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My introduction to optimum decision making, and the banyan tree story

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1 Feel very proud to be an Indian

First let me share some of my thoughts with you. As an Indian I feel very very proud of India's recent scientific achievements.

First the unbelievable Mangalyan.

Second, a relative of mine, P. S. Subrahmanyam (Chinnayya), as the person in-charge of developing the light combat aircraft, Tejas, completed this task using totally indiginous components. It has entered production, and should help the country deal effectively with fanatic, pesky neighbors (for information on this in Telugu, see Navya 9-10-2014 issue at navya@andhrajyothy.com) .

And now if Indian leaders of all religions and races can be made to realize the urgent need for population stabilization in the country, it will be a fantastic triple crown. I earnestly seek your help in starting a successful campaign to stabilize, India's and in fact the whole world's human population, at least now.

2 History of OR

Operations Research (OR) is the branch of science dealing with techniques for optimizing the performance of systems. It is a scientific method that can be used to provide executives and decision makers a quantitative and rational basis for taking decisions (e.g., those dealing with the allocation of resources, selecting designs for building structures like dams across rivers etc., selecting designs for new products being introduced into the market, production planning in manufacturing plants, setting sales prices for products, etc. etc.) optimally. The subject is also called by other names such as: management science, scientific decision making, optimal decision making, decision analysis, decision science, systems analysis, systems engineering, analytics, etc.

The urge to "optimize" seems to be innate in not only humans, but also animals. Observations have revealed that more than 100000 years ago, when people used to live in caves, those cave dwellers used the shortest paths from their caves to reach the river to access the water in it for their living. Migratory animal herds used the shortest paths for their seasonal migrations.

Even tough the subject OR was not defined at that time, the mathematical work of Newton, Lebniz, Bernouli, and Lagrange in the 17th, 18th centuries characterizing the local minimums and maximums of diffenrentiable functions, is an important part of the subject.

As a subject "OR" got crystallized during World War II (1939-1945), when the British Government hired scientists from various disciplines to assist with the operational problems of the war; and hence they named it **Operational Research**; and when it reached the US, the Americans started calling it **Operations Research**.

The impetus for the origin of OR was the development of radar defense systems for the Royal Air Force. The British Air Ministry official A. P. Rowe constitued a team to analyze the operations of the communication system and the control room at a British Radar station, with the aim of improving its operational efficiency. One of the problems they worked on had the goal of reducing the number of artillery rounds to shoot down

an enemy aircraft.

The petrochemical industry is one of the first to broadly embrace OR to improve the performance of plants, develop natural resources, and plan strategy. Today OR plays very important roles in a variety of industries, service and governmental organizations.

3 The focus, and approach used by OR to improve performance

The focus of the subject is on scientific methods of decision making that seek to understand the complex operations of any system to predict its behavior and improve its performance. The OR Approach for improving any system typically takes the following steps:

(i). Identify the decision variables: Identify the parameters whose values can be controlled, and which affect system performance; these parameters are called *decision variables*. As an example, if the system is a chemical reactor manufacturing a chemical, the decision variables may be: temperature in the reactor, concentrations of various inputs, catalysts, etc., flow rates or the amount of time for which reaction is allowed to continue, etc.

(ii). Construct a mathematical model for system operation, and objectives to optimize, in terms of the decision variables: Identify measures of effectiveness of system performance, and express each of them as a mathematical function of the decision variables, these are the objective functions in the mathematical model. The profit measures among them should be maximized, cost measures should be minimized. Then identify all relationships that must hold among decision variables by the nature of system operations, using mathematical equations or inequalities; and bounds on the decision variables or functions of decision variables in order to account for the physical limitations under which the system must operate. When the objective function(s), and all the constraints are put together, we get the mathematical model for optimizing system

performance.

(iii). Solve the model: Use an efficient algorithm to solve the model and find an optimum solution.

(iv). Implement the Optimum solution found.

4 My First Introduction to Operations Research

In the 1950s I was an employee in the SQC & OR Division of the Indian Statistical Institute (ISI) in Kolkatta, and also a graduate student searching for a thesis topic in Statistics. The Director at that time was Dr. C R Rao, he promoted the study of Statistics vigorously.

We used to get many foreign visitors at ISI giving lectures on new developments. One year a young Mathematics Professor from the USA visited and delivered a series of lectures on a new subject "Operations Research (OR)" being developed at that time. In his first lecture he mentioned a problem "Traveling Salesman Problem (TSP)" saying that the problem is very easy to explain, but nobody knows how to solve it yet. I became very fascinated by it, and on the spot decided to work on it, and switched my research area from Statistics to OR.

Subsequently, whenever my relatives asked me what I was doing, I used to tell them that I was studying "Operations Research". They used to say "what is that, we never heard about it". The subject was unknown in India at that time.

This visitor came with his young wife who was a stunning beauty, also very sociable and talkative. She became the center of attraction for all the male students like me at ISI. Whenever she showed up on campus, there used to be a throng of male students around her. She used to come to campus along with her husband and attend all his lectures. But she never seems to have paid any attention to his talks, she would sit in a back bench and immerse herself in knitting. All of us boys in class used to turn our heads back frequently to peek at her beauty.

The hostel in ISI where I lived was in a building adjacent to the main campus

building. One morning as I was getting ready in my room to go to campus, a messenger came and told me that the Director wants to see me right away. In Indian colleges, a thing like this normally occurs only when the student has done some mischief and the Dirctor calls to discipline them. So, I became afraid that may be the American Visitor's wife complained to the Director about my constant staring at her.

With this fear in mind, I approached the Director's office. The door was partly open, and I could see the vistor's wife sitting in a chair talking with the Director whose face was hidden by the door. I knocked expecting the worst, and opened the door widely. To my great relief, the Director greeted me "Murty please come in, we have been waiting for you. I am sure you have met the American visitor's wife. She is planning to go sight seeing in the city today. Can you accompany her and show her all the interesting places in our city like the Kali Maata Temple, Victoria Memorial, etc.?

I agreed and we started right away in the Institute's car. On the way she asked "Mr. Murty, what are you studying?" I replied that I was studying Operations Research, expecting that as the visiting professor's wife she would know what it is.

After spending the whole day sightseeing, we were returning to ISI along Chittaranjan Avenue. On the left there was a huge complex of well lighted buildings, she asked what that is, then we had the following conversation:

"Maam that is the famous Calcutta General Hospital, the largest hospital in Asia at this time with over 1100 beds."

"Murty, you must be spending a lot of time there!"

"Maam, why do you think so? I am quite healthy."

"No, I did not mean that way. I thought you are doing research on Operations!!"

For many years after that, when people first hear of the subject Operations Research, they used to think that it is a branch of surgery in hospitals.

My goal of studying OR faced an obstacle, because in the late 1950s OR was not part of any academic program in India.

At that time, ISI started sending some of their employees in their SQC & OR Division

to USA and UK for periods of 6 months or one year, to get training in using SQC techniques in industrial applications, on some United Nations funded program. But of course senior employees get first preference, and at that time I was not among the most senior employees, so I kept waiting, hoping for an opportunity. Each of the colleagues who has gone to England or USA under this program for advanced training used to bring back foreign goodies not available in India at that time, when they return. This made me all the more anxious for my turn, and whenever someone else was selected for this training I used to feel disappointed.

But then I would remember the proverb "Each coin has two sides". Let me illustrate this proverb with an incident which occured much later in my life. Then I spent several years as a Visiting Professor in Saudi Arabia. As you know, in Saudi Arabia, females are not allowed to drive. Once I met a faculty colleague's wife. I asked her how she feels about not being permitted to drive. She replied "Prof. Murty, don't you realize that I am the boss, and my husband is my driver"!

Remembering this proverb, I used to console myself with the thought that if I were selected under this program, they would send me for training in SQC, and not in OR in which I am interested.

Fortunately for me, in 1960 USA established the USEFI (US Educational Foundation in India) who started giving travel grants for one year study at an American University to selected Indian students. With the encouragement of my Department Head Mr. S. C. Sen, I got this travel grant, and with ISI providing money for living expenses, I left in 1961 for an year's study of OR at the Case Institute of Technology in Cleveland, Ohio.

There in the first term itself I got exposed to linear programming (LP), Hungarian method for the assignment problem (which is a relaxation of the TSP I was studying), nonlinear programming (NLP), and other OR subjects.

I needed a computer code for the Hungarian method for my research on the TSP, and a classmate, Caroline Karel, wrote the code quickly and gave it to me to use. With that I developed an algorithm for ranking the assignments in increasing order of cost,

and quickly modified it into the Branch and Bound (B&B) method for TSP, and tested it. We showed the results to an Assistant Professor at Case Institute at that time, who told me to write it as a technical report, and I had my first paper in OR (you can see this on my webpage). He was moving to MIT shortly, and he told me that he will get this algorithm tested there on large scale problems, and then submit it for publication.

At the Case Institute I learnt about the reputation of George Dantzig, then teaching at the University of California, Berkeley (UCB). Enclosing my technical report, I wrote to George Dantzig expressing my desire to persue my graduate studies for a Ph. D. at UCB. He offered me an RA position, and in Fall 1965 I joined the graduate program at UCB.

I will now relate another incident that occurred while I was at Berkeley, which illustrates how grateful I am for the education that I received during my childhood in India, from the elementary school in the village Pandillapalli in Seemandhra State where I was born, and at Hindu College High School in Machilipattnam. In the curriculum at these schools they had programs teaching " neeti SAstram (Principles for morality and life)". I remember two principles that the teachers drilled into their student's minds. They are "ArOgyamE mahABAgyaM ("Good health" is the greatest asset that a human can possess)" and '' nI anuBavAlanuMci nErcukO (Learn from your experiences)". One morning when I arrived on campus, I met George Dantzig in the corridor. He had a strange metal contraption at his back holding up his neck and head. I had never seen such a thing before, so asked him what it is. He replied "my neck is weak, so my doctor set this up to support it".

Then, remembering the principles I learnt in my childhood, I realized that the same thing may happen to me later on in my life. So, to minimize the chance of this happening to me, then itself I started doing neck exercises every morning.

When I met my advisor at Berkeley, David Gale, for the first time, he asked me "Mr. Murty, what do you want to work on?". I told him "Prof. Gale, I want to work on optimization". Thinking about this today, I am so happy that I replied in this

way at that time, as optimization has opened many opportunities for me. I also want to encourage young scholars planning their carrers to seriously consider optimization (Optimum Decision Making).

After getting my Ph.D., in Fall 1968 I joined the IOE faculty at UM as an Assistant Professor. Since then I had the opportunity to work on applications of optimum decision making in many different areas of application (container terminals in ports, airports, variety of manufacturing and service industries, warehouses, army , etc.). Please see my webpage for reports on some of these challenging applications. Also, the recent Springer textbbok on *Case studies in OR: Applications of Optimum Decision Making* (see http://link.springer.com/book/10.1007

Developing a DSS (Decision Support System) for daily operations inside a container terminal: Work carried out at HIT (Hong Kong International Terminals), a Container Terminal in Hong Kong Port. The service quality of a container terminal is measured by the "Vessel Turnaround Time" (the average time the terminal takes to process a docked vessel (i.e., unloading all the ICs (import containers) from the vessel, and loading all the ECs (export containers) into the vessel), which is directly influenced by the GCR (Gross Crane Rate; the number of ICs unloaded from, and ECs loaded into the docked vessel per hour of QC (Quay (or Shore) Crane time), which itself is influenced by the congestion that ITs (Internal Trucks that carry containers between the shore and the SY (storage yard)) encounter in their movements between the shore and the SY. When we started the work, they had the policy of allocating a separate set of ITs to attend to each QC working on the shore. We showed that all quality metrics can be improved by following a "pooling policy" that maintains all ITs in a single pool and dispatching them to the QCs as needed; and using a DSS developed for allocating storage spaces in the SY to arriving containers. These policies were subsequently implemented by all major Container terminals in the world.

Developing a DSS for allocating gates to flights at an International Airport: This work carried out at TPE (Taiwan Taoyuan International Airport) discusses

the mathematical models and algorithms to use for making gate allocations to arriving and departing flights, and a DSS developed to implement them in daily operations.

Developing a DSS for bus allocation and routing decisions at a bus rental company: Carried out at the largest bus rental company is Seoul, South Korea that rents buses with drivers provided, to visiting customer groups that request them.

Allocating Operating Room times to various departments in the surgery section, and sequencing the surgeries to be performed by a surgeon over the time of a day: This work was carried out at the University of Michigan Hospital in Ann Arbor.

Allocating patients to PCPs (Primary Care Physicians), and appointment scheduling for calling patients with their PCPs: This work was carried out at a VA Hospital in Michigan. The objectives are to equalize the workload of all PCP doctors in the hospital, and to minimize the patient waiting times.

Developing a DSS for designing trains to move all the blocks of freight rail cars from their origin yards to their destination yards: This is a very important and difficult combinatorial optimization problem encountered daily in the freight railroad industry.

US Army National Guard's Mobile Training Simulators location and routing problem: This work carried out for the US Army Training and Doctrine Analysis Command at the White Sands Missile Range. The goal was to find the optimum locations for home bases for the mobile trainers, locations for Secondary Training Sites where moblie trainers provide traing, and finally to allocate each national guard to a training site to minimize the travel distance of all the units.

Application in LTL (Less than Truck Load) carrier industry: The problem was to determine the best allocation of doors at a consolidation facility to outbound and inbound trailers.

5 The story of the Banyan tree

I was born in a small village called "Pandillapalli" after the Village Goddess named "Pandillamma", in the State "Seemandhra" in India. The village used to have many massive Banyan trees, with large aerial root systems. During my childhood in the 1940s I and my childhood friends used to play under the shade of these trees, and enjoy watching the birds living on these trees, eating the many banyan fruit that the trees used to yield.

After I joined the IOE Department in the University of Michigan, Ann Arbor (UM) as a faculty member in 1968, we bought a house on Alton Court in Ann Arbor. My neighbor there was a faculty member in the Botany Department at UM, and the Director of the UM Botanical Gardens and the beautiful green house containing many tropical plants there.

I am a lover of nature and trees, and had many discussions with my neighbor on the tree species I could grow on my lot. One year I brought some banyan tree seeds from my village Pandillapalli, and planted them in a pot. One seed germinated, and I was growing that banyan seedling as a house plant.

It started growing nicely, but by that time I had been travelling quite a bit to several foreign universities, and it was becoming difficult to find friends who would take care of it when we are away from Ann Arbor. One Summer day my neighbor saw that plant and asked me what it was. I explained to him that it is a banyan tree that I am growing from seed brought from my village in India. Then he asked me whether I

could donate it to the UM Botanical garden so that he could plant it in the green house. I agreed and gave the plant to him.

He transplanted that banyan tree seedling in the green house. It has been growing well there, and now it has grown into a medium sized banyan tree with several aerial roots , and has become the center of attraction inside the green house. If you have plans to visit Ann Arbor, make sure to visit the green house in the UM Botanical garden and see this banyan tree.