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2005

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Operations Research & Public Policy for Africa: Harnessing the Revolution in Management Science Instruction

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Abstract:

Operations research (OR) has made major contributions in the developed world to public policy domains that are of great relevance to Africa. Inasmuch as OR has failed to live up to its potential for addressing such issues in Africa, a principal barrier may have been distance between OR analysts and decision makers. However, the revolution in management science instruction and potential to train end user modelers has democratized OR. This makes training for policy makers and mangers in the public and non-profit sectors in Africa both feasible and highly beneficial. Existing Management Science courses for public and non-profit leaders, such as those that taught at Carnegie Mellon, could be adapted to fit the needs of educators and policy makers in Africa and disseminated via a "train the trainers" approach. A plan is sketched whereby 800,000 end-user modelers might be trained in Africa (1 for every 1,000 people) at an annual cost of about $5M per year. Such budgets are well within the range of investments in human capital formation currently being made in Africa.

1. Introduction

Operations Research (OR) is best known for its military and industrial applications, but OR also has a rich history of application to diverse problems in public policy and non-profit management. Because of the recent revolution in Management Science instruction OR models and methods can play an ever larger role in the analysis and resolution of public policy problems in the future. This paper argues that this logic only applies to Africa, but, if anything, is likely to be particularly relevant for Africa.

The list of policy issues to which OR has made fundamental contributions is impressive: HIV/AIDS, transportation, environmental quality, water resources planning, economic planning, energy policy, urban operations research, crime & drug control, siting hazardous facilities, auctions, and health care to name a few. Papers written in these areas have won a striking share of the most prestigious prizes in Operations Research.

The overlap between these areas and many of the challenges facing Africa is striking; there is truly little doubt that Operations Research has potential for making signal contributions in key domains of concern in Africa. Indeed, as is discussed below, in some of these domains, papers written about Africa constitute a substantial minority of all OR papers written about those classes of problems.

Skeptics might counter that though the potential is there, it has never been fully realized, perhaps due to limitations in IT infrastructure and/or numbers of policy practitioners in Africa with advanced degrees in Operations Research. Those limitations may have been decisive in the past, but any lingering skepticism is rooted in outdated conceptions of how OR models and methods are deployed in contemporary society.

The majority of mathematical modeling of real-world problems is no longer done by people with PhD's in OR working in high-tech research parks on large computers. Instead, it is done on spreadsheets by "end user modelers" who are practitioners with a generalist training (MBA, MPP, etc.). Because of Moore's Law and the phenomenal changes in the price-performance curve for information technology, the average annual income in Africa today buys as much computational power as the average annual income in the US did in 1997. The end user modeling revolution was certainly in full swing in

the US by 1997, so hardware cost need not block a parallel revolution in Africa. Likewise, although MBA/MSPPM students are the students who are most likely to see a modern, spreadsheet-based modeling course in the US, a well kept secret is that one does not need graduate level mathematics to master OR spreadsheet modeling. Indeed, typically no math beyond algebra and perhaps exponential notation is required.

For the last decade, Carnegie Mellon's Heinz School has adapted the spreadsheet revolution in Management Science to training leaders in public policy and non-profit management at two levels: (1) a semester-long required core course and (2) throughout a six course cumulative sequence. This paper outlines the philosophy and tactics of this "Carnegie Mellon Heinz approach to OR & Public Policy."

This paper concludes by suggesting plausible mechanisms by which this curriculum could be delivered to non-trivial numbers of analysts, managers, and leaders in the public and non-governmental (NGO) sectors in Africa. In particular, we project that a cadre of 800,000 end user spreadsheet modelers (1 for every 1,000 Africans) could be trained for an annual cost of about $5 million per year. Such budgets are well within the range of investments in human capital formation currently being made in Africa.

2. OR in Public Policy and in Africa: Applicability and Current Status

Since its inception, operations research (OR) has been continually expanding, tackling an increasingly wide range of problems and issues. Although sometimes not appreciated by operations researchers who focus on business or military applications, operations research has a rich and storied history of being applies in the public sector.

Indeed, operations research has its roots in 19th century Europe where statisticians collected data and applied OR methods to social issues such as the variation in mortality rates with age and voting apportionment. OR flourished in the middle of the 20th century, notably during World War II when OR was used in activities and systems such as tactical and strategic planning, radar systems and convoy sizing and routing. OR was further developed in private industry in the decades following World War II for tasks such as oil refining, product mix planning, queuing, and inventory management.

Then in the 1960's operations research in some sense returned to its 19th century roots and started to again become more widely used in the public sector (Pollock and

Maltz 1994). In the US, the impetus came from the social strife of the 1960s coupled with the advent of the Johnson Administration's "Great Society" programs. Since then, operations research has been applied to the public sector on issues ranging from emergency services deployment to forest management. Operations research has made significant contributions solving challenges in the public sector that have saved both money and lives, as the following examples illustrate.

- More efficient deployment of police, fire and medical personnel using set covering models and the hypercube queueing model have resulted in a reduction in property damage, injuries and death. (Swersey, 1994)
- Siting hazardous waste facilities, trash collection and disposal have benefited from operations research. Facility location models and decision analysis tools have helped locate facilities in areas that are less environmentally sensitive and more efficient locations. Routing models have helped save money and avoid public nuisance and health hazard issues. (Kleindorfer and Kunrether, 1994)
- Public transportation has utilized operations research to schedule crews, vehicles and spare drivers to meet demand. Air transportation has used operations research in determining the capacities of runways and simulating delays on the system. (Odoni, Roussueau and Wilson, 1994)
- Even natural resource management has benefited from the use of operations research. Models are used to estimate the sustainable harvest capacity in fisheries, engage in forest planning, and plan water release schedules on hydropower dams. (Golden and Wasil, 1994)

The prevalence of public policy in OR can be gauged by reviewing winners of OR's two most prestigious awards: the Edelman Award and Lanchester Prize. The Franz Edelman Award is given for outstanding examples of management science and operations research practice in the world. The Frederick W. Lanchester prize is given to the best contribution to operations research and the management sciences published in English. Since the awards' inceptions each has had over twenty percent of their award winners in the public policy sector.

Table 1 Franz Edelman Award Winners in Public Policy

Year	Organization
1996	South African National Defense Force
1992	New Haven Health Department, AIDS Division
1990	Health Care Financing Administration
1988	City of San Francisco Police Department
1982	Arizona Department of Transportation
1979	The Greater New York Blood Program
1974	Canadian National Energy Board

Table 2 Frederick W. Lanchester Prize Winners in Public Policy

Year	Organization	Paper Title
1994	Edward H. Kaplan	Modelling and Reducing the Spread of AIDS
1985	Michael D. Maltz	Recidivism
1974	Peter J. Kolesar	An Algorithm for the Dynamic Relocation of Fire Companies
1973	Louis M. Goreaux & Alan S. Manne	Multi-Level Planning: Case Studies in Mexico
1972	Richard C. Larson	Urban Police Patrol Analysis
1962	Robert M. Oliver & Arych H. Samuel	Reducing Letter Delays in Post Offices
1959	Robert E. Chandler, Robert Herman and Elliott W. Montrol	Traffic Dynamics
1957	Maurice F. C. Allais	Method of Appraising Economic Prospects of Mining Exploration Over Large Territories: Algerian Sahara Case Study
1954	Leslie C. Edie	Traffic Delays at Toll Booths

We sought to assess the extent to which these success of OR primarily in North America have been paralleled in Africa via searches on three data bases and subsequent literature review. In short, it appears that operations research is increasingly applied to public policy and international development issues relevant to Africa.

In particular, a list of key words for policy and development issues relevant to Africa was generated based on the topics for the First Conference on OR Practice in Africa and other sources.[1] (See Table 3 below.) A subset of operations research journals were searched using JSTOR, other academic papers were searched Google Scholar, and additional references to operations research documents were identified using Google. Each search was conducted twice, once with the topic alone and once intersecting the

[1] The complete list of sources consulted follows: the UNDP Millennium Development Goals in Africa report, the UNDP Fast Facts sheet on UNDP's work in Africa, the Executive Board of the United Nations Development Program and of the United Nations Population Fund's Second regional cooperation framework for Africa (2002 – 2006), an interview with President Blaise Compaore of Burkina Faso found in Choices magazine, a publication of UNDP and on the website for the First conference on OR Practice in Africa.

topic with the keyword “Africa”. To increase relevance, searches were limited by adding the keywords “operations research” and a select group of synonyms (e.g., “operational research”). Similar searches were conducted for Latin America and Asia for the purpose of comparison.

The most basic finding is that there are a very large number of documents available that apparently address the intersection of operations research, Africa, and public policy or international development. Using Google Scholar for example, a total of about 30,000 articles that related to Africa, operations research and the various development and public policy topics of interest were identified.

Table 3 Search Topics by category

Category	Topic	Africa Specific Hits	
		Google Scholar	Jstor
Physical	Environment	5,120	146
Physical	Energy	2,910	70
Physical	Agriculture	2,610	111
Physical	Infrastructure	2,570	11
Physical	Manufacturing	1,710	92
Physical	Transportation	1,680	92
Physical	Natural Resources	1,440	18
Physical	Information and Communication Technologies	157	1
Health	Public Health	1,900	15
Health	HIV AIDS	1,820	5
Health	Child Mortality	295	-
Health	Maternal Health	207	-
Education	Education	3,880	199
Economic	Globalization	1,010	-
Economic	Debt	905	8
Economic	Micro Finance	75	-
Economic	Macro Finance	3	-
Public	Disaster Management	580	1
Public	Armed Conflict	106	1
Public	Military Operations	76	18
Public	Effective Governance	37	-
Public	Emergency Relief Operations	4	-
Equity	Poverty Reduction	356	1
Equity	Gender Equality	113	-
Equity	Poverty Eradication	83	-

The geographically unrestricted Google Scholar searches of academic papers yielded over 5,000 hits in areas such as agriculture, energy, transportation and the environment, where international development issues overlap with wider public policy concerns. In more development specific subject areas such as poverty reduction, public health, debt and globalization, the number of hits was generally lower, but the proportion of Africa-specific hits was higher. In all but very specific sub-topic searches, multiple scholarly papers were found.

Given the power of today's search engines, one might wonder whether there are hundreds of documents at the intersection of OR, Africa, and any given public policy issue only because there are hundreds of millions of such documents more generally. I.e., that there may be a very large intersection of OR and public policy, but that the Africa-specific documents are a small subset of that universe. That does not appear to be the case, however. The precise proportion varied considerably by specific topic and search engine, but very roughly anywhere from 15% of 60% of the OR & public policy documents were Africa-relevant at least inasmuch as they turned up in an Africa-specific search.

When search topics were grouped into five categories (relating to Economic, Health, Physical, Public and Equity issues from Table 3 above), the proportion of total hits obtained when Africa was added as a compulsory search term was compared to the equivalent searches run for Latin America and Asia. Rresults are summarized in Table 4.

Table 4 Average proportion of topic hits related to Africa, Latin American and Asia (by category)

	Google			**Scholar**			**Jstor**		
Category	Africa	Latin America	Asia	Africa	Latin America	Asia	Africa	Latin America	Asia
Physical	17%	6%	**19%**	16%	7%	**18%**	**7%**	4%	**7%**
Health	**49%**	21%	42%	**47%**	23%	38%	**3%**	1%	1%
Education	**8%**	3%	**8%**	18%	8%	**19%**	**7%**	1%	2%
Economic	**50%**	20%	**50%**	35%	28%	**44%**	0%	0%	**21%**
Public	**54%**	26%	44%	**53%**	25%	42%	**17%**	13%	13%
Equity	**71%**	37%	66%	**73%**	43%	66%	**50%**	**50%**	**50%**

On average in the Public, Health and Equity categories, Africa had the largest proportion of hits. In the Physical and Economic categories (which included the majority of topics where general public policy issues overlapped with those of interest to international development), Asia had a slightly larger proportion than Africa. Proportions for Latin America were generally lower than for the other two continents, but this may be a result of the search language being English leading to work done in Spanish or Portuguese being excluded.

It was not possible to read all of this literature, but selected examples are quite interesting. Three examples serve to highlight the diversity of Africa-relevant public policy topics that have been addressed in the OR literature.

1. In 1994, the Tanzanian National Institute of Medical Research hosted a Pan-African workshop to produce a strategic plan to address malaria prevention through insecticide treated mosquito netting. The conference recommendations included using OR to: determine the optimal dose of insecticide on netting, develop procedures to achieve a more homogenous target dose on netting while minimizing waste and pollution, devise optimal delivery strategies, and explore financing mechanisms for cost recovery.
2. OR has been used extensively to model the spread of HIV/AIDS and determine policies to slow its spread. For example, Wein and Zenios (1996) show that pooled testing as an alternative for screening donated blood for HIV can result in a significant cost savings without compromising the screening process, which is particular valuable where budget constraints do not allow all donated blood to be screened.
3. Even relatively straightforward models can have significant implications. Mundia (2004) explains how Minimal Spanning Trees (MST) can be used to supply piped water efficiently to all homesteads in Kangaru Village, Kenya, saving community members time, and alleviating the health and safety concerns of collecting water from the nearby Kapingazi River.

These examples highlight some of the many diverse ways OR can be applied to issues relevant to Africa. OR methods of varying complexity all have the ability to solve

problems more effectively and efficiently, but in the US the biggest contributions come from “end user modeling” not “high-end” approaches done by someone with a Ph.D. in Operations Research. The same may be true in Africa.

In their study of Nigerian private companies in 1994, Ehie and Smith found that the top three “problems encountered in the use of OR techniques” as ranked by professionals using OR in their workplace were (1) “Insufficient number of trained personnel”; (2) “Need for software development”; and (3) “Lack of appropriate software packages.” In the decade since their research was published, the spread of Excel and development of excellent Excel add-ins for optimization, simulation, forecasting, and other OR methods address the second and third concerns. End-user modeling not only makes the software necessary more accessible, it also reduces the amount training required for someone to use OR in the workplace. Papoulias (1984) notes that OR models created for the developing world are often not implemented. End-user modeling greatly reduces the risk of “no implementation” because it is the decision maker himself or herself who creates and analyzes the model (Plane, 1994; Powell, 1997c).

Precisely because computers are now so fast and software is so user friendly, one does not need a lot of mathematical training to successfully apply mathematical modeling. Indeed, typically no math beyond algebra and perhaps exponential notation is required. Calculus is not a prerequisite for nor is it used in the *graduate-level* end user modeling classes taught at Carnegie Mellon’s Heinz School. What makes them graduate level is the sophistication of the modeling and analysis, not the equations.

Likewise, in the past when computers were weak, it was important for the modeler to have a detailed understanding of the underlying computer algorithms so that models could be carefully designed to make things as easy as possible for the computer. Today, while one should certainly know basic facts like the implications for computational complexity of linear vs. nonlinear formulations or continuous vs. integer-valued decision variables, for the most part the computers are fast enough to work well with even less than maximally efficient formulations and/or the software itself can massage or preprocess the formulation to convert it into computationally more convenient forms.

The next two sections of this paper explain in more detail the revolution in Management Science that has accompanied the changes in OR practice. The final section makes the case that it could be applied to Management Science instruction in Africa. We close this section by noting that the Revolution in Management Science instruction that has been so transformational in North America has apparently not been widely embraced to date in Africa.

We are certainly not deeply informed about OR educational practices in Africa, but we have contacted several OR instructors in Africa who report that a more traditional, equation- or math-based approach is common. Also, in the US one of the most popular textbooks geared towards the end user modeling approach is *Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Management Science*, by Cliff Ragsdale, but apparently it is in use by only one university in Africa.[2]

3. The Revolution in Management Science Instruction

Starting about fifteen years ago and maturing about 5 – 10 years ago a revolution in Management Science instruction swept the United States (Powell, 1997).[3] The old-style survey and introduction to OR course emphasizing algorithms was replaced by a modern course teaching hands-on mathematical modeling tailored for the MBA or other professional management student. (See Grossman, 2001, for a scathing critique of the traditional OR course.)

The original impetus for change was institutional. The AACSB changed the accreditation standards for business school curricula in April 1991. Before that time, OR/MS enjoyed a protected position as part of a "common body of knowledge" that every MBA program had to offer to be accredited. After the change, there was no specific requirement that OR/MS be included. (Magnanti et al., 1996). In short, deregulation eliminated a protected monopoly.

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[2] According to the Publisher, Thomas Custom Learning Solutions, Ragsdale's text is only being used by the University of Stellenbosh Business School, in South Africa.

[3] There has long been much debate about whether our field should be called "Operations Research" or "Management Science". INFORMS has officially endorsed "Operations Research", so we primarily use that term, but the revolution in instruction is usually referred to as changing the way "Management Science" is taught, so we use that term in the teaching context.

With relaxed core requirements, business schools defined more specialized missions with curricula designed around those missions. OR tools and methods were more often taught within functional courses such as finance or marketing. The stand-alone OR course, and the faculty who taught it, were downsized.

Simply put, the traditional OR course that taught students how to pivot a simplex tableau could not withstand competitive market pressures. It was revealed for what it truly was – a fraud. Management students are not well served by baby versions of the algorithmically oriented classes that are the staple of OR courses for OR majors.

OR faculty responded to the sudden imposition of market pressures with aggressive innovation. Courses were redesigned. New textbooks were written. (See Table 5.) The defining product of OR faculty – the core management science course – was fundamentally redesigned to make it competitive.

Table 5: Innovative Texts in Management Science

Author(s)	Title	Publisher Information
Christian Albright and Wayne Winston	Spreadsheet Modeling and Applications: Essentials of Practical Management Science	Duxbury (2005)
Barlow, J.F.	Excel Models for Business and Operations Management	John Wiley (1999)
Jeffrey D. Camm and James R. Evans	Management Science: Modeling, Analysis and Interpretation	South-Western (1996)
G.D. Eppen, F.J. Gould, C.P. Schmidt, J.H. Moore, and L.R. Wetherford	Introductory Management Science: Decision Modeling with Spreadsheets	Prentice Hall (1998)
Rick Hesse	Managerial Spreadsheet Modeling and Analysis	Irwin (1997)
F.S. Hillier, M.S. Hillier, and P.D. Reagan	Introduction to Management Science: A Modeling and Case Studies Approach with Spreadsheets	McGraw-Hill/Irwin (2003)
L.L. Lapin and W.D. Whisler	Quantitative Decision Making with Spreadsheet Applications	Duxbury/Thomson Learning (2002)
G.E. Monahan	Management Decision Making: Spreadsheet Modeling, Analysis, and Applications	Cambridge University Press (2000)
Donald R. Plane	Management Science: A Spreadsheet Approach for Windows	Boyd and Fraser (1996)
Stephen Powell and Kenneth Baker	The Art of Modeling with Spreadsheets: Management Science, Spreadsheet Engineering, and Modeling Craft	John Wiley (2003)
Cliff T. Ragsdale	Spreadsheet Modeling & Decision Analysis, 4e	South-Western (2003)
Sam L. Savage	Insight.xla: Business Analysis Software for Microsoft Excel	Brooks/Cole (1998)
Wayne Winston and Christian Albright	Practical Management Science: Spreadsheet Modeling and Applications	Duxbury Press (2000)

The heart of the revolution was embracing the changing reality of management and decision-making practice epitomized by "end user modeling in spreadsheets". The revolution happened very quickly. In 1995 fewer than one-third of those responding to a survey of professors who taught OR/MS in business schools said their students were using spreadsheets to model and solve assignments. By 1998, there had been a near total conversion of introductory OR textbooks to the modern approach.

Changes in Management Practice

A decade earlier, there had been a parallel spreadsheet revolution in management that changed the way managers dealt with quantitative decision problems. Managers used to satisfice their way through complex problems with intuition and a calculator, but the personal computer (PC) revolution changed the ground rules. Today, managers "live in spreadsheets". Over one hundred million people are using Excel alone, and today's Excel is powerful (Williams, 2001).

Excel has a built in optimization package, called Solver (Fylstra et al., 1998), that is more powerful than the software the average full professor of Operations Research had when writing his or her doctoral dissertation. It can be extended by the Premium Solver for a few hundreds of dollars (Albright, 2001), and there are powerful, inexpensive, easy-to-use add-ins for simulation (e.g., CrystalBall and @Risk), decision trees (see Maxwell, 2004 for a review), and other applications (e.g., Sam Savage's Insight.xla).

Now the typical manager need not be a mere consumer of others' analysis but rather can be the *analyst* of many non-trivially sized problems, including very important problems. (The strategic importance and computational size of problems are not highly correlated, so the most important problems are often small to medium size.)

In short, society has entered the brave new world of "end user modeling" (Plane, 1994; Powell, 1997c). Managers have at their finger tips analytical power that would not have been imagined fifteen years ago, and it's easy to use. All that any manager, anywhere, needs to perform effective decision modeling is a laptop with Microsoft Office. Furthermore, because of the power of Moore's Law and the phenomenal changes in the price-performance curve for information technology, sufficient computational

power to do real end-user modeling is now available essentially world-wide, not just in the first world.

At first, for many managers spreadsheets remained simply fancy calculators that let them manipulate and display data easily. (Powell, 1997a) That chasm between what managers can do with the ubiquitous spreadsheet and what they actually do is the gap a modern introductory management science course is designed to fill.

Filling this gap is not an imagined need. Whereas there was a mismatch between the "traditional" OR/MS survey course and the skills demanded by employers (Magnanti et al., 1996), "end user" modelers, who have useful quantitative problem solving skills, are in high demand. Employers of Carnegie Mellon's public policy and non-profit management students recognize and appreciate the value of having professionals who can quickly and effectively model important problems.

Powell (1997a) argues that management science instructors "should see our role as teaching computer modeling" and cites four defining characteristics of end-user modeling.

1. It is initiated and carried out by an individual (often the decision maker), not by a group of OR analysts.
2. End-user modelers like to think directly in spreadsheets, not in algebraic formulations.
3. End-user modeling is quick and dirty, often being done under tight time and budget constraints. Powell cites the example of spreadsheets being built by the decision maker/analyst on the plane as he or she flies to the key meeting.
4. Finally, end-user modeling strives to derive insight, often pertaining to one-time decisions, not to produce numerical results for repeated instances of a problem (e.g., figuring out each morning how many pints of blood a hospital should order).

Grossman (1997) summarizes the objective as preparing students so that "when faced with an ill-defined ... "mess" [they] are able to devise a useful model, manage inadequate data, perform appropriate analysis, extract insights and use them to communicate, persuade and drive change."

Spreadsheets Are Good for Learning Too

OR faculty were forced into teaching with spreadsheets (some kicking and screaming), but then discovered that spreadsheets are a wonderful way to teach OR and modeling. Spreadsheets let students build and solve models of nontrivial scale in a familiar and user-friendly environment. People who have taught with them generally believe they make it easier to focus on the deeper intellectual concepts. (Winston, 1996) There are many students who can make neither head nor tail of the double-subscripted algebraic representation of a multi-period, multi-product inventory planning problem but who have no trouble analyzing the problem in a spreadsheet.[4]

Spreadsheets are not without drawbacks. Students must be taught to be disciplined in the design and documentation of their spreadsheets or they will produce "spaghetti code"; the lack of separation between data and calculations can be problematic for the unaware (although color coding data cells can go a long way toward avoiding silly errors). Specialized modeling languages (such as GAMS) take advantage of more compact notation and so are better for doubly and triply indexed decision variables. Spreadsheets do not scale well, particularly so-called "hyper-scalability" (changing the dimension of a problem, e.g., by adding an inter-temporal dimension). (Savage, 1997) Also, spreadsheets are far better for basic simulation than for complex structured simulations. Nevertheless, these problems pale in comparison to spreadsheets' advantages (Grossman, 1999).

Perhaps the biggest advantage of teaching with spreadsheets is that students *want* to use them. When the revolution in Management Science instruction got started, faculty at the University of Virginia's Darden School (Carraway and Clyman, 1997), Indiana University's Business School (Winston, 1996), and DePaul University (1997) suddenly began reporting that their students loved linear programming and other OR topics that previously had been seen as at best the "spinach" of an MBA curriculum and at worst a pointless and painful right of passage.

[4] We see this at Heinz because we teach the algebraic formulations alongside the Excel model. Other professors and texts have converted completely to "equation-free" instruction.

4. Management Science in Public Sector Instruction

Management Science courses that focus on "End User" spreadsheet modeling make sense for business schools, but are they appropriate for managers and analysts in the public and non-profit sectors? We think the answer is a resounding "Yes"!

Indeed, Carnegie Mellon's Heinz School offers six masters-level courses related to end-user modeling for public and non-profit management.

- A semester-long required introductory core course in Management Science
- A semester long "Public Sector OR" course that is case and project oriented
- A semester-long class focused on financial modeling
- A half-semester "studio" course in policy decision modeling
- A half-semester course in decision analysis
- A half-semester class on decision support systems with VBA (cf., Ragsdale, 2001)

It is true that most Management Science textbooks talk about business problems. That is simply because there are far more students of business administration and textbook writers aim for the largest segment of the market. However, our faculty have written custom textbooks and course packs for these courses, and even texts written for business school students include examples of public sector applications.[5] Furthermore, as we will propose in the next section, it should be possible to create an end user spreadsheet modeling text tailored to African public and non-profit sector applications.

Certainly these six courses are adapted and taught somewhat differently than are their business school counterparts. However, at least 50% of the material is taught essentially the same way it would be presented to MBA students. Below, we briefly outline the exceptions or adaptations for the introductory Management Science course which is required of all masters students in Public Policy & Management and in Healthcare Policy & Management. (For more on this course, see Caulkins, 1999.)

[5] E.g., Ragsdale's (2003) text, from which we use selected chapters in the introductory course, has cases on non-profit environmental management, snow removal, food stamp policy, forecasting inflation, FDIC bank regulation, and analyzing power and influence in the Senate.

While almost one-third of Heinz students in these programs come from the developing world, the class is not designed with an international or developing world focus. However, just as this course tailored the classic end user modeling spreadsheet modeling course for MBAs, it should be possible to do the same for other audiences.

Heinz students take introductory management science course in the spring of their first year. Only a few exempt to take a more advanced course, so the class is large (two sections of about 50-70 students each). Not all students have their own computer, so the course is primarily taught in lecture format. We spend about two-thirds of class time in conventional format and one-third building and demonstrating models in Excel projected on the screen. Supplemental recitations are held in our computer lab to walk students through how to use Excel, Solver, and Crystal Ball.

The sequence of topics is outlined in Table 6. We begin not with linear programming, but rather with discounted cash flow analysis, breakeven analysis, elementary sensitivity analysis via Data Tables, and numerical calculation of production possibility frontiers the students have seen in a microeconomic-based policy analysis course. This is part of a general emphasis on financial analysis relative to operations, particularly factory operations modeling (e.g., a cutting stock formulation). It also recognizes that in public and non-profit work, more of the modeling will be descriptive, not optimization-based.

We do use linear programming to introduce the language of optimization and its key concepts. We illustrate how to "think with an optimization model" (as opposed to merely computing an answer) with a variation of the "Big Mac Attack" (Bosch, 1993), which asks students to optimize menu selection at a restaurant. Even though there are venerable, "real," public-sector LP applications (e.g., developing school desegregation plans), we agree with Petty (1997) that fun, personal examples help assuage student fears that Management Science will be "too technical" for them.

We teach sensitivity analysis quite differently than the standard approach. Too often sensitivity analysis is presented as if it were applicable specifically to linear programming when we want students to consider sensitivity analysis to be an integral part of all decision modeling exercises. We teach parametric sensitivity analysis as exploring unknown functions – model results as a function of parameter values – and

explain that the best way to develop intuition is with appropriate graphs and figures. In particular, we teach how to create and interpret two- and three-dimensional contour plots, spider plots, tornado diagrams, and strategy region tables and diagrams.

Table 6: Sequence of Topics and Rough Time Allocation

Topic	Classes
Introduction to spreadsheet modeling & sensitivity analysis	2
Optimization and linear programming	3
Network optimization, spatial networks & computational complexity	3
Integer and nonlinear programming	3
Goal programming and MCDM	3
Forecasting	2
Simulation	2
Queuing	2
Decision analysis & behavioral decision theory	2
Project management	2
Discriminant analysis	1
Days allocated for review and synthesis (throughout term)	3

Network optimization is presented in a fairly standard way, though again emphasizing finance over production planning applications. However, we augment the standard network optimization material with spatial network models employed in urban services delivery (Larson and Odoni, 1981). We also introduce the notion of computational complexity to get students used to the idea that certain problem representations are more tractable than others from “the computer’s point of view”.

In integer programming, we stress multi-period capital budgeting problems with separate constraints for each budget period. This is particularly useful to public policy students since governments often contend with rigid financial years that make shifting funds across budgetary periods difficult. Likewise set covering is taught not only in the for conventional service provision context but also in terms of satisfying political constituencies; each constituency represents a “customer group” whose interests must be “covered” by any feasible solution.

In nonlinear programming, we show how simulation and conventional financial portfolio models can be combined to optimally spread investments across multiple government programs whose cost-effectiveness are not known with certainty (Caulkins, 2005).

Goal programming is a topic of central importance because most public and non-profit management problems have multiple objectives and soft (negotiable) constraints (whereas private-sector problems can more often be reasonably be modeled as fundamentally being about the single objective of profit maximization). We note that in goal programming, Solver is essentially used as a decision-support system that, by varying weights on deviational variables, suggests alternative feasible solutions that efficiently trade-off the competing objectives. The result is a finite number of candidate solutions that executives need to consider and compare with respect to their performance on the multiple objectives.

By simply re-labeling "objectives" as "attributes," we convert the goal programming output into an alternatives-outcomes matrix and have the perfect segue into Multi-Criteria Decision-Making (MCDM). The time spent on MCDM is probably the single biggest difference between a public and non-profit class relative to a class tailored for business students.

We discuss scoring model methods' strengths and limitations (with reference to Barba Romero's (2001) wonderful government acquisition and contracting example), Data Envelopment Analysis (DEA), the Analytical Hierarchy Process (Saaty, 1994), and the parallels between the classic public choice election literature and MCDM when the alternatives can only be ranked not rated with respect to each criteria. This comprehensive approach to MCDM is valuable because students need to know how to trade-off multiple objectives and how to present analyses of multiple objective problems to decision makers.

In the probabilistic half of the course, we spend a day on discriminant analysis because Ragsdale has a marvelous case on bank regulation that ties in nicely with our finance course. In the week on forecasting we go well beyond the usual focus on time series analysis for two reasons. First, public policy students are usually exposed to time series methods in other courses (e.g., econometrics). Second, time series methods are

inappropriate for many forecasting challenges. Hence, we review various qualitative and causal modeling methods, spending the most time on decomposition and synthesis in estimating means and standard deviations.

Simulation is the heart of the second half of the course. (Winston (1996) argues that simulation ought to be the launching point for any Management Science course.) We believe that the most common applications for our students will be in forecasting and budgeting. They will build a spreadsheet model of the finances of some operation. Inevitably there will be uncertainties. They will need to model those uncertainties and analyze their implications for some bottom line performance measures (e.g., net revenues). We work a number of these examples in class and for homework. One year, for example, they revisited a case they did for another core course (policy and politics) concerning the finances of a higher educational institution. In particular, they did a formal Monte Carlo uncertainty analysis, whereas they had previously only done "what-if" analysis.

We cover queuing, but would not spend a week on it if it did not provide excellent opportunities for refining simulation skills. We discuss the hypercube queuing model for urban services management (Larson and Odoni, 1981), and use ideas from the psychology of queuing (Larson, 1987, 1988) to stimulate creativity and thinking outside the box.

Quantitative modeling classes in many public policy programs are essentially entirely devoted to decision analysis, and Chelst (1998) argues that would be a good practice for any management science course. We likewise give more than a brief introduction to decision analysis, stressing the value of information, type I/type II decision problems (e.g., whether to release someone on bail, how to respond to a positive drug or HIV test, etc.), risk aversion, and multi-attribute utility functions. Again, multiple objectives are the norm not the exception in public decision making.

We finish with project management and Microsoft Project, including how to use linear programming to implement the critical path method and crashing and also how to use simulation to handle inevitable uncertainty in activity completion times. (Heinz offers follow on courses in project management generally and in healthcare management.)

This course has helped students develop skills that let them make an impact in their positions in the public and non-profit sectors. It is the rule not the exception when students who do well in the class come back with stories of on the job successes, and the more of the six courses a student takes, the stronger their end-user modeling skills. We take particular pride, however, in hearing such stories from students who struggled in the introductory class – even hated it – and who did not take any of the advanced classes. Just this past year, two students with weak math backgrounds who failed the class the first time they took it came back with glowing stories about how end-user modeling has let them do things that that their employers never imagined to be possible.

So, we are confident that the end-user modeling approach to teaching Management Science can be as effective in the US for students pursuing careers in the public and non-profit sectors as it has been for MBA students in the US. We have no way to know whether training in end user modeling would be useful for students in Africa in the private, public, or non-profit sectors. Perhaps the only way to know is to try it. That begs the fundamental question: would it even be feasible to offer large numbers of students in Africa a modern, end-user modeling course? The next section makes the case that the answer to this question is "yes".

5. Rough Plan for Training Large Numbers of End User Modelers in Africa

The earlier sections of this paper argued that Operations Research methods are relevant to many problems important to Africa, that an end user modeling approach to OR instruction has democratized quantitative modeling in the US, and that end user modeling can be taught to public and non-profit students, not just MBAs. Is a "Revolution in Management Science Instruction" possible in Africa? The preceding section discussed management science education in a graduate program at a world class research university. However, this is not the only context in which management science can be taught.

Clearly some investment would need to be made to stimulate an African revolution in Management Science instruction large enough to make a continent-wide difference. How large an investment would it take? This section sketches a very rough budget for a continent-wide investment in end-user modeling instruction that suggests the

answer is "large in absolute terms, but not large compared to the development investments aid organizations routinely make in Africa."

What would it take for end-user modeling to truly make a difference to a continent? We do not know, but let's imagine for a moment the possibility that there might be one skilled, professional end-user modeler for every 1,000 people in Africa.

There were 14.4 personal computers per 1,000 people in 2002,[6] so this would be one end-user modeler for every 14.4 computers. Every city of 300,000 would have literally hundreds of such people. A country the size of Burkina Faso would have 11,000 trained end-user modelers, basically as many people as are members of INFORMS.[7] If end-user modeling is actually useful, one would think that size "dose" of end-user modelers ought to be enough to make a difference. Is it within the realm of reason to even imagine such a state? After all, Africa is the world's second most populous continent so that would require training 800,000 people to be end-user modelers.

There are many ways to expose people to end-user modeling. The "cheap" way to offer end-user modeling education to 800,000 people would be a purely web-based self-paced tutorial, but that could be a charade, not so much because of limited connectivity but more fundamentally because it is very difficult to learn the art of end-user modeling from a book or web page alone; it is more a way of thinking than it is a set of facts to be memorized (Powell and Baker, 2003). Even within live teaching formats, there are diverse possibilities ranging from intensive one-day workshops to a full semester class such as the one described at the Heinz School, with options in between. Presumably the best approach would be a mixture, but to make the point that dreaming big is not unreasonable, we will try to roughly estimate the investment needed to train 800,000 end user modelers via an in-person full semester course.

The feasibility and viability of this course are based on two factors: financial cost and institutional capacity. Institutional capacity can be understood to mean: are there instructors who can teach end-user modeling and adequate computing facilities for the students to learn? Given that OR groups already exist in a number of African

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[6] International Telecommunication Union's *World Telecommunication Development Report, 2003.* at http://www.itu.int/ITU-D/ict/statistics/at_glance/Internet03.pdf.

[7] INFORMS' website (http://www.informs.org/) claims a membership of 12,000.

universities, preparing faculty would not be difficult. African faculty already know how to teach OR. They would just need to tool up on how to teach end-user modeling type of OR, if they have not already done so. In addition, the capacity to teach end user modeling appears to exist in some African institutions. As previously mentioned, there are a significant number of courses in operations research currently being taught in Africa. These professors would be leading candidates to teach an end-user modeling course. Professors who were interested in doing the instruction could attend one of INFORMS' annual week-long summer workshop on teaching OR (Powell, 2004). Flying three faculty each from four different African universities to take this ~$1,000 class would cost on the order of $75,000.

Those faculty could then "train the trainers" in semester-long programs for cohorts of 25 students at a time. Over three years, that would reach 4 universities * 3 years * 3 semesters / year * 25 students per cohort = 900 students. Tuition at a first-rate African university such as the University of Cape Town is $3,500 USD per semester. However, this assumes a full courseload. Since these students would only be taking one class, we assume that the cost of instruction would be significantly lower, while the cost of room and board would remain constant. So training the trainers costs might be on the order of $1.8 M USD (900*$2,000). If 75% passed and could be retained as trainers, that would create a cadre of 675 trainers.

The major uncertainty in this budgeting concerns what salary these end user modeling trainers would need to be paid to attract and retain high quality trainers. Based on limited internet research, the salary for professors in Africa appears to range from under $1,000 USD annually to slightly over $5,000 USD per year, with South Africa as an outlier on the high end. Our budget estimate presumes $4,000 USD per year, so the annual cost of maintaining this cadre of 675 end-user modeling trainers would be $2.7M per year.[8]

If these trainers could each train 145 people per year (three semesters per year * two classes per term of 30 students each with a 80% graduation rate), then each year

[8] For some trainers, this might be a regular full time job at a fixed location. Others might be itinerant, traveling among smaller cities. The former would presumably be able to reach more students per year than the latter; the figures given below are an average across both modalities.

100,000 people would be trained in end-user modeling. If the average professional life of those end-user modelers were eight years (before retiring, moving on to other roles, needing to be retrained, etc.), that would over time lead to 800,000 people being trained in end user modeling, the conjectured one per thousand penetration that might make a substantial difference.

The 100,000 people trained per year would need to pay materials costs and "rent" on facilities, but not instructors' salaries (that is already counted in the $2.7M per year). We would imagine that the typical students would be working adults taking the class in the evening. Participants in an operations research training course could include current policy makers and professionals. While regular university students could be included as well, the point would be reach decision makers throughout Africa, and to help them inform their decisions with operations research. Participants could come from across all regions of the continent and all sectors of the economy. While students would likely need some level of higher education, no calculus knowledge would be required, though computer literacy and algebra skills would be essential.[9] The course would focus on spreadsheet-based decision modeling, and emphasize its application to real world problems. In this respect, the course could be similar to that taught at the Heinz School, but with an increased focus on development issues, particularly as they are relevant to Africa.

While there is increasing availability of computers and computing facilities in Africa, it would still be necessary to budget for hardware costs. If we assume that each of the 675 trainers would need 10 computers with which to teach, then the initial hardware costs would be 7.76 million dollars, assuming a $1,150 cost per computer. Thus hardware cost represents approximately 75% of the initial investment. We assumed a 5 year lifetime for the hardware, and built replacement costs into the annual budget, which amounted to $1.5 million USD per year or roughly one-third of the on-going annual budget. However, if the 6,750 computers could be purchased at wholesale price

[9] It is not even clear that higher education is essential. There are programs that teach OR-type decision making skills to high school students (Abbas et al., 2004). Indeed, Kenneth Chelst at Wayne State University has developed a number of high school operations research modules (see Edwards and Chelst, 2004 and http://www.hsor.org/modules.cfm).

and or grants could be obtained from computer companies, IT costs could be significantly reduced.[10]

There are other perhaps more pedestrian challenges. Theo Stewart (personal communications) notes that even in South Africa OR textbooks are too expensive for the majority of students to buy, and excellent textbooks have been a key enabler of the rapid transformation of OR instruction in the US. If the instructional costs are approximately $27 per student ($2.7M in trainers salaries for 100,000 students per year), the budget could be seriously threatened if every student were expected to buy a $100 textbook!

However, an African end user modeling project could commission its own custom textbook, retain intellectual property rights, and reproduce the text at cost. Based on personal communications with textbook authors and publishers, we estimate that it would cost on the order of $250,000 to develop the intellectual property for an end user modeling textbook and course materials (power point slides, problems tailored to Africa, etc.). Furthermore, each of the authors contacted suggested that they might be willing to donate their time and effort, reducing IP development expenses to just salary for graduate students who would write custom Africa-specific cases and problems. So intellectual property creation costs, amortized over the program scope contemplated, would work out to less than a dollar per end user modeling trained. Even if printing & reproduction costs were as high as $.05 per copied page,, textbook costs could be held to well less than one-tenth of textbook costs in the US. We budgeted for trainers to reuse textbooks, rather than requiring one for every student every time the course is taught. However, recognizing the need for students to have "refresher" materials on hand after the course ends, we have budgeted for a fifty-page packet to be given to every student at a cost of $2.50 per packet.

Note, one of the wonderful aspects of the revolution in Management Science teaching is that a culture of sharing all teaching materials, not just syllabi, has developed. This holds great promise for institutions in Africa that are looking to develop an end-user approach to management science. For example, the site

[10] Training students in end user computer modeling ought to stimulate demand for computer purchases, so a strong pitch could be made to hardware vendors that supporting this initiative could be in their self-interest.

http://education.forum.informs.org/teaching_materials contains pointers to over fifty courses in management science and allied fields, and has pointers to over a dozen courses in decision analysis, both Web-based and traditional. The central organization for promoting dissemination of these materials is the INFORMS Forum on Education (or INFORMED), which can be reached at http://education.forum.informs.org.[11]

The final budget estimate, summarized in Table 7, is that a training program such as this would require $10 million USD in initial costs, including faculty training, the training of the 900 trainers, textbook and course materials, and IT hardware, which accounted for the bulk of the investment. The annual cost is estimated at $4.5 million USD, which includes trainer salaries, training replacement trainers as needed, hardware maintenance and replacement, textbooks, and administrative costs. The program would be able to train 800,000 end user modelers in 9 years at a total cost of approximately $50 million USD. While this may seem like a large sum, the average cost of training an end user modeler would only be $63.

Table 7: Budget Estimate Summary

Initial, One Time Costs	
Textbook and Course Materials	$ 385,000
Training Instruction for faculty	$ 75,000
Train the Trainers costs	$ 1,800,000
IT hardware for Trainers	$ 7,762,500
Total One Time Costs	**$ 10,022,500**
Annual Costs	
Course Packets	$ 227,813
Salary for Trainers	$ 2,700,000
Training trainer replacements	$ 225,000
Hardware maintenance/ replacement	$ 1,552,500
Administrative costs	$ 100,000
Total Annual Costs	**$ 4,577,500**

Where would the money come from? It is probably not realistic to expect to charge full tuition to be paid by the participants, their employers, or their governments. A different option would be to seek funding through a capacity building foundation or

[11] James Cochran, President of INFORM-*ED* (INFORMS Education forum, views outreach efforts to promote the spread of end user modeling as part of his organization's mission and was enthusiastic about

multilateral institution. The Africa Capacity Building Foundation (ACBF) is based in Zimbabwe and financed through the African Development Bank, The World Bank, and the United Nations Development Programme. The ACBF provides grants to policy institutions, NGOs, and other organizations that do capacity building and training. For example, the ACBF provides $5 million USD to support the Kenya-based African Economic Research Consortium and their Collaborative Masters Program in Economics, slightly more than the $4.6 million annual cost of a continent-wide training program for end user modelers. Similarly, in December of 2004, the ACBF approved $37.48 million USD for capacity building initiatives in sub-Saharan Africa. The $10 million dollar start-up cost of the training program would only be approximately 25% of that investment.

Additionally, many multi-lateral institutions have their own capacity building programs that provide funding for initiatives in Africa. In 1999, the United Nations Economic and Social Council, ECOSOC, established the International Institute for Capacity Building in Africa. The IICBA's tasks include:

1. *addressing the educational, technical and professional*
2. *bringing the latest research and development in Africa*
3. *enhancing the capacities of regional, national and local level institutions*[12]

An end-user modeling course for policy makers and practitioners falls within this set of directives. Other capacity building initiatives include the USAID Africa Bureau Environmental Assessment Capacity Building Program, the World Bank's STATCAP program (a lending program aimed at supporting more efficient and effective statistical systems in developing countries), and the Water Utility Partnership for Capacity Building in Africa.

To conclude, "dreaming big" for end user modeling OR in Africa is not out of the question. The vision we have outlined is ambitious, but well within the parameters of aid and investment that is currently invested in capacity building in Africa. A partnership between academic institutions with expertise in operations research, NGOs with expertise

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the ideas sketched here.

[12] www.unesco-iicba.org

in running capacity building initiatives, and the financial support of the international community could prove very profitable. It would allow for training informed decision makers, accelerating the management science revolution in Africa, and developing solutions and strategies that could improve the quality of life for all Africans.

Conclusion

Operations Research has made major contribution to solving problems in the public and non-profit sectors in North America. Indeed, a significant share of INFORMS' most prestigious prizes have gone for public and non-profit applications. Reviewing the topics to which OR has contributed and the topics of greatest relevance in Africa suggests that OR ought to be able to play a similar role in Africa. To the extent that it has not, one reason may be the gap between high-end OR modelers and decision makers on the ground.

Spreadsheets and the information revolution more generally make it possible to close that gap, and closing the gap is an explicit goal of the Revolution in Management Science instruction that swept the US over the last decade. The revolution is not confined to MBA curricula. Carnegie Mellon's Heinz School has successfully adapted it to professional training for the public and non-profit sector. Even students exposed to a single semester-long course in end user modeling report being able to make major contributions on the job because of those modeling skills.

We roughly sketch a plan suggesting that it would be financially and technically possible to train large numbers of end user modelers in the public and non-profit sectors in Africa as well. An up front investment of $10 million USD with an on-going cost of $5 million USD might be enough to train and maintain a cadre of 800,000 end user modelers, one for every 1,000 people in Africa.

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