patch-patch ecological variation*
- *Regional, national and international travel and migrations*
- *Climatology and meteorology*
- *Effects of vaccination, rodent control, rodent genetic resistance to Y. pestis, pesticide application, and others*

Evaluation to include

- *Single-patch incidence, prevalence, R_0*
- *Patch-patch disease propagation and spatial spread*

DYNAMICS TECHNOLOGY, INC.

www.nytimes.com
The New York Times ON THE WEB

July 7, 2002

U.S. to Vaccinate 500,000 Workers Against Smallpox

By WILLIAM J. BROAD

The federal government will soon vaccinate roughly a half-million health care and emergency workers against smallpox as a precaution against a bioterrorist attack, federal officials said. The government is also laying the groundwork to carry out mass vaccinations of the public - a policy abandoned 30 years ago - if there is a large outbreak.

Until last month, officials had said they would soon vaccinate a few thousand health workers and would respond to any smallpox attack with limited vaccinations of the public. Since 1983, only 11,000 Americans who work with the virus and its related diseases have received a vaccination, according to the Centers for Disease Control and Prevention.

The plan to increase the number of "first responders" who receive the vaccination to roughly 500,000 from 15,000 and to prepare for a mass undertaking of vaccinations in effect acknowledges that the government's existing program is insufficient to fight a large outbreak.

Mathematical techniques relevant to bioterrorism

- mathematical epidemiology
- ODE, dynamical systems
- PDE
- numerical analysis, scientific computation
- probability, statistics
- graph theory, network analysis
- game theory
- control theory
- optimization
- . . .

Industries using mathematics

Aerospace	Financial services
Automation and control	Geosciences
Automotive	Healthcare
Computing	Information Technology
Defense	Manufacturing
Energy	Telecommunication
Transportation	Shipping

scores of others and increasing

Areas and Applications (MII '98)

Mathematical Area	Application
Algebra and number theory	Cryptography
Computational fluid dynamics	Aircraft and automobile design
Differential equations	Aerodynamics, porous media, finance
Discrete mathematics	Communication and information security
Formal systems and logic	Computer security, verification
Geometry	Computer-aided engineering and design
Nonlinear control	Operation of mechanical and electrical systems
Numerical analysis	Essentially all applications
Optimization	Asset allocation, shape and system design
Parallel algorithms	Weath modeling and prediction, crash simulation
Statistic	Design of experiments, analysis of large data sets
Stochastic processes	Signal analysis

Are all mathematical fields of interest to industry?

Just about, but some more so than others.

> *What kind of mathematics is useful? Every kind, but at Kodak partial differential equations are useful more often than topology. – Peter Castro*

Industry hired 50% of the 2001 PhDs in statistics, 43% in numerical analysis, and 10% of those in geometry/topology.

Field of specialization is a secondary condition in industry. An academic mathematician very well may spend his career working around the area of their thesis, but an industrial mathematician almost never does.

> *We never know what kind of mathematics is the right kinds, so an "algebraist for life" is not the right kind of mathematician.*

An industrial mathematician must be a generalist, learning whatever kind of mathematics the problem calls for. She should be interested in all kinds of mathematics, and also in things other than mathematics.

Depth in one area is certainly a plus, especially if the area seems relevant to the industry, but breadth is more important.

What do mathematicians bring to industry?

- logical thinking
- the ability to abstract and recognize underlying structure
- knowing the right questions, recognizing the wrong ones
- familiarity with a wide variety of problem-solving tools

Problems never come in formulated as mathematical problems. A mathematician's biggest contribution to a team is often an ability to state the right question.

What can't mathematics do for industry?

Solve its problems.

There are countless problems in industry that require deep mathematics, but almost none that can be solved by mathematics alone.

> *The strength of the mathematical sciences is that they are pervasive in many applications. The challenge is that they are only a part of each application. – Shmuel Winograd*

∴ a mathematician in industry must be part of a team.

∴ communication skills and social skills matter (while, according to popular opinion, these are positively harmful for an academic mathematician).

Traits of successful industrial mathematicians

- skills in modeling and problem formulation
- flexibility to go where the problems leads
- breadth of interest, interdisciplinarity
- balance between breadth and depth
- knowing when to stop
- computational skills
- written and oral communication skills
- social skills, teamwork

IMA Industrial Programs

- Industrial Problems Seminar
- Industrial math modeling workshop
- IMA Industrial Postdocs
- Hot topics workshops
- IMA Participating Corporation program
- symbiotic relation with MCIM

Recent IMA Industrial Problems Seminars

- Infectious Disease Modeling (Dynamics Technology Inc.)
- Micromagnetic Modeling of Writing and Reading Processes in Magnetic Recording (Seagate Technology)
- Mathematics and materials (3M)
- Mathematical modeling in support of service level agreements (Telcordia)
- Global Positioning Systems (Honeywell)
- F. John's Ultrahyperbolic Equation and 3D Computed Tomography (General Electric)
- Mathematical Modeling of Mechanical and Fluid Pressures in Chemical-Mechanical Polishing (Motorola)

Industrial math modeling workshop 2002

10 days of intensive work in 6 teams of 6 w/ industrial mentor.

- Designing Airplane Engine Struts using Minimal Surfaces (Boeing) differential geometry
- Mobility Management in Cellular Telephony (Telcordia) discrete math and optimization
- Optimal Pricing Strategy in Differentiated Durable-GoodsMarkets (Ford) game theory
- Modeling of Planarization in Chemical-Mechanical Polishing (Motorola) differential equations
- Modeling Networked Control Systems (Honeywell) graph theory, control theory
- Optimal Design for a Varying Environment (3M) differential equations, optimization

Institute for Mathematics and its Applications

Time and funding is split 50–50% between the IMA and an industrial sponsor. Mentors at both organizations.

- Network design and optimization (Christine Cheng, Telcordia, McGill)
- Modeling of epicardial ablation (Jay Gopalakrishnan, Medtronic, U. Florida)
- Multiresolution approach to computer graphics (Radu Balan, IBM, Siemens)
- Diffractive and nonlinear optics (David Dobson, Telcordia, U. Utah, Siliconoptics)

- E-auctions and markets (Ford and IBM)
- Modeling and analysis of noise in integrated circuits (Motorola)
- Mathematical challenges in global positioning systems (Lockheed Martin)
- Text Mining (West Group)
- Scaling phenomena in communications networks (AT&T and Telcordia)

Closing remarks

- Industry provides a rich source of problems involving a wide range of advanced mathematics.
- A math job in industry can provide intellectual challenge, a good salary, and a chance for real impact.
- The distinction between industrial mathematics and academic mathematics is more one of attitude than content.
- Future potential is tremendous potential. Mathematics can, and should, have much greater impact in the future.
- Traditional graduate math training helps develop several skills useful in industry, but downplays others.
- Many grad programs are adapting. Many programs for students are available (workshops, internships, conferences).

Encourage your students (and faculty) to think deeply about how they want to spend their lives, to collect information about the alternatives, to look outward as well as inward, to avail themselves of non-traditional and interdisciplinary programs, and to keep an open mind.

Two useful references

The SIAM Report on Mathematics in Industry (MII), 1998,
http://www.siam.org/mii/miihome.htm

Mathematics: Giving Industry the Edge, 2002,
Smith Institute,
http://www.smithinst.ac.uk/news/RoadmapLaunch