"2009 NAE Convocation of the Professional Engineering Societies"

Operations Research/Operational Systems Engineering: Applications in the Delivery of Health Services

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Organization of this Talk

- **Some aspects of the U.S. Health Care System**
- **Economics of the Health Care System and Roles of Technologies and Quality**
- **Role OR Has Played in Health Care Delivery – Some Examples**

Main Issues Facing Health Care Delivery in the U.S.A.

- **Unacceptable Rates of Growth in Health Care Costs**
- **Inefficient Delivery Systems and Poor Performance**
- **Varying Levels of Quality and Unacceptable Levels of Adverse Events**
- **Too many Specialist Physicians in many regions**
- **Gaps in Access to Services**
- **Income Protection When Very Costly Medical Care is Required**

Features of the Health Care System

- **Relatively Unique to Health Care**
  - **Uncertainty at All levels of Needs, Decisions, Delivery, an Outcomes**
  - **Life Quality/Pain/Death Decisions**
  - **Shared Institutional Governance**
  - **Difficulty of Measuring/Uncovering Quality and Risks**
  - **Consumer Usually Not the Direct or Primary Payer**
  - **Decentralized/Multiple Choice System**
  - **Uninformed Consumers (asymmetric knowledge)**
    - **Usually Not the Decision Maker**

Features of the Health Care System

- **Relatively Unique to Health Care**
  - **System must have mastery of perhaps the largest sector knowledge base in the world at most delivery locations**
  - **Consumers with unique genetics and multiplicity of diseases/conditions**
  - **A Right Rather Than a Privilege**
  - **Disconnect between specialist physician and patient wants (quality of procedure vs. ADL - silos)**

Features of the Health Care System (continued)

- Somewhat Unique to Health Care
  - Many Treatment Modalities
  - Technology Largely Cost Increasing
  - Many Hi-Tech Treatment Regimes
  - Fairly Inflexible Treatment Processes
  - Consumers of All Ages, Sexes and other Demographic Characteristi
  - Complex Set of Institutional, Societal and Consumer Goals and Objectives
  - Heavy Government Involvement in Private Individuals' and Institutions' Actions, Costs and Incomes
  - Actions by Individuals Can Impose Costs or Create Benefits for Oth

Features of the Health Care System (continued)

- **Lifelong Progression of Health Care Consumer Services with Many Feedback Loops**
  - **Well-Being**
  - **Intermediate Care (In Institution or Outside)**
  - **Intensive Care**
  - **Self-Care (In Institution or Outside)**
  - **Continuing Care (In Institution or Outside)**
  - **Extended Care in Facility**
  - **Home Care**
  - **Hospice Care**
  - **Death**

Economics of Health Care Delivery in the United States

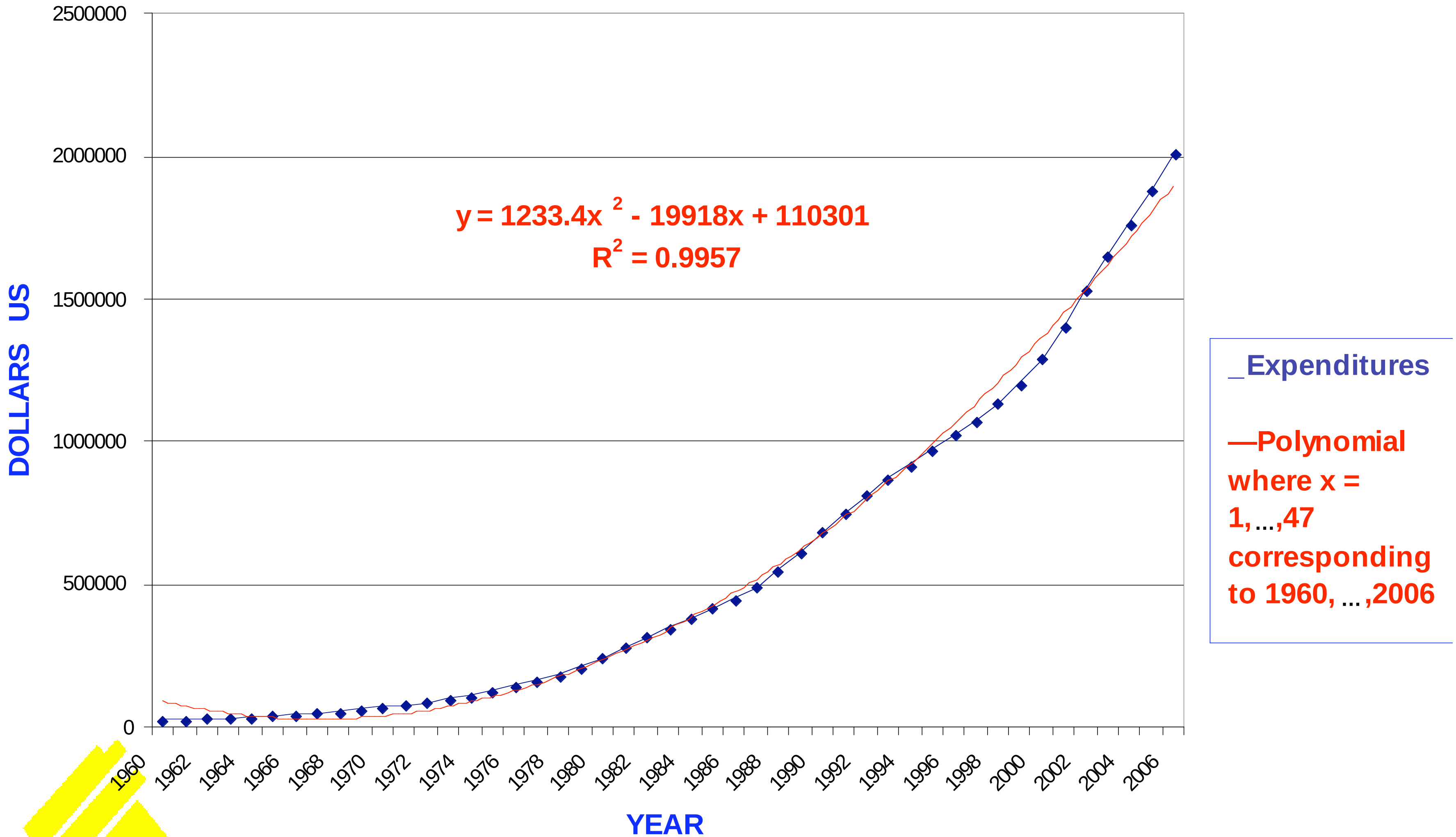
Each of them is named after one of my medications

YEAR 2007

- Health Care spending per person in USA **increased by 6.1% *** (**total $2.2 trillion** or ≈ **16.2% of GDP**)
- Who paid: **Employees and the Elderly**! (Employers? – largely NO, Governments? – NO)
  - **Disposable wages** →
  - **Co-payments and deductibles** ↑
  - **Insurance premiums** ↑
  - **Medicare premiums and deductibles** ↑
  - **Taxes allotted to HC** ↑

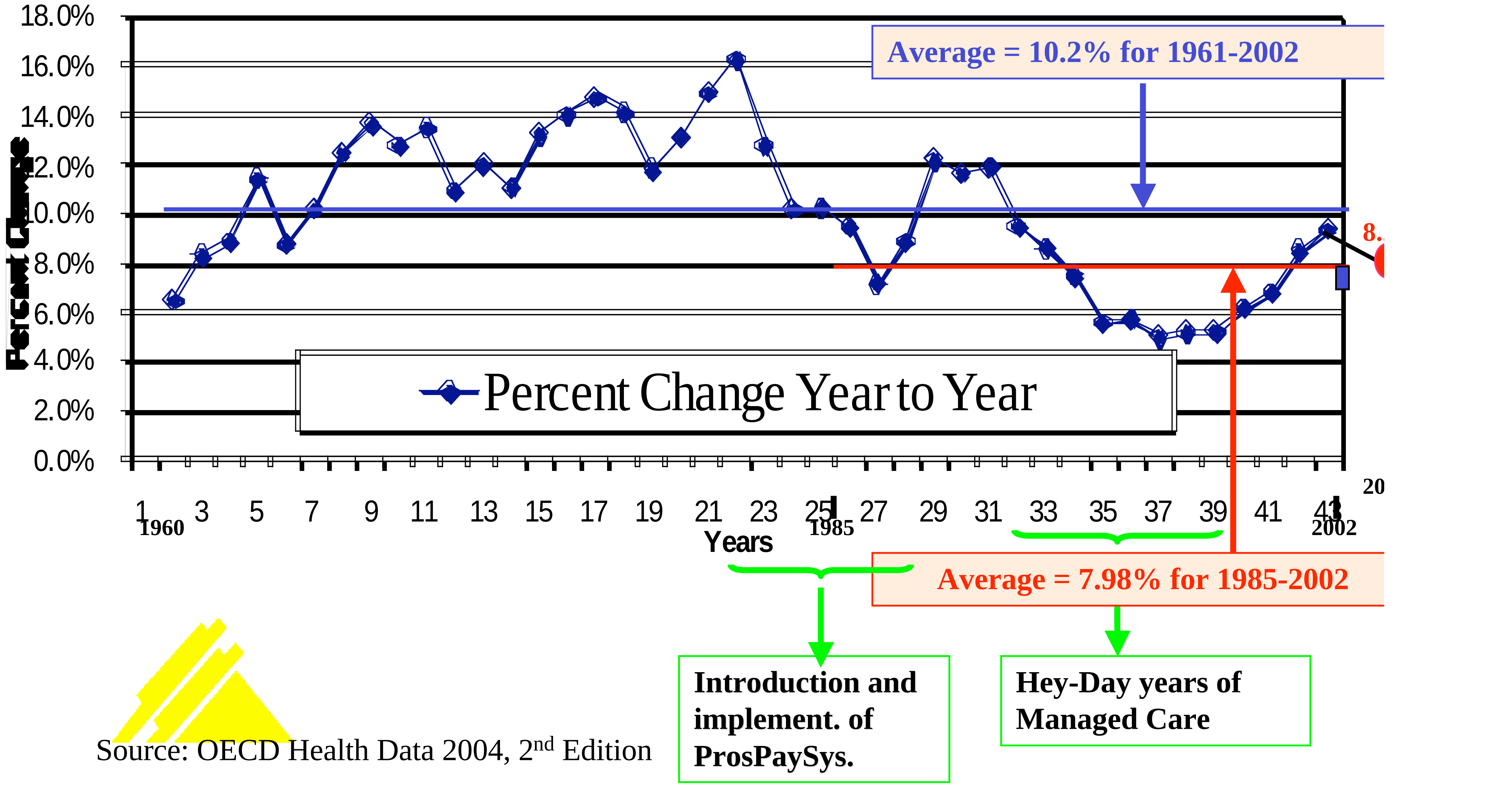
*Source: OECD Health Data 2008

United States Total HC Expenditures 1960-2006



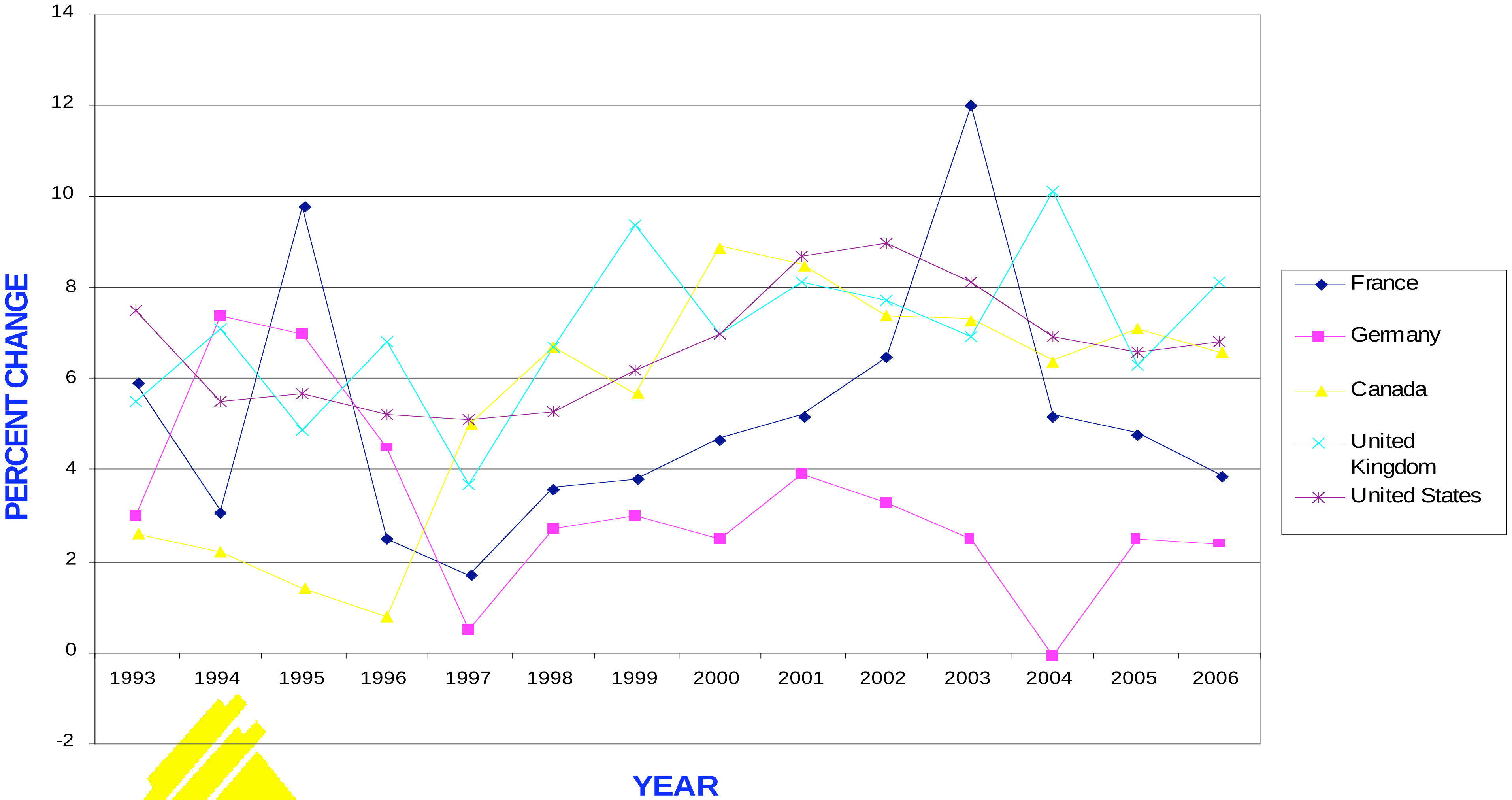
Source: OECD Health Data 2008

Percent Change in Health Care Expenditures 1961 -2006



Source: OECD Health Data 2004, 2nd Edition

ANNUAL CHANGE IN TOTAL EXPENDITURES IN NCUs



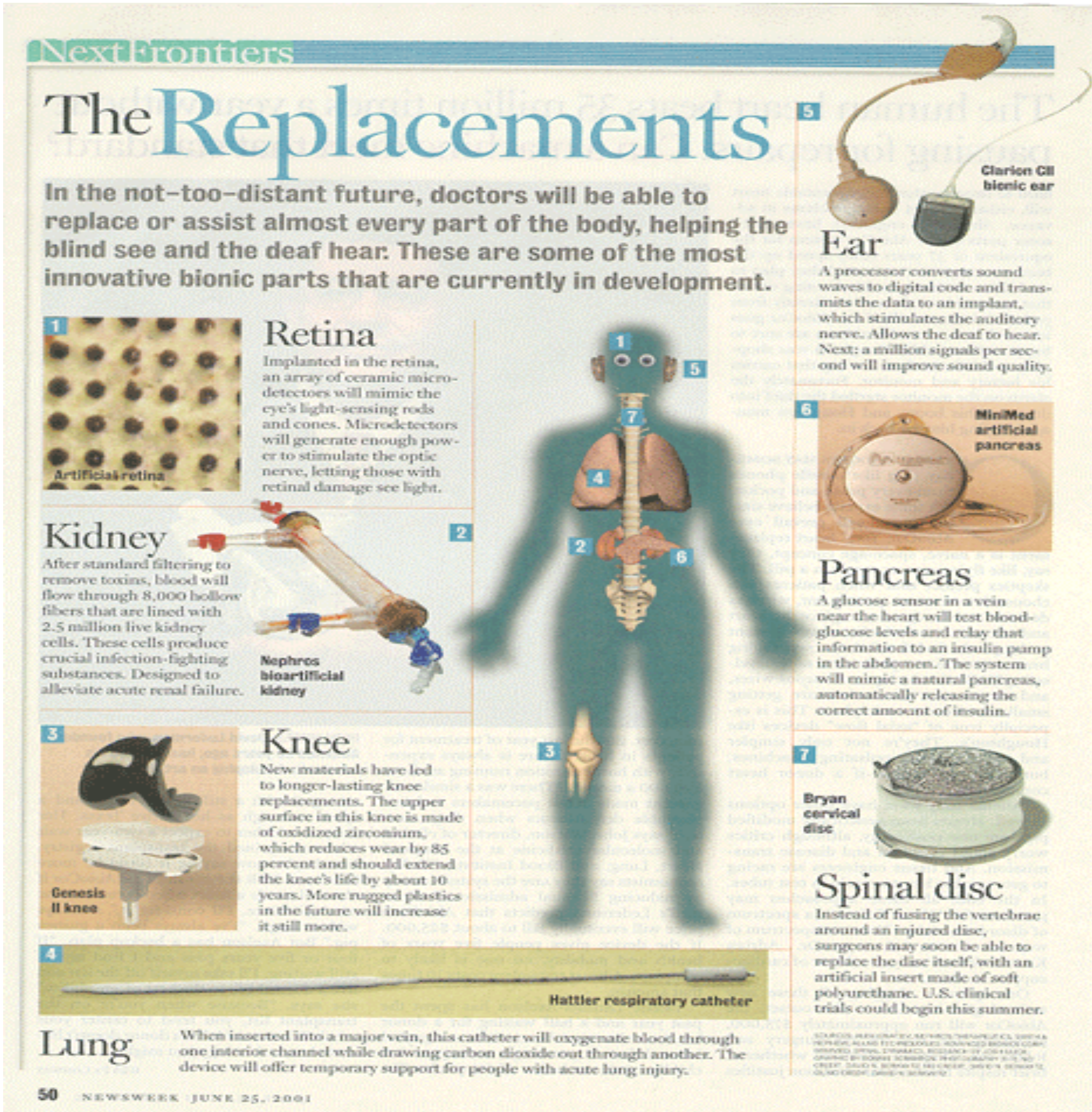
Source: OECD Health Data 2008 NCU = National Currency Units

Table 2: Accounting for the Increase in Health Costs 1940-1990

Factor	Increase Due To	Share of Total
Static Factors		
Demographics	14	2
Income	37	5
Spread of Insurance	100	13
Relative Price Change	147	19
Administrative Expense	101	13
Factor Rents	0	0
All Static Factors	399%	51
Residual (**technology/intensity**)	**391%**	**49**
Total Increase	790%	100

Source: David M. Cutler, "Technology, Health Costs and NIH," Harvard University and paper presented at the NIH Economics Roundtable on Biomedical Research, October

TECHNOLOGY



Next Frontiers

The Replacements

In the not-too-distant future, doctors will be able to replace or assist almost every part of the body, helping the blind see and the deaf hear. These are some of the most innovative bionic parts that are currently in development.

1 Retina

Implanted in the retina, an array of ceramic microdetectors will mimic the eye's light-sensing rods and cones. Microdetectors will generate enough power to stimulate the optic nerve, letting those with retinal damage see light.

Artificial retina

2 Kidney

After standard filtering to remove toxins, blood will flow through 8,000 hollow fibers that are lined with 2.5 million live kidney cells. These cells produce crucial infection-fighting substances. Designed to alleviate acute renal failure.

Nephros bioartificial kidney

3 Knee

New materials have led to longer-lasting knee replacements. The upper surface in this knee is made of oxidized zirconium, which reduces wear by 85 percent and should extend the knee's life by about 10 years. More rugged plastics in the future will increase it still more.

Genesis II knee

4 Lung

Hattler respiratory catheter

When inserted into a major vein, this catheter will oxygenate blood through one interior channel while drawing carbon dioxide out through another. The device will offer temporary support for people with acute lung injury.

5 Ear

Clarion CII bionic ear

A processor converts sound waves to digital code and transmits the data to an implant, which stimulates the auditory nerve. Allows the deaf to hear. Next: a million signals per second will improve sound quality.

6 Pancreas

MiniMed artificial pancreas

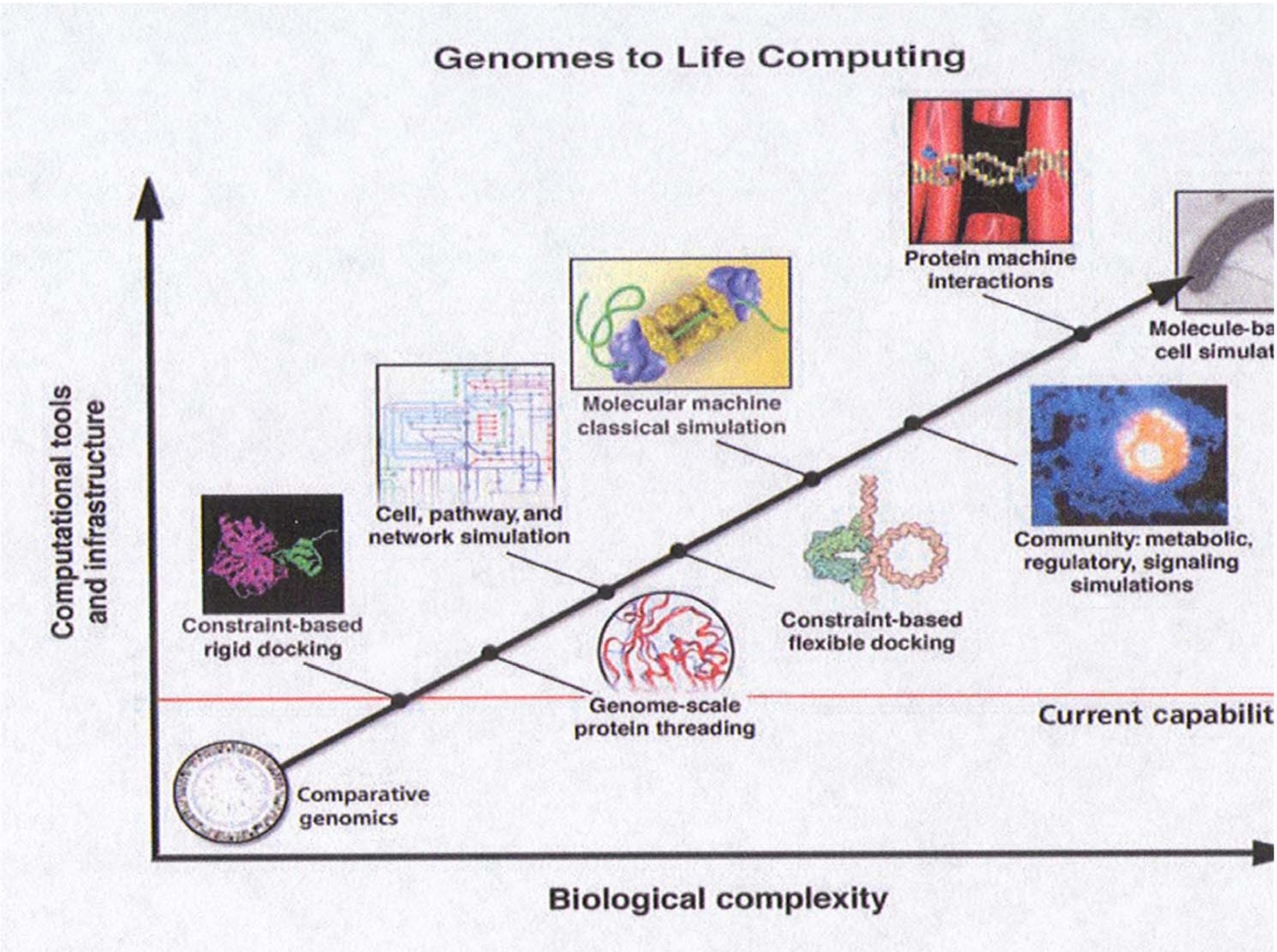
A glucose sensor in a vein near the heart will test blood-glucose levels and relay that information to an insulin pump in the abdomen. The system will mimic a natural pancreas, automatically releasing the correct amount of insulin.

7 Spinal disc

Bryan cervical disc

Instead of fusing the vertebrae around an injured disc, surgeons may soon be able to replace the disc itself, with an artificial insert made of soft polyurethane. U.S. clinical trials could begin this summer.

50 NEWSWEEK JUNE 25, 2001



Genomes to Life Computing
Protein machine interactions
Molecule-ba
cell simulat
Molecular machine classical simulation
Cell, pathway, and network simulation
Community: metabolic, regulatory, signaling simulations
Computational tools and infrastructure
Constraint-based rigid docking
Constraint-based flexible docking
Genome-scale protein threading
Current capabilit
Comparative genomics
Biological complexity

Pricey Cancer Drugs Today – 2008

Wholesale prices of some widely used cancer drugs, before distributor or physician markup – sources are the companies*

Drug	Manufacturer	Treatment	Monthly cost
Avastin	Genentech	Metastatic Breast Cancer	$ 7,700
Revlimid	Celgene	Multiple myeloma	$ 6,000
Nexavar	Onyx, Bayer AG	Kidney, liver cancer	$ 4,967
Sutent	Pfizer	Kidney, liver cancer	$ 4,411
Herceptin	Genentech	Breast cancer	$ 3,300
Erbitux	Imclone, Bristol-Myers Squibb	Metastatic colon cancer	($ 18,000-38,000 for 7-1 week treatment)

*Some oncology drugs are used to treat various conditions; costs are for shown conditions

Quality

Five of IOM/NAE Quality Reports

- November 1999 (IOM): “To Err Is Human”
  - **Found that 44,000 to 98,000 Americans die each year as a result of medical errors.**

- March 2001 (IOM): “Crossing the Quality Chasm: A New Health System for the 21st Century”
  - **Found that the healthcare system is “plagued by a serious quality gap” and called for elimina handwritten clinical information by 2010 and refocusing the healthcare system on treating ch illnesses.**
- October 2002 (IOM): “Leadership by Example: Coordinating Government Roles in Improving Health C Quality”
  - **Argued that the federal government should lead the development of clinical standards for me care and proposed financial incentives for organizations that improve quality.**
- November 2003 (IOM): “Keeping Patients Safe: Transforming the Work Environment of Nurses”
  - **Identifies solutions to problems in hospital, nursing home, and other health care organization environments that threaten patient safety through their effect on nursing care.**

- In 2005 (NAE and IOM): “**Building a Better Delivery System: A Engineering/Health Care Partnership**”
  - **“Purpose is to forge a new partnership between Systems Engineering, Operations Resea Management Science and Medicine” to manage quality, costs and access challenges.**

Adverse Event*

an unintended injury or complication which results in disability, death or prolonged hospital stay and is caused by (poor) health care (patient) management.**

* Wilson McL. Ross, et al., "The Quality in Australian Health Care Study", The Medical Journal of Australia, November, 1995, Vol. 163

** parentheses are mine - WPP

Adverse Event Rates from Four Research Studies

	Patient rate	Preventable
Harvard Study	3.7% *	69%
Australian Study	16.6%	51%
Chicago Study	17.7%	100%
Harvard Drugs Study	12.0%	28%

* lower bound

Rates of 10% or more are very plausible in many hospitals

Converging Crises—Safety, Quality, Cost, Access

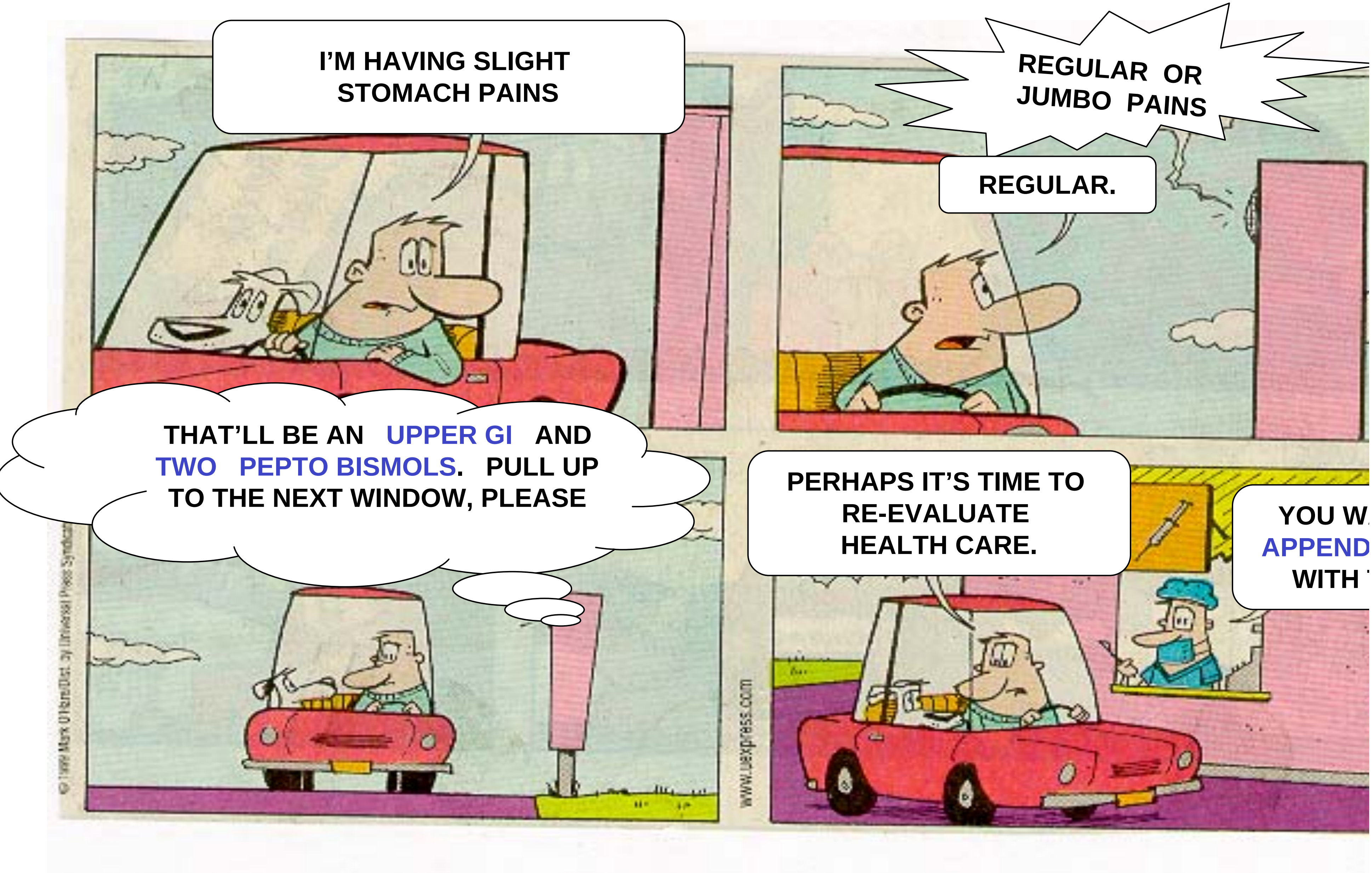
- Safety failures
  - 1 million injuries; 98,000+ deaths annually in U.S. from process/system failures (some progress from IHI's 100,0(Campaign)
  - **Between $17 Billion and $29 Billion (not counting Opportunity Costs where this money could be spent for Be Purposes)**
- Knowledge—Practice Gap
  - patients receive "best practice" treatment only half of the time
- **Waste, Inefficiency, Spiraling Costs**
  - **30 to 40 cents of every health care dollar covers costs of "overuse, underuse, misuse, duplication, system failures, poor communications and inefficiency"**

    30% of $2.2 trillion = $660 billion/yr (2008)
  - **Health care costs rising at or near 3X rate of inflation**
- Growing uninsured population ~ estimated 45 million in 2006
- Revenue squeeze on care providers → Staff cuts/workforce shortages impact safety, timeliness, access, patient-centeredn

ERRORS

BY STAYSKAL FOR THE TAMPA TRIBUNE

OVERUSE

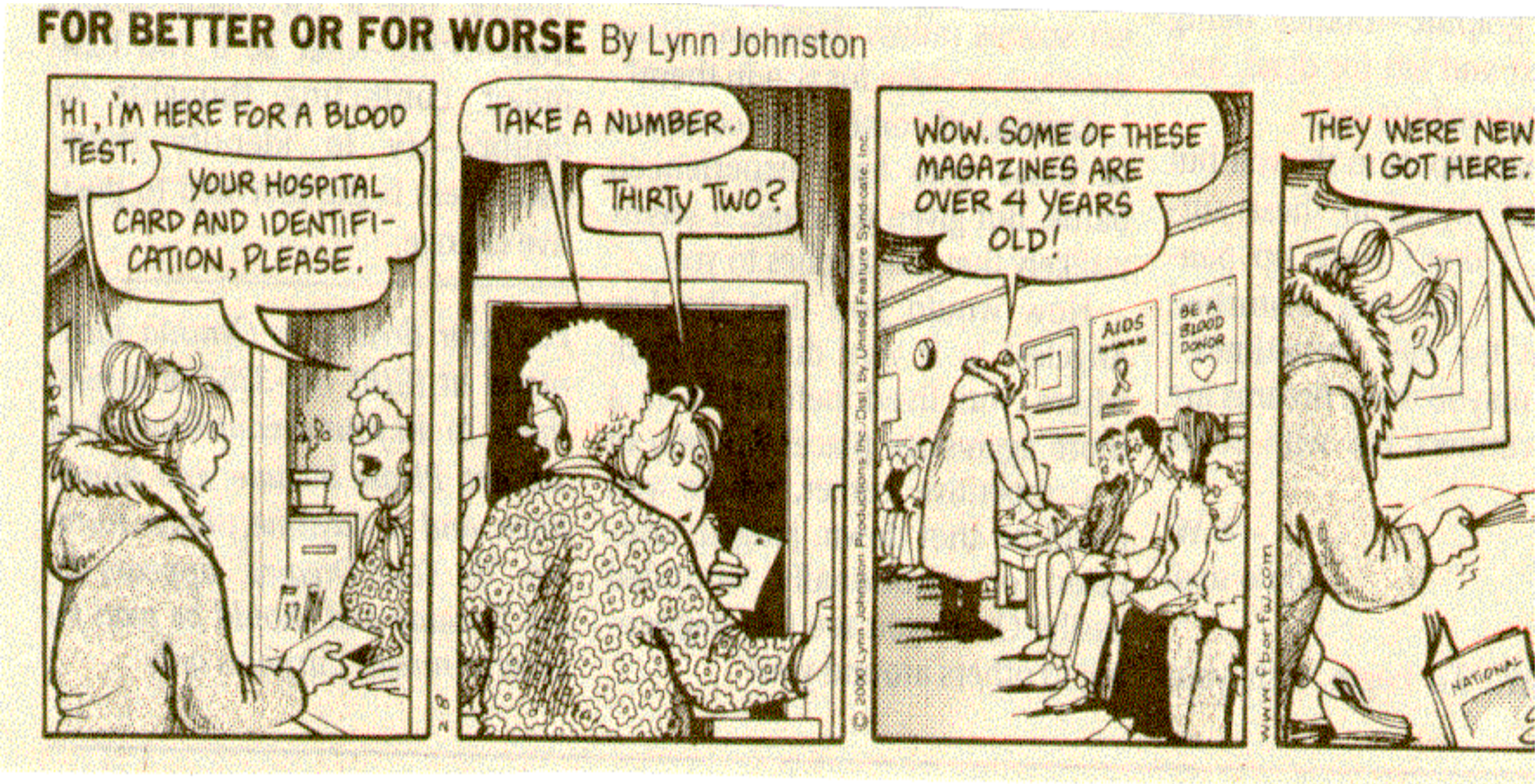

I'M HAVING SLIGHT STOMACH PAINS
REGULAR OR JUMBO PAINS
REGULAR.
THAT'LL BE AN UPPER GI AND TWO PEPTO BISMOLS. PULL UP TO THE NEXT WINDOW, PLEASE
PERHAPS IT'S TIME TO RE-EVALUATE HEALTH CARE.
YOU W
APPEND
WITH
www.uexpress.com

MISUSE

BIZARRO BY **DAN PIRARO**

INEFFICIENCY

Inefficiency



Role OR Has Played in Health Care Delivery – Some Examples

Operations Research Advances Cancer Therapeutics

Eva Lee and Marco Zaider

Interfaces 38(1), pp. 5–25, 2008

Brachytherapy = placement of radioactive seeds inside a tumor (example is prostate)

- **Goals:**
  - **Reduce cancer-related mortality (Assure full dosimetric coverage of the diseased site)**
  - **Lessen treatment-related morbidity (minimize radiation exposure to critical healthy structures)**
  - **Dynamic placement of seeds in real time during the operation**

- **Model: Mixed integer mathematical program with special solution strategies**

Eva Lee and Marco Zaider: *Operations Research Advances Cancer Therapeutics*
Interfaces 38(1), pp. 5–25, ©2008 INFORMS

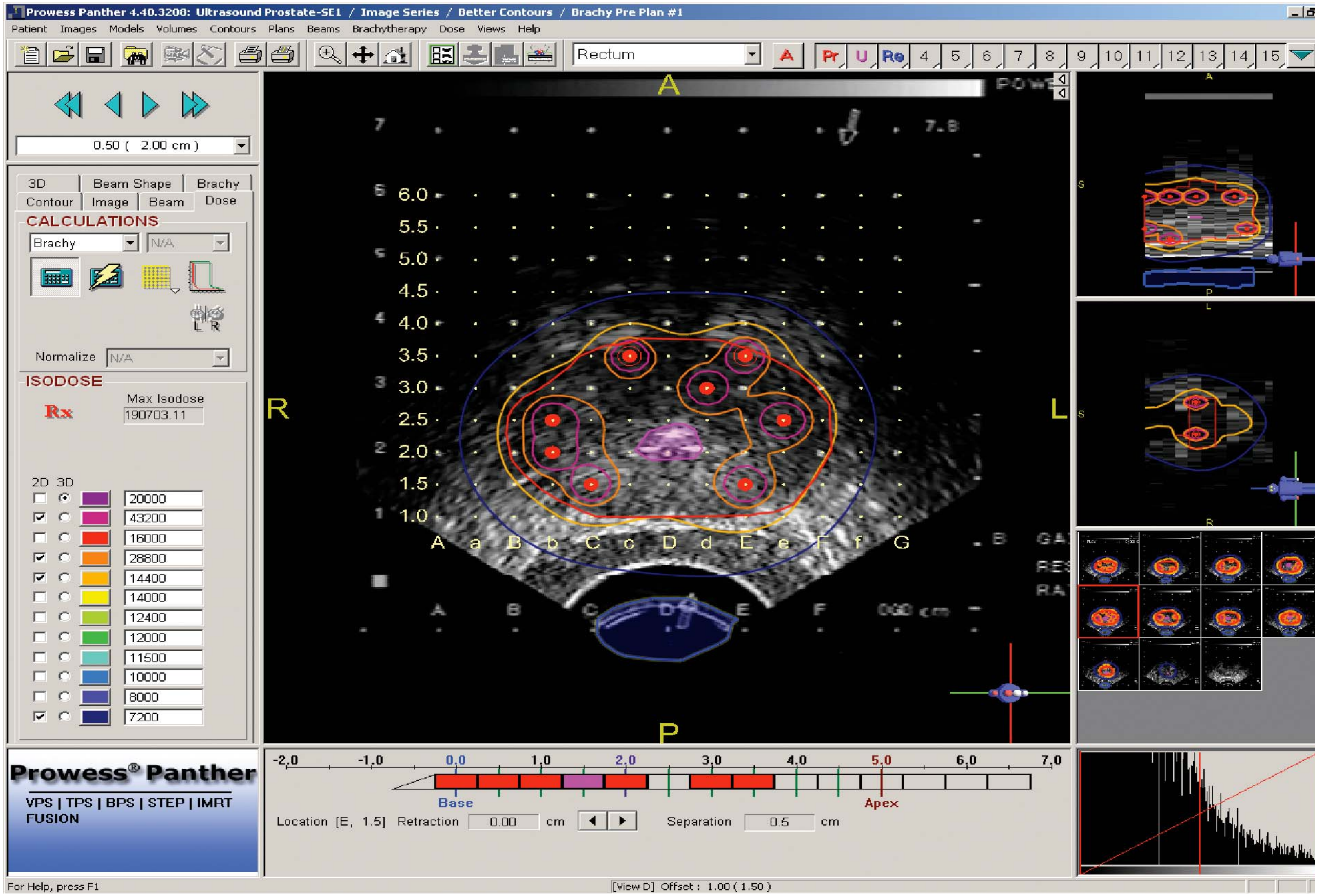


Figure 10a: This figure illustrates the commercial system. Note the excellent conformity of the OR plan. The brown isodose curve, representing points that receive 100% prescription dose, conforms well to the red curve, which delineates the boundary of the planning target volume.

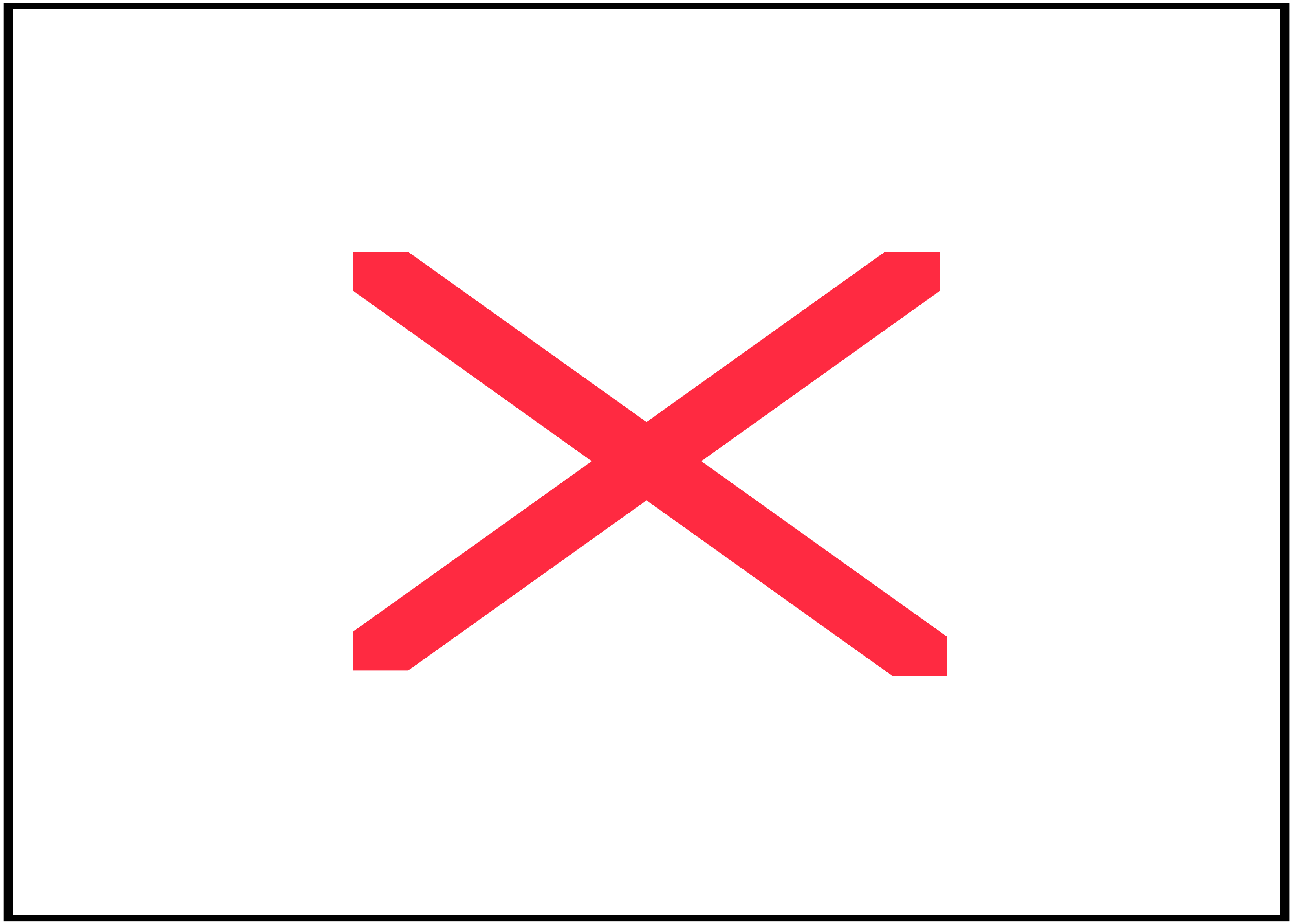


Figure 10b: This figure shows the 3D seed locations inside the prostate, as determined via the OR-based treatment planning system. The blue structure is the rectum, and the purple indicates the urethra.

Optimal Brachytherapy for Prostate Cancer

- **Results**
  - **Implants are optimally placed to meet the above goals**
    - **Prescribed dose delivered to 98% of the prostate**
    - **Reduces urethra dose 23-28%**
    - **Reduces rectum dose 15%**
    - **Uses 20-30% fewer radioactive seeds and 15% fewer placement needles**
    - **Results in an under-dose within 3% of the prescribed dose**
    - **Impacts substantially the quality of life of the patient post surgery – signi reduction in Grade 2 urinary toxicity and in sexual dysfunction**
    - **Direct surgical cost savings of $5,600 per patient (total U.S. would be $3 million annually)**
    - **Large indirect cost savings from fewer complications and higher quality**

Eva Lee and Marco Zaider: *Operations Research Advances Cancer Therapeutics*
Interfaces 38(1), pp. 5–25, ©2008 INFORMS

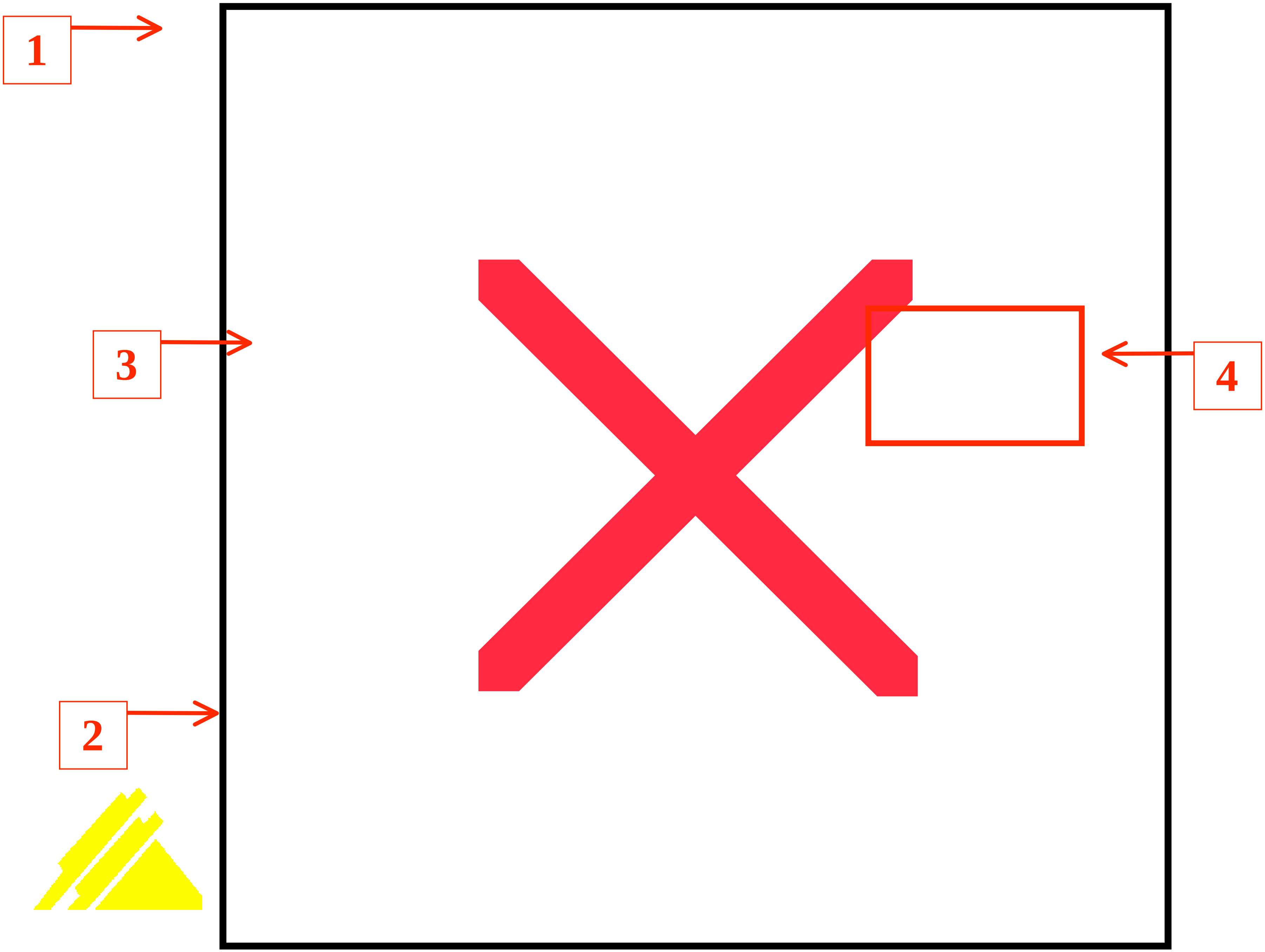
Optimal Brachytherapy for Prostate Cancer

- **Results**
  - **Implants are less dependent on operator skill**
  - **The potential exists to establish standards for quality control and assurance**
  - **Eliminates need for extensive patient/operator placement pre-planning and errors**
  - **Use as a teaching tool for students and residents**

Dynamic Influence Diagrams: Applications to Medical Decision Making

Gordon B. Hazen

Chapter 24 in Operations Research and Health Care, edited by M. Brandeau, F. Sainfort, and W. Pierskalla. Boston, Mass.: Kluwer Academic Publishers 2004.


1
3
4
2

QALY = quality adjusted life years

National technology assessment and management modeling

- **UK, Australia and Canada (after efficacy has been established) use an Incremental Cost-Effectiveness Model:**

$$\frac{\text{Incremental cost of the new vs. existing technologies}}{\text{Incremental effectiveness of the new vs. existing technologies in QALYS}}$$

QALYS = Quality Adjusted Life Years

- **UK – NHS Established a National Institute for Clinical Excellence (NICE) to consider whether new and/or existing health care technologies contribute to the efficient use of National Health Service resources using evidence-based analyses**

UK NHS - National Institute for Clinical Excellence (NICE)

“By September 2001 NICE had recommended adoptio 10 new drugs based on the results of the evaluat process.* However adoption of these drugs has led to increase of 250 million pounds in NHS expenditure (hence pharmaceutical company sales) [17]. No evide has been presented to show that this has lead to a increase in health improvements from NHS resources other words, NICE has resulted in an increase in utilisation of resources without any evidence that th resources have been used to maximise health benefits.”*

***Used a cutoff COST EFFECTIVENESS of about 30,000 £ per additional QALY**

**BIRCH, STEPHEN and AMIRAM GAFNI, “The ‘NICE’ Approach to Technology Assessment: An Economics Perspective”, Health Care Management Science 7, 35–41, 2004

National technology assessment and managemen modeling

- **Is it possible to build a "quick review yet high reliabilit technology assessment Model?**
  - **Currently all we (U.S.) do is assess efficacy for the intended u**
  - **What are the key issues involved in the assessment that can b accelerated?**
  - **What will be lost from future development of the technologie that are discarded? - Type 1 and Type 2 errors**
  - **How will technologies be removed from use?**

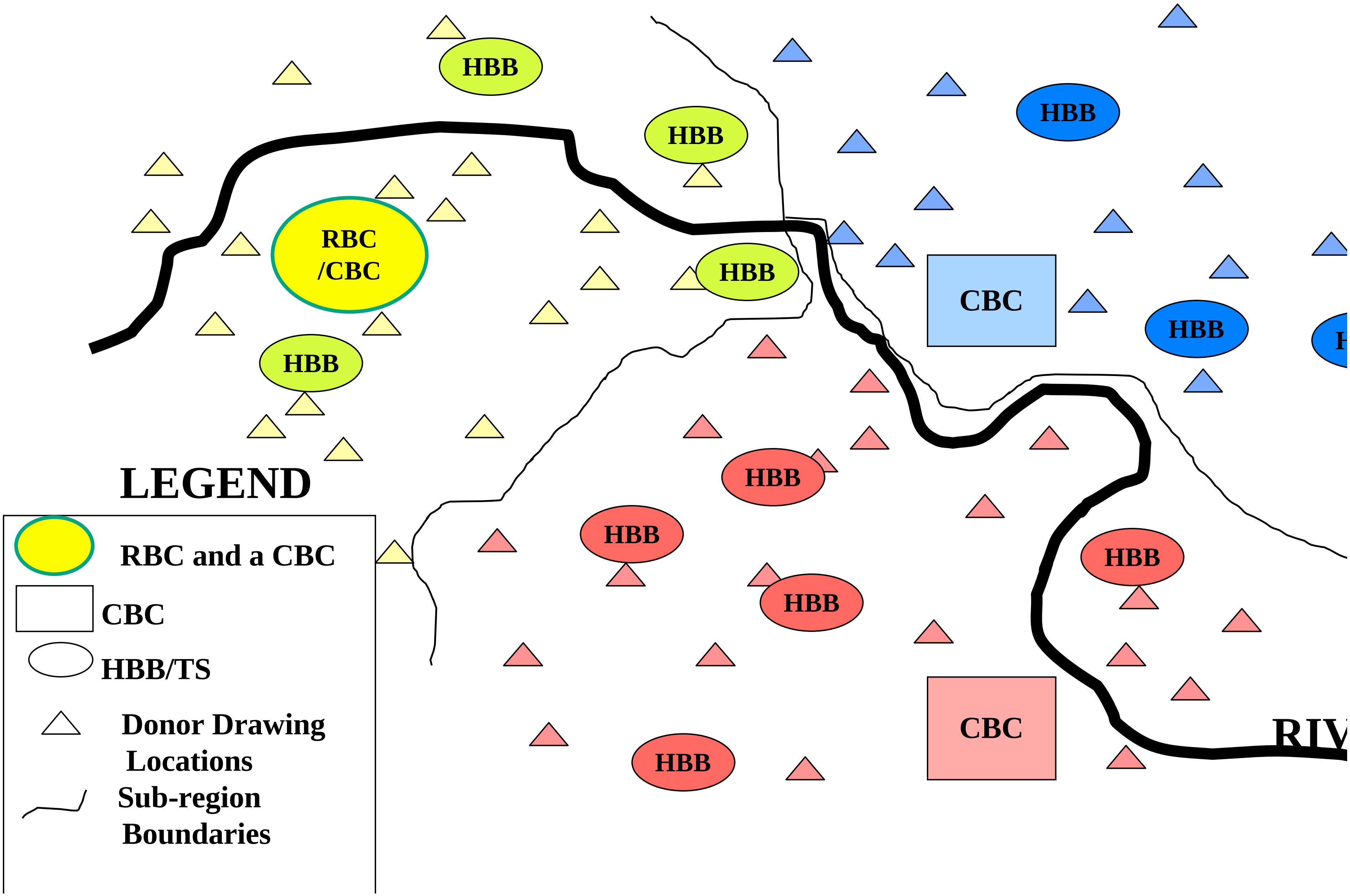
Supply Chain Management of Blood Banks
William P. Pierskalla

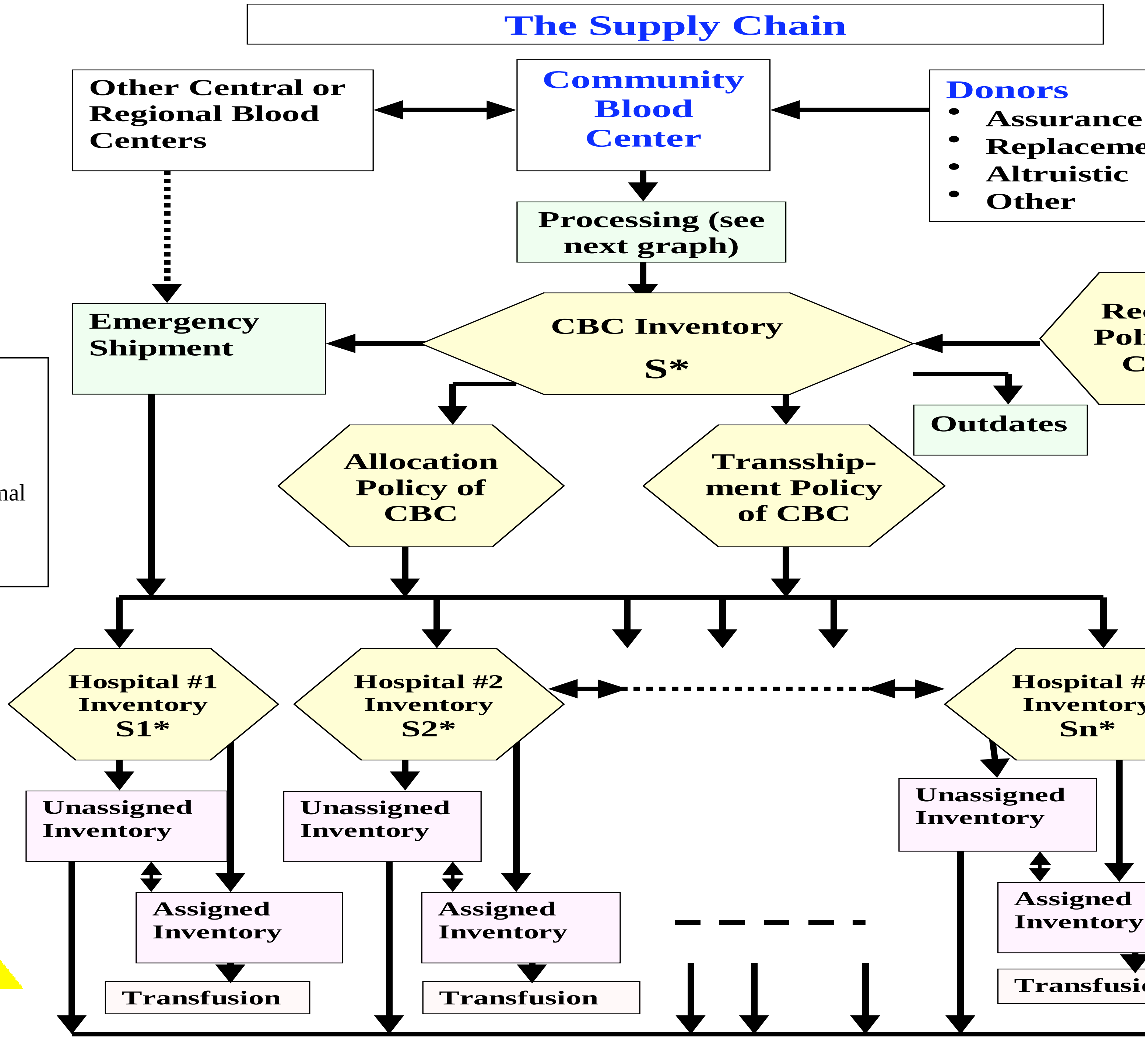
Chapter 5 in Operations Research and Health Care, edited by M. Brandeau, F. Sainfort, and W
Pierskalla. Boston, Mass.: Kluwer Academic Publishers 2004.

Blood Bank Supply Chain Problems

- **15-25% red cell outdates nationally in the 1970s and 8 but now 2-3%**
- **20-30% outdates of platelets today**
- **Transmission of contagious diseases from donors-HIV the 1980s now under good control**
- **Redundant facilities**
- **Shortages of blood and/or components**
- **Competition for volunteer donors**
- **Non-uniform application of standards, pricing, qualit control**
- **Lack of management knowledge**

A Geographic Region for Blood Supply and Demand



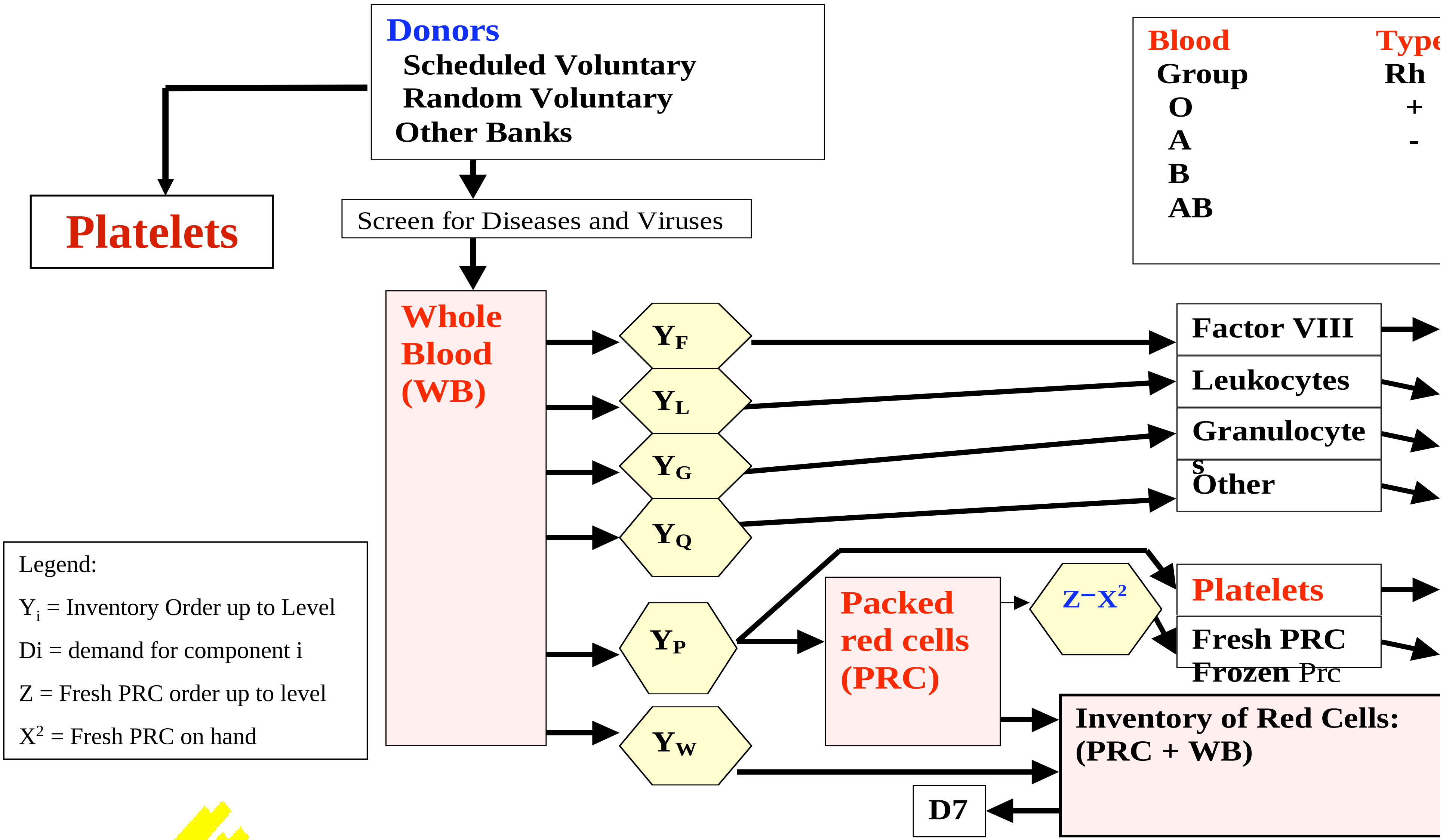


Legend:

S^* = vector of CBC optimal inventory order up to levels

Si^* = vector of HBB #i optimal inventory order up to levels

PROCESSING WHOLE BLOOD INTO COMPONENTS



Other Operations Research (OR) Applications

OR Applications

- **Regional planning and network models**
- **National workforce planning models**
- **Medical/nursing education models**
- **Technology diffusion models**
- **Prevention of disease models**
  - **Public Health**
  - **Contagious and Non-Contagious Disease**
  - **Vaccination/Inoculation**
- **Bioinformatics (e.g. genetic sequencing, phylogenetic trees, protein folding)**
  - **Mathematical programming/combinatorics/heuristics**
  - **Hidden markov processes**

OR Applications

- Benchmarking (DEA) models within and among Health Care Delivery Systems (HCDS)
- Drug selection models for patients with comorbidities and complications
- Clinical Diagnostics/Therapeutics Modeling
- Equipment Evaluation and Selection Models
- Access and availability population models

OR Applications

- Laboratory/Radiology/Other Facilities Scheduling
- Perishable and Nonperishable Inventories
- Patient Management
  - ER/Admissions/Transfers/Discharges
- Ambulance and other Vehicle Scheduling and Location
- Ambulatory Services Planning and Scheduling
- Disease Prevention Services
- Patient Satisfaction Models

OR Applications

- Demand Forecasting and Planning Models
- Location/Allocation Modeling of Which Hospitals to Merge, to Close, to Reorganize Services Offered
- Alternative Quality of Life and Priority Setting Models for Patients and Physicians
- Layout and Bed Rationalization Models
- Patient Scheduling (ER, OR, ICU, beds, services)
- Optimal Pricing and Costing Models
- Workforce and Workload Models
  - Planning, Staffing, Scheduling, Allocation

DECISION SUPPORT SYSTEM USE & ISSUES

DECISION SUPPORT SYSTEM	SYSTEMS	WIDE-SPREAD USE	ISSUES
Operations Management Strategy	Yes	Medium	Don't know the questions to ask
Demand Forecasting	Yes	Low	Limited Availability—don't always like the
Capacity Planning	Yes	Low	Cost
Location Decisions	Yes	Low	Lack of management understanding
Process and Layout Design	Yes	Consulting	Acceptable systems and data
Scheduling and Staffing	Yes	Medium	High use by consultants
Productivity	Yes	Medium	Future will require these types of decisior (therefore systems)
Quality Control Data and Methods	No	Low-Med	Large organizations support these systen
Health Status and Severity Assessment	Yes	Medium	
Quality Assurance	Yes	High	
Total Quality Management	Limited	Low-Med	
Purchaser's Perspective on Quality	Market Research	Low	Growing through e-health companies
Inventory and Maintenance	Yes	High	
Regional Planning	Yes	High	Government focus

Clinical Decision Support System Use & Issues

Clinical Decision Support System	Systems	Widespread Use	Issues
CPOE	yes	No, but growing	Only in a few advanced h care systems
Diagnostic	A few	No	Still in research mode
Therapeutic	A few	No	Still in research mode
Preventive	A few	No	Still in research mode
Disease management	A few	No	Only in a few large mana care org.s and only a few diseases-also still in resea mode
Progressive care	None	No	Not yet even in research

Internet and Other Digitally Related Technologies

- Internet
  - **Internet (network) computing**
  - **Extensible Markup Language (XML)**
  - **Faster Internet Access**
  - **Push technology/new media**
- Point of Care
  - **Personal digital Assistants**
  - **Wireless LAN and WAN**
- EMR/EHR & Related Technology
  - **Common medical vocabulary**
  - **Natural language processing**
  - **Rules-based systems**
  - **Neural networks/Math programming**
  - **Data Mining**
- Interaction Technology
  - **Speech recognition**
  - **Handwriting Recognition**
  - **Wearable computers**
- Security
  - **Public key infrastructure**
  - **Biometrics and Smart cards**
- Application Integration
  - **Integration middleware**
  - **Component software**
- Process Automation
  - **Process modeling and Workflow man**
  - **Rules-based systems**
  - **Knowledge management**

Rational (optimal?) rationing

- **All nations ration in some way or other**
  - **Accessibility/availability**
  - **Waiting**
  - **Limits on technologies/drugs**
  - **Coverages under insurance**
  - **Other demand restrictions**
    - **E. g. Deductibles, co-payments, PPO rules**
    - **Age limitations**
  - **Other supply restrictions**
    - **E.g. Purchasing and building permits**
- **Can models be built to make this process more rational (optimal)? What would be the goals/objective functions and how would we get consensus for them? Dynamic longer-term trial/experimentation usage processes**

A mixed integer programming model to locate traumatic brain injury treatment units in the Department of Veterans Affairs: a case study*

Abstract

For the Department of Veterans Affairs (VA), traumatic brain injury (TBI) is a significant problem facing active duty military personnel, veterans, their families, and caregivers. The VA has designated TBI treatment as one of its physical medicine and rehabilitation special emphasis programs, thereby providing a comprehensive array of treatment services to those military personnel and veterans with TBI. Timely treatment of TBI is critical in achieving maximal recovery, and being in geographical proximity to a medical center with specialized TBI treatment services is a major determinant of whether such treatment is utilized. We present a mixed integer programming model for locating TBI treatment units in the VA. This model was developed for the VA Rehabilitation Strategic Healthcare Group to assist in locating new TBI treatment units. The optimization model assigns TBI treatment units to existing VA medical centers while minimizing the sum of patient treatment costs, patient lodging and travel costs, and the penalty costs associated with foregone treatment revenue and excess capacity utilization. We demonstrate our model with VA TBI admission data from one of the VA's integrated service networks, and discuss the expected service and cost implications for a range of TBI treatment unit location options.

Keywords Facility location and allocation . Health care planning . Mixed integer programming . Traumatic brain injury .Veterans health

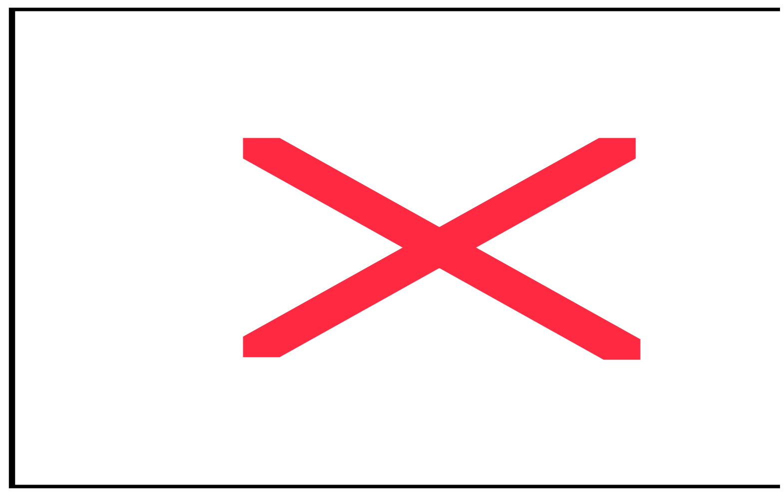
*Murray J. Côté & Siddhartha S. Syam & W. Bruce Vogel & Diane C. Cowper, A Mixed Integer Programming Model to Locate Traumatic Brain Injury Treatment Units in the Dept. of Veterans Affairs, Health Care Management Science, 10(3): 253-267.

A mixed integer programming model to locate traumatic brain injury treatment units in the Department of Veterans Affairs: a case study*

- **The purpose of this model is to decide where to locate TBI treatment centers within the VA system which minimizes the sum of patient treatment costs, patient lodging and travel costs, and the costs associated with foregone treatment revenue and excess capacity utilization at the VA centers being used for TBI treatment.**
- **Many variables and parameters are included in the model such as medical center locations, patient locations and travel distances to the centers, patient attendance attrition due to distance and costs of travel and lodging, TBI severity levels, lengths of stay by severity, center sizes, capacities and capabilities for TBI treatment and the costs associated with these variables.**

A mixed integer programming model to locate traumatic brain injury treatment units in the Department of Veterans Affairs: a case study*

- The model was applied to treatment location decisions in the six Florida based VA medical centers in VISN 8.
- Many scenarios were evaluated wherein decisions were made to open only one, some or all six of the medical centers for TBI treatment and at what levels.



A mixed integer programming model to locate traumatic brain injury treatment units in the Department of Veterans Affairs: a case study*

- **Each scenario was then evaluated on the bases of admission retention rates, severity levels and numbers of TBI patients treated at each center that was open, expected treatment costs, expected lost admission penalty costs, expected capacity penalty costs, and expected lodging and travel costs.**
- **VA management could use the results of the model to make more informed decisions as to the number, location, capacities, personnel and costs of opening facilities throughout the region to treat TBI patients with or without family members in attendance.**