Practical Managerial Decision Making Tools: Operations Research

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The purpose of this paper is to advocate the managerial practice of making decisions based not only on intuition, but intuition coupled with quantitative analysis. Operations Research (OR) or Optimization is one of the leading managerial decision science tools used by profit and nonprofit organizations such as Ford Motors, AT&T, Merrill Lynch, Samsung, US Army Recruitment and Olympic games organizing committees. Such technique is utilized by functional groups such as Industrial Engineering in effort to support Operations Managers to make economically feasible decisions on a range of systematic challenges. In order to make the effective yet efficient decisions, managers must have fundamental understanding of the decision science tools utilized in developing set of recommendations to choose from. With this motivation, this paper includes brief discussion on background of OR, its methodology and publicly reported benefits of implementing OR and challenges in OR. Since the purpose of this literature is to disseminate information to advocate the importance of scientific approaches in the process of managerial decision-making, research and academic disclosures are intentionally omitted.

INTRODUCTION

The main responsibilities of operations management are to manage and operate as efficiently and effectively as possible with the given resources. With today's global market, and large-scale systems, achieving the optimum performance is a challenge. Many decision science tools are available for all levels of decision makers. Quantitative methods such as Operations Research (OR), which comprises of simulation, linear and nonlinear programming, queueing theory and stochastic modeling, are well-accepted techniques by both research and practice communities. Large profit organization such as Ford Motors (Chelst, Sidelko, Przebienda, Lockledge, & Mihailidis, 2001), Merrill Lynch (Atschuler et al., 2000), AT&T (Ambs et al., 2000) and

Samsung (Leachman, Kang, & Lin, 2002) reported millions dollars of savings with OR. OR has a strong presence in nonprofit organizations as well. US Army Recruiting Office (Knowles, Parlier, Hoscheit, & Ayer, 2002) and Warner Robins Air Logistics Center (Srinivasan 2006) won the world's most prestigious award, 2006 Franz Eldelman Award for outstanding achievements of OR.

Functional entities such as Industrial or Systems Engineering uses both methodologies to provide feasible alternatives for operations mangers to decide on. An important component of decision-making process is verifying and validating alternatives, which typically involve decision makers and engineers or analysts. Thus, high-level understanding of the tools or methodologies used for recommendations is essential in making the effective decision for achieving the organization's common goal of maximizing profit. In the following sections a brief background on Operations Research is discussed along with selected OR techniques including Linear Programming, Discrete Event Simulation and Queueing Theory, and a typical problem solving procedures for OR. Also, Success cases of OR from both practical and research perspectives are discussed. The paper is concluded with a brief summary of the materials discussed. The primary motivation and purpose of this literature is to disseminate knowledge; hence, neither academic nor research disclosures are conversed.

OVERVIEW OF OPERATIONS RESEARCH

During World War II, a set of diversified scientists from England and the United States developed scientific methods of planning military logistics such as most economical method of disseminating resources to various war sites. The scientists developed a famous quantitative method for such operations and named it Operations Research (OR) or often referred as managerial or decision science (Hillier, 2005; Turner, Mize, Case, & Nazemetz, 1993). With its proven successes, OR spread to private sectors promptly. With rapid improvements in computer technology, to this date, OR is one of the most powerful decision making tools in the Operations Management and Industrial Engineering disciplines. Murty defines Operations Research as a discipline that deals with techniques for system optimization (1993). OR's primary objective is to find optimal or near optimal solution to complex business to engineering problems.

Operations Research techniques are used to answer the common managerial questions such as:

- How many and much resources are required to meet the key performance target?
- Which alternatives require minimum cost and generate maximum profit?
- What is the optimal resource schedule to minimize overhead cost?
- What is the maximum and minimal resource utilization level?
- Where are primary and secondary constraints or bottlenecks?
- What range of queue and process time is allowed to achieve goal?
- What is the current capacity and required capacity to meet the goal?
- What are the anticipated risks for accepting or making new product or model?

OR evaluates the system of interest globally. It considers all factors or all factors identified the decision makers. For example, to maximize or optimize production performance, characteristics of each or management identified areas such as rate of production per work station, rate of material usage per product or program, average time spent in transition and available capacity in terms of space are considered in the OR models. Viewing such system with the philosophy of local efficiency, the management will be only interested in maximizing production performance at a workstation, not entire work stations. Numerous OR techniques are available to use; however, the scope of this paper is limited to the following commonly used techniques: Linear (LP), Discrete Event Simulation (DES) and Queueing Theory (QT). Combination of such techniques in optimization studies, especially in practice. Discussions of LP, DES and QT techniques are in the following sections.

Linear Programming

Linear programming techniques are considered as mathematics based decision-making tool. Such technique requires two fundamental types of functions, objective and constraints, that is developed to generate closed-form solution. In a typical OR problem, the objective function, often expressed as *Z,* is formulated to determine the maximum profit while minimizing cost with given set of rules or constraints such as business policies, resource availability, preventative maintenance schedule, transportation distance or time and capacity.

Consider a bank that is expecting an increase of customers due to the new investment programs, which recently were introduced to the customers. Thus, the operations management team has a task to determine the number of resources, tellers specifically, to obtain to sustain the current customer satisfactory level for its 24-hours operations with minimal cost. The following set of data was requested by and provided to a cross-functional team responsible for the analysis. This is a modified version of Hiller's (2005) the Union Airways Personnel Scheduling Problem.

Table 1.0 Personnel Scheduling Data
(Based on 5 days per week, 8 hours per day)

TIME PERIOD	SHIFTS 1	2	3	4	5	MINIMUM NUMBER OF TELLERS NEEDED
8:00 A.M. - 12:00 P.M.	x					64
12:00 P.M. - 4:00 P.M.	x	x				111
4:00 P.M. - 8:00 P.M.		x	x			180
8:00 P.M. - 12:00 A.M.			x	x		78
12:00 A.M. - 4:00 A.M.				x	x	19
4:00 A.M. - 8:00 A.M.					x	25
DAILY COST PER TELLER	$160	$176	$192	$208	$224	

Based on the problem description given by the management, the goal of this study is to minimize total daily personnel cost. Following is the mathematical expression of this problem statement with a brief description of each function.

Minimize $Z = 160 X_1 + 176 X_2 + 192 X_3 + 208 X_4 + 224 X_5$ (Sum of daily cost)

Subject to

$X_1 \geq 64$ (8:00 A.M. – 12:00 P.M.)

$X_1 + X_2 \geq 111$ (12:00 P.M. – 4:00 P.M.)

$X_2 + X_3 \geq 180$ (4:00 P.M. – 8:00 P.M.)

$X_3 + X_4 \geq 78$ (8:00 P.M. – 12:00 A.M.)

$X_4 + X_5 \geq 19$ (12:00 A.M. – 4:00 A.M.)

$X_5 \geq 25$ (4:00 A.M. – 8:00 A.M.)

and

$$X_i \geq 0, \qquad for\ i = 1, 2, 3, 4, 5$$

where

X_i = *number of tellers assigned to shift i*

Using the OR software program called, LINDO® for computation, the following set of optimal solution is found: Z = 48768, (X_1, X_2, X_3, X_4, X_5) = (64, 102, 78, 0, 25). The minimum operating cost to sustain the customer satisfactory level is $48,768 which includes the requirement of recruiting 64, 102, 78, 0 and 25 tellers for 1st, 2nd, 3rd, 4th and 5th shift, respectively. Note that the 4th shift requires no additional tellers since the time slot of 8 P.M to 12:00 A.M. and 12 A.M. to 4 A.M. for 3rd and 5th shift, respectively, cover the time slot of 4th shift, 8:00 P.M. to 4:00 A.M.

As mentioned above, application of LP is abundant. LP models reality with determined, expected or most-likely values. In contrast, Stochastic Programming (SP) uses law of probability to model the randomness of reality. Though Stochastic Programming may represent the reality more closely, but the solution generated may or may not be more accurate than LP generated solution (Murty, 1995). Accuracy of solutions depends on the accurate representation of the accurately collected past data. LP solution may be more accurate, if the data is approximated more realistically than SP, vice versa. SP models are more complicated and time consuming than LP models since SP tries to model all possible or variable events. LP models are less time consuming than SP due to its deterministic nature. LP, however, allows decision makers to perform sensitivity analysis by creating multiple variable scenarios to see the more accurate insights of the system. Choice of modeling techniques depends on the complexity of the problem and economic constraints. As a decision maker, knowing the difference of the modeling techniques allows confidence in making the economically feasible and effective decisions.

Simulation

A simple definition of simulation is an imitation or mimic of a system. There are two main types of simulation modeling techniques; Discrete Event and Continuous. Discrete event simulation (DES) is an event driven simulation. In other words, DES models chorological sequence of independent events. Referring to the bank example, arrival of a call, agent answering the call, system dropping a call or customer abandoning a call is discrete events. In opposition, continuous simulation models continual events where events change continuously not in increment. Examples for continuous systems include chemical or fluid flows, stock market prices, conveyors to move parts, etc.

Simulation is an excellent communication tool. Unlike the Linear Programming or Stochastic Programming, simulation graphically represents a system along with visible display of relative numerical results. In a typical facility layout studies, decision makers will be provided with a set of graphical representation of potential layouts for the facility with people or parts moving through the system. A typical simulation of paperwork process will have process maps or flow charts as simulation layout and graphically show the different paperwork moving through the system.

As in LP and SP, DES uses estimated data; however, it does not find optimal solutions. Instead of finding the most achievable production rate with a given resources, DES finds expected or average production rate. When setting a goal for a system, LP or Stochastic Programming is ideal; however, simulation is more suitable for measuring on-going production performance. Almost all simulation software packages have accompanying optimization software; SimRunner® for ProModel and OptQuest® for Arena®. Certain decision science skills are required for simulation modeling. Computer programming skill is required to build a simulation model using a software package. To optimize the model, basic optimization techniques are required to interpret results. As simulation modeling requires some level of computer programming skills, simulation optimization packages such as SimRunner® and OptQuest® also require optimization techniques. Awareness and basic knowledge of such optimization techniques along with simulation can play a positive role in making more realistic and economically feasible solutions.

Queueing Theory

Waiting is a simple definition of queue. Bank has a queue of customers for service, parts are in queue to be processed, grocery shoppers are in queue to pay, etc. Queueing or Queuing Theory (QT) is a mathematical or statistical study of waiting lines. A typical queueing system has three relative processes defined as arriving, waiting and servicing. With a set of common assumptions such as empty and full system, QT measures and reports performance of the system with the indicators such as average time a customer is expected to wait, probability of a customer waits more than certain hours or minutes in the queue, number of customers receiving services, etc.

QT uses Kendall's notations, A/B/C, where A, B, C represent arrival process, service process and number of servers, respectively. A and B can have Markov (M), Deterministic (D) or G (General). For example, M/M/1, which is the simplest queueing system, is interpreted as a system with arrival and service pattern of exponential or Markovian probability with one server. QT analyzes a system with Little's Theorem, $N = \lambda T$, where N = average number of customers in the system, λ = average arrival rate of customers and T = average service time. Based on Little's Theorem, different queueing systems have different mathematical formulas for calculation. Like Linear Programming, Stochastic Programming and Discrete Event Simulation, Queueing Theory also has a challenge of modeling reality accurately, which is common difficulty for mathematically restrictive approaches.

OPERATIONS RESEARCH METHODOLOGY

Depending on the complication of problem, the common business questions can be answered using qualitative tools such as fishbone diagrams, value stream maps and more. However, complex problems such as large-scale system's optimization problems, quantitative techniques combined with qualitative approaches are recommended and is common practice. A general procedure for solving Operations Research problems is as follows:

Step 1 Define the problem
Operations manager along with cross-functional team must define the problem. The problem definition should include symptoms and the systems objective.

Step 2 Identify the decision variables and collect relevant data
Decision variables are parameters that can be controlled and affects performance and is often identified the management. In the bank example, a number of tellers per shift is a decision variable. Depending on the size of the problem and in reality, multiple decision variables involved in optimization studies.

Step 3 Formulate a mathematical model of the system operations and goal or objective

Functional group such as Operations Analyst, Industrial and/or Systems Engineering are responsible for formulating the model. The mathematical model should read: maximize profit or minimize cost subject to set of parameters. In our bank example, the mathematical model is built to minimize cost based on the number of tellers assigned per shift.

Step 4 Solve the model for an optimum solution and alternatives

Though manual computation of optimization problems is possible, however, such a method is not efficient and unrealistic especially for the real-world problems that have multiple objectives and decision variables. In large problems, the computation can take more than 24hours easily. Thus, Software programs such as LINDO® API, LINGO®, ILOG and Microsoft Office Excel Solver, are used to solve real world problems which often is large and complex.

Step 5 Perform sensitivity analyses

In this step, active participation from operations managers is required. Management presents series of "what-if" questions and series of sensitivity analyses are performed using the model by the modelers. In the bank example above, management can inquire about the level of impact on cost if more or less tellers are assigned per shift.

Step 6 Update the model based on the management's prescription and decisions

After reviewing the results of various "what-if" scenarios, management needs to make a decision(s) then the optimization model is updated accordingly.

Step 7 Implement

This is one of the most important steps where the decisions determined by the model are implemented. Hence, active participation from the management is crucial in achieving the goal.

OPTIMIZATION IN PRACTICE

OR has strong presence in industries such as financial planning, health care, telecommunication, military, manufacturing and public services (Hillier, 2005). Ford Motors used OR for new design verification and reported annual saving of $250 million. The world's largest manufacturer of digital integrated circuits, Samsung reduced production cycle time from more than 80 days to less than 30 days capturing additional $1 billion in sales revenue (Leachman et al., 2002). Merrill Lynch, brokerage and lending service provider, the Management Science Group developed optimization models to seize marketplace and reported savings of $80 million (Altschuler et al., 2002). In 2001, Continental Airlines reported savings of $40 million for major disruptions and leading five airlines in recovering operations after September 11 terrorist attack (Yu, Arguello, Song, & McCowan, 2003).

Nonprofit organizations such as The US Army reported savings of $204 million from a $1 billion recruiting program (Knowles et al., 2002). Warner Robins Air Logistics Center received the 2006 Franz Eldelman Award for its outstanding OR practice adding the center's annual revenue of $49.8 million (Srinivasan 2006). In addition to these companies, organizations including, but not limited to: GM, Athens 2004 Olympic games Organizing Committee, IBM, Motorola, Phillips, Waste Management, UPS, Texas Children's Hospital, GE, Hewitt Packard, National Car Rental Systems, Harris Corporation and Proctor and Gamble have publicly disclosed significant achievements using OR techniques.

CHALLENGES IN OPERATIONS RESEARCH

Due to vast quantities of data and calculation, solving optimization problems is challenging and time consuming. Thus, such approach towards performance improvement may or may not be economically feasible for some organizations. Numerous studies are conducted on development of more effective and efficient heuristic and exact algorithms that can solve large scale optimization problems (Scholl & Becker, 2006; Levin & Aldi, 2004; Bhat, 1998).

OR is quantitative problem solving technique; hence, data plays important, if not the most important, role in producing high quality and executable solutions. With an organization that has data readily available using information system such as MRP, MES and ERP should be able to use the required data with certain level of integrity. However, for a system that is highly manual, data driven decision science techniques presented her may or may not be the appropriate approach. With companies moving towards managing business with some form of company-wide information system, Linear Programming, Discrete Event Simulation and Queueing Theory will be most suitable and appropriate decision tools.

Integrity of data depends on many factors. Information system that requires manual input of data, unstable network systems, unstable programs and defective hardware are some of the factors. The most important factor that determines high data integrity is human error when inputting data. Human errors can be minimized through education combined with hands-on training such as on-the-job training. Unfortunately, many organizations tend to focus heavily on physical system implementation and give little or no attention on education and training. Regardless, employees are often reprimanded for not entering the data correctly and the quality of hardware and/or software is questioned for poor data integrity. Sustainment is as important implementation. An organization can implement the world's greatest database, but if the personnel responsible for operating and sustaining the system lacks knowledge of performing his or her job, attaining and implementing the world's greatest system is meaningless.

CONCLUSION

Another name for managers is decision makers. To survive and lead the today's highly competitive and demand driven market, pressure is on management to make economical decisions. One of the essential managerial skills is ability to allocate and utilize resources appropriately in the efforts of achieving the optimal performance efficiently. In some cases such as small-scale low complexity environment, decision based on intuition with minimal quantitative basis may be reasonably acceptable and practical in achieving the goal of the organization. However, for a large-scale system, both quantitative and qualitative (i.e. intuition, experience, common sense) analyses are required to make the most economical decisions. Using Operations Research techniques including Linear Programming, Discrete Event Simulation and Queueing Theory, organization leaders can make high quality decisions. Operations managers are not expected to be experts in any decision science tools; however, he or she must have fundamental knowledge of such tools to acquire right resources and to make the most economically sounding decisions for the company as a whole.

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