Towards an Operations Research Sustainable Healthcare: An Overview of Recent Applications of OR in Healthcare

Isaac Atuahene¹, Philip Appiah Kubi², Rolando Acosta-Amando³, Ivonne Lacera-Cortes⁴, Rupy Sawhney⁵, Emmanuel Atuahene⁶, and Girish Upreti⁷,
University of Tennessee
Dept. of Industrial and Systems Engineering
Knoxville, TN, 37996, USA¹,⁵,⁷
Dept. of Industrial Engineering
Ohio University, Athens, OH 43230, USA²
Grupo de Investigación MyOS, Facultad de Ingeniería Industrial,
Universidad Pontificia Bolivariana Seccional Bucaramanga
Autopista Piedecuesta Km 7, Floridablanca, Santander, Colombia³,⁴
Council for Scientific and Industrial Research (CSIR-CRI),
Kwame Nkrumah University of Science and Technology, Ghana⁶

Abstract

Healthcare systems and care settings involve many complex and compounding problems that could benefit from operations research-type (OR) analysis, solutions and applications. Healthcare operations design, planning and control comes with a host of decision choices. These choices have subsequent effect on cost, efficiency, quality and patient satisfaction among others. Effective service requires efficient, reliable and sustainable delivery processes which can be attained by OR applications. OR attempts to achieve optimality and forecasts the consequences of decision choices. This study presents a review of recent development of OR applications in health care to enhance specifically quality, efficiency, safety and cost minimization. The study discusses research on different quality measures, healthcare management strategies, resource allocation, emergency medical services (EMS), facility location, disease treatment and scheduling. The study also discusses OR as it relates to the qualitative judgmental decision-making that is used in health systems. Also common techniques and approaches in optimization and operations research used for combating the variety of healthcare problems related to the defined subjects are discussed. Research into operational aspects of healthcare, patient flow, capacity planning and facility location are covered. Finally, suggestions and recommendations are provided on some important areas that warrant further research.

Keywords
Optimization, optimal, mathematical programming, decision-making, scheduling.

1. Introduction

The urgency to improve healthcare systems has been a priority for many years. Various researchers have made significant progress through scientific methods as well as OR applications to improve healthcare. Before OR applications were adopted to be applied to healthcare, researchers had used crude techniques and the various technology inventions to improve healthcare as well as solve its many problems. Technology advancement have been successful to a point over the years, nevertheless, a combination of optimization and mathematical modeling with these technologies have proved to help contribute to a reliable and efficient system. OR employs a predictive modeling investigative paradigm, mathematical equations, computer logics and related tools to forecast the
consequences of particular decision choices without actually implementing them which systematically search for the best or optimal choices [1–4]. Particularly, OR applications in healthcare can lead to reduced operational friction, optimized efficiency, optimal resource allocation, improved operational efficiency, improved revenue realization, reduction in operational expenses as well as quality and safety of patients. Study on OR application in healthcare can be traced back to the 70’s. Fries (1976), presented a study on the bibliography of OR in healthcare systems that were published before March 1976 [1]. The literature Fries reviewed, described specifically applications of OR techniques to health-care delivery systems. The study we present covers OR applications in healthcare that are related specifically to emergency response, scheduling, disease treatment, cost minimization, and health care facility location. The study does not discuss OR applications in every area of healthcare as this is a broad subject, but focus on the selected areas noted above. This study is intended to promote and assure sustainability in healthcare settings with OR applications. Moreover, we makes significant endeavor in promoting an effective healthcare system and highlight safe and quality strategies that suffice the needs of patients and the government. This study is deemed useful for future researchers and medical technology application developers for effective and efficient medical systems. Finally, this study serve as an academic tool in informing its reader about the different OR applications in healthcare systems.

In the sections that follows, we group OR applications into three categories; Disease Management (DM), System operational management (SOM), and Resource Allocation (RA). For the purpose of this study, we define the 3 categories as follows: Disease management involves diagnosis and treatment of diseases as well as development of disease treatment and prevention strategies. System operational management involves management of the different departments in healthcare, management of emergency department and medical services as well as ambulance services, and location of health care facilities. Finally, resource allocation involves scheduling the various activities in healthcare systems, allocation of funds and other resources to minimize cost. Literatures used in this study are careful selected on the basis of real applicable OR techniques that have been experimented in real life, that have produced evidence and that have yielded positive results. The paper begins with a brief overview of OR and review of previous works done on OR applications in healthcare. This is followed by a brief overview of some OR applications tools and techniques used in healthcare, a review on the categories of OR applications and finally conclusions and recommendations for future research.

2. Overview of Operations Research

Optimization has been applied to many instances unknowingly but the roots for modern day optimization can be traced to the Second World War [2]. The OR society of Great Britain defines OR as the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government, and defense [3]. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls - The purpose is to help management determine its policy and actions scientifically [3]. Winston (2004) defines OR as a scientific approach to decision making, which seeks to determine how best to design and operate a system, usually under conditions requiring the allocation of scarce resources [4]. In Hillier and Lieberman, OR is defined as concerned with optimal decision making in, and modeling of, deterministic and probabilistic systems that originate from real life. These applications, which occur in government, business, engineering, economics, and the natural and social sciences, are largely characterized by the need to allocate limited resources [5]. Gould et al (2001) reiterates: The word “optimal” is strictly a mathematical notion. An “optimal (or best) decision” produced by a model should be interpreted, at best, as being a “good decision” for the real problem; the term optimality is theoretical (i.e., mathematical), as opposed to a real-world, concept [6].

Prior literature have developed a variety of approaches using OR applications to solve different healthcare problems. The national science foundation’s report presented by WTEC (2005) highlights review of various OR applications in healthcare delivery systems in Europe [7]. Teow (2009) presented a study on raising the awareness of healthcare managers with regards to practical OR applications [8]. OR applications in healthcare have now advanced and articles on these applications are scattered all over in different journals, publications and online databases. We present a selected list of some recent studies on review of OR applications in healthcare in table 1. This does not include every OR review article but the most relevant to our aim and the specific area under consideration.

<table>
<thead>
<tr>
<th>Year</th>
<th>Reference</th>
<th>Year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>Papageorgiou [58]</td>
<td>2007</td>
<td>Proudlove1 et al. [61]</td>
</tr>
</tbody>
</table>
3. Brief Overview of Selected OR tools and techniques applied in healthcare

An overview of OR tools and techniques used in solving healthcare problems is presented in this section with emphasis on primarily those used in the selected papers reviewed. These comprise mathematical modeling and simulation, stochastic model applications, genetic programming and algorithms, queuing theory, fuzzy multi-objective covering, linear programming and fuzzy goal programming, branch-and-price approach, heuristics, analytic hierarchy process (AHP), dynamic programming, artificial neural network, linear programming, constraint programming, tabu search metaheuristics, mixed-integer programming, binary integer programming, and mathematical programming. Not every tool or technique is discussed but the ones that have been mostly used are briefly discussed. Brief references are given for each OR tool and technique (table 2). It is noteworthy that these are not the only references. There are many literature about the subject, but the ones given in this study are aimed at the focus of the study and to give readers a clear knowledge in the field.

Table 2: Selected OR Tools and Techniques used for solving healthcare problems.

<table>
<thead>
<tr>
<th>Tools and Techniques</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical modeling and simulation</td>
<td>[36],[54],[35],[67],[73],[69],[70],[85],[89]</td>
</tr>
<tr>
<td>Stochastic model applications.</td>
<td>[97],[15],[71],[68],[94]</td>
</tr>
<tr>
<td>Genetic programming and algorithm</td>
<td>[39],[34],[78],[79],[80]</td>
</tr>
<tr>
<td>Queuing theory</td>
<td>[42],[50],[51],[32],[95]</td>
</tr>
<tr>
<td>Fuzzy multi-objective covering, linear and fuzzy goal programming</td>
<td>[44]</td>
</tr>
<tr>
<td>Branch-and-price approach</td>
<td>[96]</td>
</tr>
<tr>
<td>Analytic hierarchy process (AHP),</td>
<td>[40],[30]</td>
</tr>
<tr>
<td>Dynamic programming and simulation</td>
<td>[11],[52]</td>
</tr>
<tr>
<td>Artificial neural network</td>
<td>[43]</td>
</tr>
<tr>
<td>Linear programming, constraint programming, and (meta-)heuristics</td>
<td>[46]</td>
</tr>
<tr>
<td>Tabu search metaheuristics, (Meta-) Heuristics</td>
<td>[33],[48],[75],[72]</td>
</tr>
<tr>
<td>Mixed-integer, constraint and Binary integer programming</td>
<td>[47],[98],[45],[29],[76],[77]</td>
</tr>
<tr>
<td>Mathematical and Multi objective programming, and spreadsheet</td>
<td>[27],[31],[28]</td>
</tr>
</tbody>
</table>

3.1 OR Tools and Techniques

3.1.1 Dynamic programming

Dynamic programming was developed by Richard Bellman in the 50’s to solve inventory management problems [9-10]. The technique developed has been successfully applied to production scheduling, capital budgeting, allocation of funds for R&D, and many other situations where problems can be decomposed into discrete stages and now successfully applicable in all areas in healthcare. Haijema et al. (2007) combines Markov dynamic programming (MDP) and simulation approach and applies it to a real life case of a Dutch blood bank; - By down-sizing the dimension and applying this combined approach, the study showed that order-up-to-type replenishment rules that perform quite well can be found [11]. Dynamic programming is an approach that permits decomposing large complex models into smaller simpler problems and when all smaller problems are solved, put back together, and optimal solution to the larger problem is obtained [4]. This can be applied to effectively optimize and solve various problems almost in every area of healthcare. Examples of dynamic programming applications are listed in table 2, and more information about dynamic programming can be found in references [12-14].

3.1.2 Stochastic Processes

Stochastic processes deals with quantitative description of a natural phenomenon. The word stochastic is derived from Greek and means random or chance; a stochastic model predicts sets of possible outcomes weighted by likelihoods or probabilities [15]. A stochastic process is one whose random variable evolves over time. The input data is uncertain and subject to variability as compared to deterministic processes with inputs being certain. Daiki et al. (2009) formulated a stochastic dynamic programming model to address a scheduling problem where patients with
different priorities are scheduled for elective surgery in a surgical facility, which has a limited capacity. When the capacity is available, patients with a higher priority are selected from the waiting list and put on the schedule [15]. Other papers presenting applications of stochastic processes are listed in table 2. More information about stochastic processes can be found in reference [16] and in the journal of stochastic processes and their applications [17].

3.1.3 Genetic algorithm (GA)
Genetic algorithm is a search heuristic that mimics the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms, which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover[18]. Examples of its application in healthcare are presented in table 2. More information about genetic algorithms can be found in references [19, 20].

3.1.4 Simulation
Simulation are computer applications which are used to attempt to model a real-life or hypothetical situation so that it can be studied to know how the system works, and set up different improvement scenarios in order to recommend the best scenario [21]. It helps to compare various options and applications and to come up with the best of two worlds. The ability to analyze planning and operational strategies, compare the various options and procedures, and determine the most cost-effective combination of optimal strategies with the aid of a simulation tool is a beneficial application to the success in healthcare settings. The application could improve patient admission process, optimal resource allocation as well as scheduling problems. Table 2 shows examples of literature with simulation applications in healthcare. More information about simulation tools can be found references [22, 23].

3.1.5 The Analytic Hierarchy Process (AHP)
The AHP was developed by Thomas L. Saaty and is a powerful tool that can be used to make decisions in situations involving multiple objectives. AHP has been applied by decision makers in countless areas, including Engineering, accounting, finance, marketing, energy resource planning, microcomputer selection, sociology, architecture, political science and now in healthcare [24]. In the real world, few decisions are based strictly on single criteria; i.e. profit, cost, time, etc. They are rather based on multiple criteria that arise from complex decision problems and multiple objectives. The AHP method requires the decision maker to provide judgments about the relative importance of each objective/criterion/alternative and then specify a preference on each objective/criterion/attribute for each decision alternative. The output is a prioritized ranking indicating the overall preference for each decision alternative [24]. Examples of AHP applications in are shown in table 2 and more information about the AHP can be found in references [25, 26].

4. Categories of OR Application in Healthcare; Disease Management, System operational management, and Resource Allocation.
OR uses various optimization and mathematical modeling tools to obtain an optimum decision to a variety of problems. Some of the OR application tools and techniques includes simulation, stochastic programming, genetic programming, queuing theory, linear programming, non-linear programming, goal programming, branch and price approach, heuristics, analytical hierarchy process, dynamic programming, artificial neural network, constraint programming and tabu search meta heuristics amongst others. Table 2 shows a list of different OR tools applied in different areas of healthcare and their corresponding references. Application of OR in healthcare provides solutions to questions such as; how will smooth information flow among service providers in healthcare settings? How much capacity at various facilities is needed to provide the required services and how should it be adjusted from day-to-day with variation in demand? How much delay will patients experience in the process of getting service? What mechanisms will be established to assure compliance, quality and patient safety? What will be the cost with different options? How can resources be effectively allocated in healthcare to minimize cost? Etc. We have categorized OR applications to healthcare into 3 groups for the purpose of this study; (1) Disease Management; applications related to disease treatment and control. (2) System Operational Management; applications related to emergency response and healthcare facility location and (3) Resource allocation; allocations related to scheduling and cost minimization. The various categories are discussed in the next section.

4.1 Disease Management
4.1.1 Disease treatment and control
Research on the use of OR applications to disease treatment and control can be traced back to the 80’s. A study by Barnett (1983) presented a program selection/resource allocation model for control of malaria and related parasitic diseases using mathematical programming [27]. Margarida and Margarida (2005), presented a study that used a sequence of procedures, “Cohort Cascade”, built up from estimated progression rates for time-to-AIDS of an HIV-infected cohort to transform the published official U.S. AIDS onset data into an estimated dataset for years 1976-1985/1986 to 1995 [28]. OR application to disease treatment has improved over the years and is still being applied in different forms and fields in healthcare. These applications have recently been efficient and has successfully lead to the treatment of various diseases including cancer, tumors, treatment of breast, cervix, esophagus, biliary tract, pancreas, head and neck, eye, etc. OR has enormously advanced procedures performed in the operating room as well as disease treatment strategies and this has had profound impact on both health-care costs and quality of life of patients. OR tools and techniques developed have been used to perform disease-propagation analysis, to understand, monitor and treat various internal diseases, and aid in deriving dynamic response strategies to mitigate different ailments [27-29]. In Lee and Zaider’s (2008) study, OR approaches were used to devise sophisticated optimization modeling and computational techniques for real-time (intra-operative) treatment of prostate cancer using brachytherapy which resulted in savings of hundreds of millions of dollars per year in the United States [29]. Liberatore and Myers (2003) presented a study that used AHP to develop and implement a decision-counseling protocol for prostate cancer screening [30]. Archetti, 2009 presented a genetic programming framework for anticancer therapeutic response prediction using the NCI-60 dataset. Table 3 provides a list of literature on recent OR applications and techniques to disease treatment, control and prevention.

<table>
<thead>
<tr>
<th>Year</th>
<th>Reference</th>
<th>Year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Yu and Schell[78]</td>
<td>2008</td>
<td>Lee and Zaider [29]</td>
</tr>
<tr>
<td>1997</td>
<td>Gallagher and Lee [76]</td>
<td>2010</td>
<td>Archetti et al. [39]</td>
</tr>
<tr>
<td>1997</td>
<td>Yu et al. [80]</td>
<td>2010</td>
<td>Lebcir et al. [67]</td>
</tr>
<tr>
<td>1998</td>
<td>Yang et al. [79]</td>
<td>2010</td>
<td>Cairns et al [70]</td>
</tr>
<tr>
<td>1999</td>
<td>Lee et al. [77]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2 System Operational Management

4.2.1 Emergency Response
Application of OR to emergency in health care settings come in different forms and are applied in the different sectors of health care. For instance, applications to emergency medical services (EMS) that are directed towards logistical problems of vehicle routing and location, emergency department configuration, emergency drug or vaccination dispensing, etc. Application of optimization techniques in emergency services aids in efficiently distributing services and serving the needs of patient in a timely manner. A study by Travakoli and Constance (2004) focused on mathematical modeling approach for locating/allocating emergency vehicles and facilities in a manner that increases the number of calls that are answered within the 8-minute national average [31]. Emergencies in healthcare ranges from patient calling in for an ambulance, ambulance service to an accident site, patient arriving at the emergency department and needing immediate treatment, emergency distribution of drugs during a pandemic outbreak of a disease or infection, etc [31, 32]. In some instances, emergencies demand priority assignments to prevent delay, hence death and loss. OR tools and techniques can be efficiently used for priority assignment as in the case of Silva and Serra (2007) [32]. These researchers formulated and solved a covering model for emergency service which considered different priority levels. Table 4 provides a list of references focused on OR applications to emergency services.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Kaplan et al. [83]</td>
</tr>
<tr>
<td>2003</td>
<td>Wein et al. [81]</td>
</tr>
<tr>
<td>2004</td>
<td>Travakoli and Lightner [31]</td>
</tr>
<tr>
<td>2005</td>
<td>Takedaa et al. [51]</td>
</tr>
</tbody>
</table>
4.2.2 Healthcare facility location
Healthcare facility location becomes more important especially in recent days as the population keeps growing and expands at an alarming rate. Facility location in healthcare deals with determining optimal locations for care facilities, dispensing facilities and other healthcare facilities to serve the growing population equally, efficiently and in the most cost effective way. Facility location in this regard involves determining locations for hospitals, clinics, nursing homes, point-of-dispensing facility setup, and designing customized and efficient floor plans. Optimal location of health facilities encourages health checkups for some targeted population, for instance the mothers’ neonatal abstinence syndrome infants who may need to attend periodic physiatrist appointments, the elderly who may need constant health checkups among others. Table 5 shows examples of such applications.

<table>
<thead>
<tr>
<th>Year</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Mehrez et al. [88]</td>
</tr>
<tr>
<td>2000</td>
<td>Rahman and Smith [91]</td>
</tr>
<tr>
<td>2001</td>
<td>Hahn and Krarup [90]</td>
</tr>
<tr>
<td>2004</td>
<td>Daskin and Dean [86]</td>
</tr>
<tr>
<td>2006</td>
<td>Ndiaye and Alfares [45]</td>
</tr>
<tr>
<td>2009</td>
<td>Zhang et al. [95]</td>
</tr>
<tr>
<td>2010</td>
<td>Gu et al. [87]</td>
</tr>
</tbody>
</table>

4.3 Resource Allocation

4.3.1 Scheduling
Scheduling in healthcare comprise scheduling nurses’ roster, post-discharge nurse home visits, physician visits and physiatrist appointments, drug delivery, logistics activities and scheduling patients with different priorities amongst others. Sophie and Angel (2005) presented a study on scheduling logistic activities to improve hospital supply systems [33]. The approach used tabu search meta-heuristics and put the emphasis on the scheduling decisions: when to buy a product, when to deliver to each care unit, when each employee should work and what task should they do, etc. In some circumstances where nurse’s rosters must be redesigned, meta-heuristic search can be applied to create a flexible schedule and also prevent bias. This can occur when one or more nurses are not able work in their previously assigned shifts [34]. Both the original roster and the redesigned roster must comply with the labor rules, institutional constraints and policy as well as must be fair to all employees [34]. Thus OR applications in such scheduling presents a schedule with no bias and with effective consideration of all possible constraints. Margarida and Margarida (2005) presented a genetic algorithm approach to a nurse re-rostering problem that takes into consideration all possible constraints [34]. Lee’s (2008) study presented a critical instance of “Bioterrorism” that required the application of OR. The study noted that in a situation as Bioterrorism, the distribution and dispensing plan of medical supplies have to be effective since it would influence health and lives of many people and there would be no time to fix or adjust plan once the emergency event occurs. Lee developed a simulation model to help a major U.S. city in evaluating the effectiveness of alternative dispensing plans and identified improvement opportunities in the event of bioterrorism [35]. Provided in table 6 are a list of references on OR applications to various scheduling problems.

<table>
<thead>
<tr>
<th>Year</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>Randhawa and Sitompul [48]</td>
</tr>
<tr>
<td>2001</td>
<td>Glowacka et al. [69]</td>
</tr>
<tr>
<td>2005</td>
<td>Bertels and Fahle [46]</td>
</tr>
<tr>
<td>2005</td>
<td>Lapierre and Ruizb [33]</td>
</tr>
<tr>
<td>2005</td>
<td>Moz and Pato [34]</td>
</tr>
<tr>
<td>2008</td>
<td>Lee [35]</td>
</tr>
<tr>
<td>2009</td>
<td>Cardoen et al. [96]</td>
</tr>
<tr>
<td>2009</td>
<td>Min and Yih [15]</td>
</tr>
<tr>
<td>2009</td>
<td>Harper et al. [68]</td>
</tr>
<tr>
<td>2009</td>
<td>Burke et al. [72]</td>
</tr>
<tr>
<td>2010</td>
<td>Topaloglu and Ozkarahan [47]</td>
</tr>
<tr>
<td>2010</td>
<td>Campbell [71]</td>
</tr>
</tbody>
</table>
4.3.2 Cost minimization
Recently, OR have been used to assess resources and determine minimum needs to prepare for treating regional populations in emergency situations for optimum cost, efficiency, carry out large-scale virtual drills and performance analyses, and also investigate alternative strategies that leads to optimum or minimum treatment cost [36, 37]. These applications have also been used to design a variety of dispensing and care setting scenarios including emergency-events. The scenarios are then compared to select the one yielding the optimum or minimum cost. The ability of a healthcare institution to analyze planning strategies, compare the various options, and determine the most cost-effective combination of treatment, operating and dispensing strategies is critical to the ultimate success of both the institution and the patient [36]. Eva et al (2009) puts it well; Optimization tools and powerful computational strategies also allows hospital management and coordinators to quickly analyze, design decisions, generate feasible plans based on best estimates and analyses available, and reconfigure emergency situations in order to administer cost effective treatments as various events unfolds[36]. Table 7 shows a list of OR applications focused on cost minimization in health care.

<table>
<thead>
<tr>
<th>Year</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Swisher et al. [54]</td>
</tr>
<tr>
<td>2003</td>
<td>Sloane and Liberatore [40]</td>
</tr>
<tr>
<td>2007</td>
<td>Melachrinoudisa et al [98]</td>
</tr>
<tr>
<td>2007</td>
<td>Chalabi et al. [99]</td>
</tr>
<tr>
<td>2009</td>
<td>Kros et al. [97]</td>
</tr>
</tbody>
</table>

5. Major healthcare system issues and problems identified from review
Health care systems have a variety of inherent complexities with its many components. For instance, there is an ill-defined product and the definition of services provided lacks specificity. Some of the issues that affect healthcare system analysis include: Is the service to affect a cure, ease suffering, administer medications, prolong life, or what? And who are the service beneficiaries? The patients? Their families? The physicians? The pharmacists? The insurance conglomerates? All of the above?. Optimization of care may need to consider these decisions correctly defined so as to rightly model the real life situations for a 100% efficiency and effectiveness. These greatly influences quality, safety and patient satisfaction. Another issue of great concern is; after OR approaches have been applied for optimality, how is quality measured? Does success mean that the patient lives? Or that a diagnosis is corroborated? Or, that a patient’s care is not dependent on his/her ability to pay? These questions stress how little is understood about healthcare delivery as a system with OR approaches and the prevailing challenge to try and establish that connection. Future research can use OR applications to design mathematical models to help understand these issues and also to design computation strategies for these metrics. OR can help gain a better understanding of the delivery of healthcare at the patient-care giver interface, and to use this knowledge to develop improved metrics and mathematical models for evaluating quality, and finally to engineer and test an improved system that narrows the gap between provider and patient expectations. Our on-going project targets this and uncovers the definition of quality with defined metrics as it relates to care.

This project has reviewed various literatures of seminal and recent journal articles as they pertain to OR applications and techniques in healthcare systems, the hospital environment, healthcare providers and the patient. The various OR tools and techniques, methods, models, approaches, applications, and solutions to healthcare problems used mathematical programming techniques which aided is describing the healthcare system to gain better understanding, to facilitate taking measurements on the real system, to predict future results, to aid in decision-making and finally to develop and recommend effective and sustainable models to solve the various problems in the system, as well as better the systems outputs. This study gives great insight and a better understanding of the various current applications of OR in healthcare through the review of methods, models, approaches, applications, and solutions of healthcare problems through the extensive literature reviews of seminal and recent literature. Most importantly, this study is aimed to help researchers and health professionals etc. to acquire the skill of analyzing, critiquing, and reviewing technical journal articles that specifically relate to OR tools and its application in healthcare. A deep insight understanding of mathematical programming techniques used in OR can be applied to healthcare systems to successfully develop models to save cost, reduce waste and assure patient safety, satisfaction and quality in all healthcare systems. Literatures used in this study are carefully selected on the basis of real applicable OR techniques
that have been experimented in real life, that are evidence-based and that have yielded positive results. Some studies apply more than one OR tool and technique, but for representation and purposes of this study, we categorize such paper under the technique that was used at least 80% to accomplish the aim of that study.

6. Conclusions and Recommendations

This study has analyzed and reviewed recent applications of OR in health care that are related to disease treatment, emergency services, scheduling, cost minimization and health care facility location. The trend of OR applications has proved it to be helpful to healthcare systems and will continue to provide effective solutions to the variety of problems faced in healthcare delivery systems. Based on the experiences and knowledge learned from this review, various studies can be conducted to test a variety of hypothesis through research activities developed within a coalition of health care organizations, researchers, medical technology developers and health practitioners with the aim of optimizing healthcare. For instance our on-going project is investigating the following hypothesis; Hypothesis 1: OR applications; is more likely to continue to give healthcare professionals additional tools to make the complex nature of health care delivery safer to assure patient safety, quality and optimum cost. Hypothesis 2: accuracy of clinical information, operating procedures and timely access to all patient information can be enhanced through the adoption of practical OR applications.

The improvement of healthcare delivery systems can benefit from a variety of OR approaches. The complex nature of healthcare requires OR applications to better understand the system executed activities effectively and hence assure quality and cost minimization. Future research can also be conducted focusing on using OR applications to view healthcare with a system approach. Healthcare delivery has the characteristics of, and functions as, a system. Specifically, healthcare delivery receives demands from the external environment, processes inputs (resources) from the environment by using them in activities needed to respond to the demand, and then outputs a finished result in response to the demand. Each system is generally composed of smaller interacting systems (subsystems), and each system is part of a larger super system. Each system may interact with other external systems. Thus, assuming that any healthcare provider can be defined as a service-producing enterprise and studied as a system with OR applications and techniques, the system inputs and outputs as well as loopholes and waste can be effectively identified, measured, quantified, modeled and corrected. Another area which can be considered as part of the health care system is post discharge infant home visitation by health professionals and para-professionals. OR can employ models that will effectively model follow-up visitation process and aim at maximal coverage and cost reduction at the same time. Finally, this study hopes to raise the awareness of the helpful applications of operations research in healthcare to researchers and healthcare professionals.

References


92. Leroy White, Honora Smith, Christine Currie, OR in developing countries: A review, European Journal of Operational Research, 208 (2011) 1–11


94. P. Beraldi, M.E. Bruni, A probabilistic model applied to emergency service vehicle location Volume 196, Issue 1, 1 July 2009, Pages 323–331


97. John Kros, Scott Dellana, David West, 2009, Overbooking Increases Patient Access at East Carolina University’s Student Health Services Clinic. Interfaces, Informs, 39 (3), pp. 271–287, June 1, 2009
