University of Dar es Salaam Library Journal
Vol 18, No 1 (2023), pp 134-151
ISSN: 0856-1818

The Application of Operations Research Information System Tools in Hospital Operations Management in Developing Nations: A Systematic Literature Review

Sumaya, M. Kagoya
Department of Applied Computing and Information Technology, Makerere University Business School, Kampala, Uganda
E-mail: skagoya@mubs.ac.ug

Allen, R. Mushi
Department of Mathematics, Mzumbe University, Morogoro, Tanzania
Email: allenmushi66@gmail.com

Abstract

Hospital services in the developing world are always overwhelmed due to scarce resources compared to the demand from the public. Operations Research provides a set of tools that are very useful in the optimization of resources, hence providing a highly needed service in assuring that, the resources are optimally utilized to save lives and provide better healthcare services. This paper reviews applications of Operations Research information system tools(ORIST) in hospital operations to find ORIST status in developing nations like the East African Region.This study used a systematic literature review method and thematic analysis. Results revealed that there is a lot of OR work about hospital operations in the developing world. However, little has been reported from East Africa. A proposal is presented about research opportunities on hospital operations in East African regions by grouping applications into four areas namely; planning, management, medical practice and prevention. The paper concludes by inviting all stakeholders to cooperate and provide the necessary support to Operations-Research practitioners.

Keywords: operations research, information system tools, hospital operations management, developing nations
https://dx.doi.org/10.4314/udslj.v18i1.9

Introduction

Hospitals provide very important services to the livelihood of people and therefore efficient operations are important. Hospital operations management is concerned with planning, organizing, directing and controlling hospital daily services (Faccincani *et al.*, 2022)[106]. These include outpatient, inpatient, emergency and diagnostic services. These involve management of other associated activities (like; hospital pharmacy, inventory control, supply chain and warehouse management). Operations Research (OR) plays a vital role in optimizing innumerable resources and designing logistical operations to provide better services to patients. Significant literature is available that shows various efforts and success stories on applying OR in improving performance of service provisions in the developed world; see for example; Bailey (1957)[49] for hospital planning and design and Teixeira and De Oliveira (2015)[50] for hospital admissions system. However, only limited literature is available about OR usage in hospital operations in the developing world like the EA region. The scarce literature in East Africa on hospital operations that authors have been able to retrieve, is mostly about the use of Data Envelopment Analysis to

University of Dar es Salaam Library Journal
Vol 18, No 1 (2023), pp 134-151
ISSN: 0856-1818

determine technical efficiencies in Uganda, Kenya and Tanzania. Other processes including inpatient, outpatient, emergency and theatre operations, are unexplored in the region. It is imperative to note that, utmost hospitals in the developing world are public funded hence facing challenges to meet the needs of an ever-growing population that needs access to high quality healthcare services (Waitzberg *et al.* (2022) [1]; Chuma and Ngoepe (2022) [3].

East Africa has some of the worst health statistics in the world with a shortage of healthcare facilities and healthcare workers. For instance, there are only 1.49 healthcare workers for every 1000 population, see Yamin and Maleche (2017) [104]. The 2019 report by Medic East Africa shows that Sub-Saharan Africa has about 11% of the world's people, but carries 24% of the global disease burden and that almost half the world's deaths of children under five take place in Africa (Watermeyer *et al.,* 2022; Dansie, Odoch, Årdal, 2019) [106; 105]. Given the current situation of healthcare provision in the region, OR is extremely important in ensuring the meagre resources are optimally utilized for better performance and to provide tools that can assist decision makers on the best strategies to be taken to avert the situation.

This work categorizes the applications of OR in hospital operations into four areas namely; planning, management, medical practice and prevention. These areas cover important aspects of the operations of hospitals with OR applications which have been reported in literature mostly from the developed world than the EA region which shows a clear research problem which are highlighted in the Table 2. It should be recalled that, the sole objective of this paper is to review applications of operations research information system tools (ORIST) in hospital operations to find ORIST status in developing nations like the East African Region and offer opportunities for research with recommendations.

Methodology

Searching through literature, 106 articles were reviewed on applications of operationsresearch in hospital operations throughout the world. Special attention is given to applications in the East African region compared to elsewhere. The period of study ranges from 1957 to 2019, and most were obtained through internet search engines and only refereed articles were considered. Searches were performed to include the term "operations research" AND "Hospital" OR "Health" in the title, abstract or keywords. More searches were done using terms that relate to operations research, hospital operations, locations and applications as shown in Table 1. A combination of terms with AND while others with OR yields different results and leads to articles relevant to the study.

Table 1: Literature search terms

Operations research terms	**Hospital operations terms**	**Location terms**	**Outcome terms**
OR	Hospitals	Africa	Disease control
Optimization	Bed Assignment	East Africa	Diagnosis
Mathematical Programming	Theatre	Sub Saharan Africa	Treatment
Simulation	Hospital admission	South Africa	Prevention
Linear Programming	Ambulance	Developing Countries	Forecasting
Integer Programming	Outpatient	Developed Countries	Planning

Goal Programming	Inpatient	Tanzania	Reduce overcrowding
Multi-Criteria Programming	Waiting time	Kenya	Scheduling
Decision Analysis	Patient	Uganda	Rosters
Heuristics	Health	Rwanda	Efficiency
Algorithms	Healthcare	Burundi	Recovery
Markov models	Health systems	Low income Countries	Review
Queuing Models	Global health	Europe	Survey
Analytical Hierarchy Process	Patient flow	America	
Data Envelopment Analysis	Physician	Asia	
Meta-heuristics	Nurse roistering	Middle East	

Source: Literature review (2020)

The search was done using Google and Google Scholar and databases including JSTOR, Research Gate, Taylor & Francis Online, Wiley Online Library, NCBI Resources, BMC and Academia; these are the databases that authors had access to.

Some of the search terms include; "Applications of operations research in Hospital Operations", "OR in hospital systems", "OR in Health Systems", "OR in hospitals in developing countries", "OR in African Hospitals", "OR in Hospitals in East Africa", "OR in hospitals in Sub-Saharan Africa', "OR in Hospital Operations Management" and "Optimization methods for hospital operations". The searches resulted in more specific searches including "Data Envelopment Analysis Applications in Hospital Systems", "Queuing theory applications in Hospital Operations', "Linear Programming in Hospital Operations", "Simulations in Hospital Optimization" and other techniques that arose from literature. The literature was classified according to observed applications and these are Planning, Management, Medical practice and Prevention as used in Rao (1974) [48]. Table 2 presents a summary of reviewed papers according to classification area and problem type.

Table 2: Reviewed articles by area and problem

Area	Problems	Number of articles	Percentage
Planning	Forecasting Efficiency Health Policy	[2], [3], [4], [5], [6], [7], [8], [9], [10], [31], [35], [36], [37], [40], [42], [48], [49], [51], [54], [65], [66], [67], [74], [75], [76], [78], [79], [93], [103], [104], [105], [106]	31
Management	Patient Scheduling Staff Scheduling Facilities Scheduling (Beds, Theatres)	[1], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [32], [38], [39], [41], [43], [44], [45], [46], [47], [50], [52], [53], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [68], [69], [70], [71], [72], [73], [80], [94], [95], [96], [97], [98], [99], [100], [101], [102]	59
Medical Practice	Diagnosis Treatment	[33], [34], [77], [81], [82], [85]	6
Prevention	Disease prevention Organ donation	[84], [85], [86], [87], [88], [89], [90], [91], [92],	9

Source: Literature review (2020)

Literature Review

University of Dar es Salaam Library Journal
Vol 18, No 1 (2023), pp 134-151
ISSN: 0856-1818

The review of the literature resulted into articles which are presented according to the subsections mentioned earlier as follows;

Planning Activities of the Hospitals

Several pieces of literature in OR were found to fall into planning activities of the hospitals. These include forecasting of patients, resource planning and determination of hospital systems efficiency. The main research work found that focuses on hospital OR in East Africa involves the application of Data Envelopment Analysis (DEA) to determine the efficiency of hospital systems. DEA is a Linear Programming method that is used to compare relative efficiency of multiple service units. A handbook by Cooper *et al.* [93] provides a detailed description of DEA methodology which is summarized below;

To find the technical efficiency of unit j relative to other units, one needs to solve the following Linear Programming Problem;

Maximize $h_j = \sum_i u_i y_{ij}$

Subject to: $\sum_i v_i x_{ij} = C,$

$$\sum_i u_i y_{ij} - \sum_i v_i x_{ij} \leq 0 \quad u_i, y_i \geq \varepsilon$$

Where $u_i = weight\ given\ to\ output\ i,$

$y_{ij} = amount\ of\ output\ i\ from\ unit\ j\ ,$

$v_i = weight\ given\ to\ input\ i,$

$x_{ij} = amount\ of\ input\ i\ to\ unit\ j\ ,$

$C = constant,\ \varepsilon = sufficiently\ small\ value$

Finding the efficiency of each unit involves solving this model for each unit j. The most efficient unit will hit the top value of 1 and the most inefficient units will approach a value of 0.

Kirigia *et al.* [4] measured technical efficiencies of fifty-four (54) public hospitals in Kenya using DEA. They found that 26% of the hospitals are technically inefficient, they singled them out and showed the extent of input reductions or output increases required to make them efficient. Mwihia *et al.* [5] analysed technical efficiency of public hospitals in Kenya in a two-stage DEA. Their analysis indicated that small hospitals are more efficient than large hospitals. They suggested internal and external supervision mechanisms for improvement of efficiency. Mujasi *et al.* [6] presented their findings on efficiency of referral hospitals in Uganda using Data Envelopment Analysis and Tobit Regression approach. They concluded that efficiency could be achieved by transferring the excess 216 medical staff and 454 beds to other levels of the health system without changing the total number of outputs. Bwana [7] analysed technical efficiencies of 15 faith-based hospitals in Tanzania from 2009 to 2012 using DEA. The results indicate that only 26.6% of the hospitals were technically efficient and proposed an equal increase of resources to improve efficiency. Bwana [8] reported the results of DEA on Tanzania teaching not-for profit hospitals from 2009 to 2013. Out of 18 hospitals only 22.3% were operating close to technical efficiency and called for measures to be taken to improve efficiency.

Kirigia *et al.* [9] measured technical and scale efficiency of hospitals in Benin using Data Envelopment Analysis (DEA). The work proposed areas for improvement in the running of the hospitals without additional financial investment into the facilities. They collected data from 23 regional hospitals over the period of five years and concluded that 87% of the hospitals were run inefficiently between 2003 and 2004. Mbonigaba *et al.* [10] measured relative efficiency of South African municipalities in providing health care. They used efficiency scores estimated through DEA. They concluded that South African municipalities are generally inefficient; however, there is a room to learn from each other's best practices.

Global health is a study of health systems improvements in achieving equity in health for all people worldwide. Various papers have been found that applies OR techniques in addressing global health problems and influencing policy. Bradley *et al.* (2017)[2] reviewed OR applications in global health. They concluded that poor availability of quality data and lack of collaborations between OR experts and stakeholders are common challenges in global health. Forecasting tools are very common in medical care due to uncertainty nature of patients and high demand for services. Toerper *et al.* (2014) [34] presented an inpatient forecasting tool for the daily bed need for admissions from the cardiac catheterization laboratory. They used data mining techniques and applied multivariable logistic regression model to predict admissions successfully which can be used as a decision analysis tool. Forecasting is also done on the spread of infectious diseases; Douglas *et al.* [36, 37] forecasted influenza using Google Flu Trends.

The emergency department is a critical department in any hospital and is likely to face overcrowding due to demand from patients whose arrival is stochastic in nature. Forecasting of emergency department crowding has been investigated including the works by Hoot *et al.* [40, 42]. Hospital planning activities including planning and design of hospitals are also the subjects of study by OR techniques. For instance, an early work by Bailey (1957) presents OR models for designing the size of hospital buildings, beds, ambulances, traffic surveys, walking distances and outpatient appointment systems. Resource planning including radiotherapy, admissions and many others are studied extensively. Vieira *et al.* (2016)[75] provide a literature review on the use of OR in medical resource planning. However, only one article was found on OR for forecasting and resource planning from Sub-Saharan Africa. This is a recent article (2019) by Bigelow *et al.* (2019) (102) that uses paper-based registry data to model hospital operations in the obstetrics ward in Addis Ababa Ethiopia. Authors have noted that OR techniques have been under-utilized in global health in low and middle income countries; specifically little research has examined the utility of existing data sources for improving hospital operations.

Management of Hospital Resources

Management of hospital resources is always a challenge due to their scarcity and high demand for services. Blake (1998)[11] developed a lexicographic goal programming model for allocation of resources to physicians at Mount Sinai Hospital in Toronto Canada. The model treated physicians and administrators as competitors for control of scarce resources. The model suggested several critical resources for the efficient running of the hospital including availability of operating room time.

The relationship between the emergency department and inpatient ward operations is of paramount importance. Overcrowding in Emergency Department (ED) is mostly associated with unavailability of inpatient wards space immediately after operation. Shi *et al.* (2016)[12] studied

University of Dar es Salaam Library Journal
Vol 18, No 1 (2023), pp 134-151
ISSN: 0856-1818

the dynamics of such systems based on empirical studies from Singaporean hospital data and proposed a stochastic processing network to model inpatient operations. They model the General Ward (GW) admission processes using data collected over time and apply queuing theory to estimate important properties of the system including Length of Stay (LoS), waiting times and overflow proportions. Patients gets into GW from either Emergency Department (ED), Intensive Care Unit (ICU), Elective (EL) patients who come during the afternoon for elective operation or Same Day Patients (SDA) who register and get operated on the same day before moving into GW. The General Ward admission sources are presented as shown in Figure 1.
Patients from all sources are considered to be customers and each bed in the GW is treated as a server which then turns into a multiple-servers network model. The model provided insights that have been useful for policy makers in reducing congestion in hospitals in Singapore.

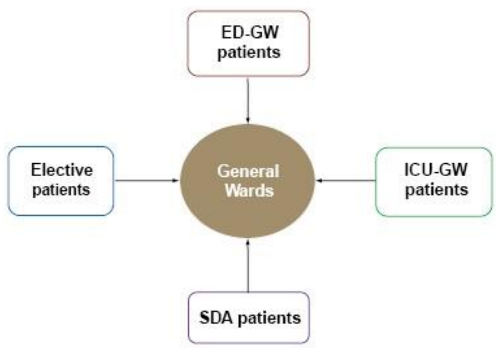

Figure 1: General ward admission sources
Source: Shi *et al*. (2016) [12]

Hospital inpatient admission systems have many challenges due to uncertainties associated with patient arrival, treatment and release. Markov processes have been applied often to provide insights about the characteristics of the operations with the aim of proposing improvement policies. Colesar (1970) [13] presented a Markovian model for hospital admissions combined with queuing models. The results were a linear programming model which is used to guide hospital administrators in their decision making activities. Reenberg *et al.* (2017) [14] presented a case where patients can be re-located and beds can be re-distributed within wards to optimize inpatient admission. They modelled the problem using homogeneous continuous-time Markov chain using a Danish hospital as a case study. The paper reports 11.7% reduction of patient relocation due to re-distribution of beds within wards of the case study hospital.

Mubiru (2015) [15] presented a Markov decision model for hospital ward admission scheduling using a case of Uganda. Applying a Markov chain decision process on weekly admission data, a policy is proposed for the decision on whether to admit new patients over a finite period planning horizon using dynamic programming. Markov Decision Process is also applied by Clissold *et al.* (2015) [16] for optimization of patient flow using a South Australian hospital. An optimal policy was found using dynamic programming approach that proposes strategies for reducing possible patient congestion. To reduce the problem of emergency department overcrowding, some hospitals have introduced short stay units where patients can be temporarily accommodated in short periods of time before being admitted to inpatient wards when space becomes available. Zonderland *et al.* (2015) [17] modelled the effect of short stay units on patient admissions. An overflow model is developed from queuing theory to evaluate the effect of short stay units on elective and urgent patient admissions.

Due to growing population in many countries around the world, hospital systems have a witnessed high demand for healthcare services. This has resulted in problems of overcrowding and long waiting lines. Queuing theory has therefore been used in the analysis of waiting lines in hospital systems. Mahale and Deshmukh (2016) [18] analysed delays due to waiting lines in healthcare delivery. The resulting model is used to suggest system improvement for optimal operations. Armony *et al.* (2015) [19] apply Exploratory Data Analysis to study patient flow data for a large hospital in Israel and provid ed answers for various queuing challenges including how to control delays. Afrane and Appah (2014) [20] reported on a queuing model for controlling waiting times in hospitals and used a case study of Anglo Gold Ashanti Hospital in Ghana. More queuing models for hospital systems include the work by Aziati and Hamdan (2018) [21] for hospitals in Malaysia.

Operating room planning is also an important area that requires optimization and several research papers are available. Carter and Ketabi (2013) [22] presented a bed balancing problem for surgical wards through block scheduling. In this case, surgeons are assigned blocks of time which can be repeated over time; these are then scheduled against the available operating rooms. Patients are selected and sequenced within each block depending on the type of operations required. An integer programming model was developed and the results presented the maximum number of beds for each surgical service throughout the planning horizon. Chow *et al.* (2001) [23] asserted that surgical scheduling practices that focus on efficient surgery room utilization only have negative effect on downstream bed utilization. They proposed a mixed integer programming model combined with simulation to come up with a better model that considers both room utilization and downstream effects. Other papers on surgery scheduling include; Khare *et al.* (2008) [24] who have investigated the effect of adding more beds versus reduction of admitted boarding time to determine a better option through simulation methods.

Outpatient departments are also faced with many challenges including appointment scheduling. Gupta and Denton (2008) [25] jotted-down factors affecting outpatient scheduling like, arrival and service time variability, patient preferences and experience levels of scheduling staff. Hence, a flexible appointment management system using operations-research models was provided. One of the most challenging tasks in outpatient scheduling involves chemotherapy scheduling for cancer patients. Goldberg-Hahn *et al.* (2014) [26] presented a solution to the chemotherapy outpatient scheduling problem at Odette Cancer Centre in Toronto Canada using constraint programming. In this case, delivery of chemotherapy is divided into four stages; chart review, drug preparation, treatment setup and drug delivery. These stages require sharing of personnel such as nurses, pharmacy and clinic resources which creates a complex scheduling problem. Constraint programming is used to develop a deterministic model which performed better than a mixed integer programming formulation. Other research works on chemotherapy scheduling include Garaix *et al.* (2018) [27], Goldberg-Hahn (2014) [28], Huggins *et al.* (2014) [29] and Athawale (2015) [30].

Nurse scheduling is a very important problem for optimization of nurse services while satisfying several constraints. Many approaches can be applied including both exact and heuristic algorithms depending on the size of the problem. One typical exact approach to the problem is the use of Linear Programming (LP) formulation and solve by using branch and bound methods. Lorraine *et al.* (2006) [94] provides an LP formulation of a Nurse Rostering Problem (NRP) which is of the form;

Suppose $x_{ijk} = \begin{cases} 1 & if\ nurse\ i\ works\ on\ shift\ k\ on\ day\ j \\ 0 & otherwise \end{cases}$

The objective is to create a schedule that will bring a balanced load distribution among nurses, and violation of the objective is penalized so that p_{jk} = penalty associated with allocating nurse j to shift k. If p_{max} = upper bound on the penalty of each nurse and p_{min}= lower bound on the penalty of each nurse, then the objective function becomes;

Minimize $z = p_{max} - p_{min}$

Where $p_{min} - \left(\sum_j \sum_k \frac{1}{R_i} p_{ijk}\right) \leq 0, \forall i$ and $p_{max} - \left(\sum_j \sum_k \frac{1}{R_i} p_{ijk}\right) \geq 0, \forall i$ with R_i=working rate of each nurse i ($= 1$ for full time and < 1 for part-time)

Subject to a set of constraints including the following;

Each shift must the required number of nurses

$\sum_i x_{ijk} = R_{jk}\ \forall i, \forall j$ where R_{jk}=number of nurses required on shift k of day j.

Number of working hours per each nurse cannot exceed S

$\sum_{k=1}^{S} x_{ijk} \leq 1\ \forall i,\ \ \forall j$

Other constraints include the limit on the number of working days per week, limits on the number of consecutive night shifts, leaving a gap between shifts and others such as individual nurse preferences. If the complexity allows, the problem may be solved by exact methods (Trilling, Guinet, & Magny, 2006 [94]; Hakim, Bakhtiar & Jaharuddin, 2017 [95]), otherwise heuristic algorithms have been employed (Gómez, Santos & Poltosi, 2012[96]; Xu, Wong & Chin, 2012 [97]; Wong, Xu & Chin, 2014 [98], Zhong, Zhang & Zhang, 2017 [99]; Jafari & Salmasi, 2015[100]; Jamom, Ayub & Hadwan, 2011 [101]).

Table 3 summarizes the papers reviewed by OR technique, country and region; showing that very little has been done for East Africa.

Table 3: Summary of reviewed problems and approaches by region

Problem	Approach	Papers	Country	Region
Hospitals Technical Efficiency(THE)	Data Envelopment Analysis(DEA)	[4,5, 6,7,8,9, 10,93]	Uganda, Kenya, Tanzania, South Africa, Benin	West Africa, East Africa South Africa
Inpatient Wards Operations Optimization (IWOO)	Goal Programming, Stochastic Processing Network Model, Discrete Event Simulation	[11,12,31,38,57, 58,80]	Egypt Singapore United States	North Africa Sub-Saharan Africa Asia, North America
Hospital Wards	Markov Processes	[13,14,15,50, 54, 65]	Denmark	Europe,

Admission Systems Optimization(HWASO)	and Queuing Model		Uganda Belgium	East Africa
Emergency Department Optimization(EDO)	Queuing Theory Models, time-series regression, Stochastic Discrete Event Simulation, Forecasting models, Survival Analysis	[17,33,35,37,39, 40,41,42,43], 44,45,47,47,32]	United States	North America
Operating Rooms Planning(ORP)	Block Scheduling, Integer Programming, Simulations	[22,23,24, 53]	Canada United States	North America
Waiting queues optimization (WQO)	Queuing theory Exploratory data Analysis, Markov Decision Process	[16,18,20,21,19,59,64, 68,69,72,73]	Israel, Malaysia, Australia Ghana Iraq, Turkey	Middle East Asia Australia West Africa
Outpatient Department Planning (ODP)	Flexible Appointment Models Constraint Programming, Scheduling Algorithms, Simulation	[25,26,27,30,36,53,55,56,34,60, 61]	Canada United States Norway	North America Europe
Staff Scheduling (Nurse rostering, Physician scheduling)	Heuristic Algorithms Mathematical Programming Constraint Programming, Goal Programming	[62,63,71,94,95, 95,96,97,98, 99, 100,101]	Egypt, New Zealand, Turkey, Malaysia, France, Indonesia, Brazil, Hong Kong, USA, Iran	Africa Europe Asia America Middle East
General Healthcare (Global Health, Public Health, Mobile Health, Family Planning)	Reviews Mathematical Modelling	[66,67,70,74,75,76, 78,79, 87,88,90,91, 92,102, 104,105]	India, USA, Ethiopia, Sub-Saharan Africa	Asia Africa
Medical Decision Making (MDM)	Reviews Analytical Hierarchy Process	[77,81,82,83,84, 85,86,89,103]	USA, Developing Countries	America Developing Countries

Source: Literature review (2020)

Medical Practice

OR is also used in the actual medical practices including diagnosis and treatment processes. Redd *et al.* (2015) [33] studied the effect of policy changes in using Magnetic Resonance Imaging (MRI) in the emergency department for stroke diagnosis. They applied time series analysis and segmented regression analysis to compare utilization pre and post-utilization patterns to determine differences in utilization, demographics, and clinical characteristics of

University of Dar es Salaam Library Journal
Vol 18, No 1 (2023), pp 134-151
ISSN: 0856-1818

cohorts. Toerper *et al.* (2014) [34] studied medication waste in the paediatric ward by developing an algorithm to detect wasted medication based on time-stamped computerized provider order entry information. They compared the effect of pre-intervention and post-intervention strategies and developed a simulation model that can help to reduce medical waste in the paediatric pharmacy. Medical Decision Making (MDM) is the application of systematic approaches to solve decision making problems in healthcare [89]. Tunc, Oguzhan and Burnside (2014) [77] demonstrated the opportunities of OR in the MDM by providing quantitative tools that can assist decision makers and cited several success stories using Markov decision processes. Medical decisions are very complex and require multi-criteria decision analysis tools. Analytical Hierarchy Process (AHP) is one of such tools and has been applied by various researchers in aiding medical decision making.

Liberatore and Nydick (2008) [82] presented case studies of applications of AHP in medical decisions. Sloane *et al.* (2002) [81] gave a literature review of 50 articles that applies AHP in medical decisions. Very little is reported about work done in developing countries and none of the papers presented work from East Africa. Detection and treatment of diseases involve many possible and complex situations that require OR tools to aid decision making. For instance, early detection of diabetes can help the patient control the disease and therefore save lives; however screening for diabetes is a costly exercise if it has to be done to all people in the society and repeated after every period of time. Over-screening can be costly and various decisions have to be made to optimize the use of resources, and OR is the field that provides such tools. Zhang *et al.* (2011) [85] provided a good account of the applications of OR in both diagnosis/screening and treatment.

Prevention Measures

It is well known that prevention is better than cure, and therefore a lot of effort is placed on prevention measures. The application of OR in vaccination processes is well presented by Zhang *et al*. (2011) [85] where various complex decisions have to be made involving the manufacturing process, quality control, supply chain logistics, and optimal storage locations. Non-communicable diseases (NCD) occur more frequently in developing countries and therefore a cause for concern. Bosu (2014) [86] discussed the possible uses of OR techniques in infectious diseases to help address problems in the NCD. The aim is to reduce the problem by prevention techniques which in turn involves OR tools; especially in prediction of trends through modelling and optimization strategies.

Global health issues have considerable requirements in OR techniques and have received recognition by the World Health Organization (WHO) especially in TB and HIV programmes (Stop, 2011) [88]. Geoff Royston [87] presented the report on ways to meet global health challenges through OR and Management Science. The work asserts that OR tools are not well exploited, creating a gap between practical and analytical approaches. Ronny Zacharia *et al.* [90] discussed the important role of OR in infectious disease control and presented a concern on low use of OR tools in low income countries. The article suggests strategies for capacity building in OR for medical practitioners and to ensure that they end up doing research by supporting them and placing more funding for research. Low funding for OR research in health systems in middle and low income countries is also recognized by GianLuca Quaglio *et al*. [91]; consequently, they call for Western support in the area.

University of Dar es Salaam Library Journal
Vol 18, No 1 (2023), pp 134-151
ISSN: 0856-1818

Opportunities for Operations Research in Hospitals of East Africa

As observed from applications elsewhere and the importance of optimization of resources in hospital operations, there are tremendous opportunities for research in East Africa. The research opportunities can be grouped into four classes as presented in Rao (1974) [48] namely; planning, management, practice and prevention. Healthcare planning involves setting objectives and strategies for meeting the health needs of society. OR provides the tools for demand forecasting hence better planning and budgeting for needed resources. Healthcare management is about the provision of quality healthcare services when patients have to attend healthcare facilities. Many problems arise here that require the use of OR-tools as stated earlier. These include patient scheduling [60], resources scheduling in rooms, beds (Holm, Lurås & Dah, 2013) [61], machines (x-rays, CT-Scanners, MRI and others), staff scheduling especially nurses (Ozscan, 2005)[62] and doctors (Puente, 2009)[63] and operating-room scheduling. This is a vital imperative in Africa due to the cost of medical equipment and a limited number of medical personnel versus the community needs hence the need to optimally utilise the few available resources.

Algorithms for Scheduling have been highly useful here, both exact and heuristics. Health care practices include: drug treatment planning, infectious diseases prevention and control and organ donation. OR has a lot of tools to offer in these processes including Multi-Criteria Decision Analysis tools such as Analytical Hierarchy Process (AHP) and a recent methodology by Cathal Brugha; Priority Pointing Procedures (Brugha, 2000)[103], mathematical programming, simulation models and heuristic algorithms. Efforts by the WHO to recognize the importance of OR in health care research is highly commendable, however, more effort is needed to stimulate OR applications into the challenging health problems in the developing countries and specifically the East African region due to high demand for medical services.

Specifically, as future research direction; the question of data quality, accessibility and interpretation has emerged as a major issue in healthcare in the EA region. Investment in data collection tools and providing access to research community is one of the challenges in the region. However, using existing data, experts can apply data mining and data warehousing techniques to provide insights into various features that may need attention and further research ideas. Furthermore, the Data Envelopment Analysis has been applied in a few hospitals; for instance in Tanzania, the technique was only applied to a few faith-based hospitals. An extension to a wider range of healthcare institutions may lead to better insights into their performances and advice accordingly. Resource forecasting is rarely done in the region despite importance in planning for healthcare needs. This is an area that may benefit tremendously from OR techniques. Application of techniques such as regression analysis, time series analysis, queuing theory, decision analysis and many others have been used successfully elsewhere and can therefore provide service to the healthcare process in the region.

Conclusion

A review of applications for OR tools in addressing problems associated with hospital operations has been researched. The research is motivated by the importance of hospital services in saving lives and the fact that these healthcare facilities are always overwhelmed due to high demand especially in the developing world. OR provides an opportunity to optimize the use of these resources and services in the best way. The area has successfully been widely researched in the developed world. However, little has been done in the developing world (East African region).

Implications, recommendations and limitations

This paper has practical implications to the OR practitioners, policy makers and other hospital stakeholders with an obligation to get involved in these noble projects and provide the necessary service that is almost missing in the region for better utilization of the meagre hospital resources. These findings will provide an empirical foundation for future academia in the subject area.

This article recommends all stakeholders in hospital operations management to support these projects and work together to improve hospital services in terms of efficiency and effectiveness in EA. Scope-wise, this study is limited to reviewing applications of OR information system tools in hospital operations in the EA. Future researchers should apply it in other regions to obtain a comparative analysis. The study used a systematic literature review hence other future researchers should employ other methods like quantitative or both qualitative and quantitative to obtain similarities and differences in the results.

References

Adan, I., &Vissers, J. (2002). Patient mix optimization in hospital admission planning: A case study. *International Journal of Operations & Production Management*, 22(4), 445-461 [54]

Adoly, E. A, A., Gheith, M., & Fors, N, M. (2018). A new formulation and solution for the nurse scheduling problem: A case study in Egypt. *Alexandria Engineering Journal*, 57(3), 2289–2298. [57]

Afrane, S., & Appah, A. (2014). Queuing theory and the management of waiting-time in Hospitals: The case of Anglo Gold Ashanti Hospital in Ghana. *International Journal of Academic Research in Business and Social Sciences*, 4(2), 34-44. [20]

Armony, M., Israelit, S., Mandelbaum, A., Marmor, Y. N., Tseytlin, Y., Yom-Tov, G. B. (2015). On patient flow in hospitals: A data-based queuing-science perspective. *Stochastic Systems*, 5(1), 146–194. [19]

Aslan, I. (2015). Applications of Queues in Hospitals in Istanbul. *Journal of Social Sciences* (COES&RJ-JSS), 4(2), 1-12. [72]

Athawale, S. (2015). *Chemotherapy appointment scheduling and operations planning*. The University of Akron. [30]

Aziati, A, H, N., & Hamdan, N, S. (2018). Application of queuing theory model and simulation to patient flow at the outpatient department. *Proceedings of the International Conference on Industrial Engineering and Operations Management, Bandung*, Indonesia, 2018. [21]

Bahadori M, Teymourzadeh E, Ravangard R.,& Raadabadi M. (2017). Factors affecting the overcrowding in outpatient healthcare. *Journal of Education Health Promotion*, 6(1), 21-39. [51]

Bailey, N, T. (1957). Operational research in hospital planning and design. *Journal of the Operational Research Society*, 8(3), 149-157. [49]

Barnes, S., Hamrock, E., Toerper, M., Siddiqui, S., & Levin, S. (2016). Real-time prediction of inpatient length of stay for discharge prioritization. *Journal of the American Medical Informatics Association*, 23(e1), e2-e10. [32]

Bartolozzi, F., De Gaetano, A., Di Lena, E., Marino, S., Nieddu, L., & Patrizi, G. (2000). Operational research techniques in medical treatment and diagnosis: A review. *European Journal of Operational Research*, 121(3), 435-466. [83]

Bigelow, B., Desalegn, D, N., Salomon, J, A., & Verguet, S. (2019). Modelling hospital operations: Insight from using data from paper registries in the obstetrics ward at a hospital in Addis Ababa, Ethiopia. *BMJ Glob Health* 4(1), e0012- e0018. [102]

Blake, J. T. (1998). *A goal programming approach to resource allocation in acute care hospitals*. University of Toronto. [11]

Bosu,W, K. (2014): Learning lessons from operational research in infectious diseases: Can the same model be used for non-communicable diseases in developing countries? *Advances in Medical Education and Practice*, 5,469–482. [86]

Bradley, B. D., Jung, T., Tandon-Verma, A., Khoury, B., Chan, T. C., & Cheng, Y. L. (2017). Operations research in global health: a scoping review with a focus on the themes of health equity and impact. *Health Research Policy and Systems*, 15(1), 1-24. [2]

Brugha, C., M. (2000). An introduction to the priority-pointing procedure. *Journal of Multi-Criteria Decision Analysis*, 9(2), 227–242. [103]

Burke, E, K., Curtois, T., Qu, R., & Berghe, V, G. (2010). A scatter search methodology for the nurse rostering problem. *The Journal of the Operational Research Society*, 61(11), 1667-1679. [71]

Burke, E. K., Curtois, T., Qu, R., & Vanden Berghe, G. (2008). Problem model for nurse rostering benchmark instances. *ASAP, School of Computer Science, University of Nottingham, Jubilee Campus, Nottingham, UK*. [70]

Bwana, K, M. (2015b). Technical efficiency of Tanzania teaching hospitals: The case of private not for-profit hospitals. *Business Management and Strategy*, 6(1),97-110. [8]

Bwana, K., M. (2015a). Measuring data envelopment analysis (DEA). *Research in Applied Economics*, 7(1), 1-12. [7]

Carter, M., & Ketabi, S. (2013). Bed balancing in surgical wards via block scheduling. *Journal of Minimally Invasive Surgical Sciences*, 2(2),129-137. [22]

Chow, V, S., Puterman, M, L., Salehirad, N., Huang, W., & Atkins, D. (2011). Reducing surgical ward congestion through improved surgical scheduling and un-capacitated simulation. *Production and Operations Management*, 20(3), 418- 430. [23]

Clissold, A., Filar, J., Qin, S., & Ward, D. (2015). Markov Decision Process Model for Optimization of Patient Flow, 21st International Congress on Modelling and Simulation, Gold Coast, Australia, 29th Nov to 4th Dec 2015, 1752-1758. [16]

Colesar, P. (1970). A Markovian model for hospital admissions scheduling. *Management Science*, 16(6), B384-B396. [13]

Cooper, W., Seiford, L., Zhu, J. (Eds) (2011). *Handbook on Data Envelopment Analysis. International Series on Operations Research and Management Science*. Springer.[93].

Dansie, L. S., Odoch, W. D., & Årdal, C. (2019). Industrial perceptions of medicines regulatory harmonization in the East African Community. *PLoS One*, 14(6), e0218617. [105]

Demeester, P., Souffriau, W., De-Causmaecker, P., & Berghe, G, V. (2010). A hybrid tabu search algorithm for automatically assigning patients to beds. *Artificial Intelligence in Medicine,* 48(1), 61-70. [58]

Dhar, S, Das, K. K., & Mahanta, L. B. (2014). Comparative study of waiting and service costs of single and multiple server system: A case study on an outpatient department. *International Journal of Scientific Footprints*, 2(3),18–30. [73]

Dugas, A. F., Hsieh, Y. H., Levin, S. R., Pines, J. M., Mareiniss, D. P., Mohareb, A., & Rothman, R. E. (2012). Google Flu Trends: correlation with emergency department influenza rates and crowding metrics. *Clinical infectious diseases*, 54(4), 463-469. [13]

Dugas, A, F., Jalalpour, M., Gel, Y., Levin, S., Torcaso, F., Igusa, T., & Rothman, R, E. (2013). Influenza forecasting with Google Flu trends. *PLoS One.* 8(2), e56-76. [36]

Faccincani, R., Stucchi, R., Carlucci, M., Sannicandro, R., Formenti-Ujlaki, G., Pascucci, F., & Fumagalli, R. (2022). Evaluation of interaction between emergency medical system and hospital network during a train derailment in Milano. *Disaster Medicine and Public Health Preparedness*, 16(2), 829-834.[106]

France, D, J., Levin, S, Hemphill, R., Chen, K., Rickard, D., Makowski, R., Jones, I., Aronsky, D. (2005). Emergency physicians' behaviors and workload in the presence of an electronic whiteboard. *International Journal of Medical Information*, 74(10), 827-37[47]

France, D. J., & Levin, S. (2006). System complexity as a measure of safe capacity for the emergency department. *Academic Emergency Medicine*, 13(11), 1212-1219. [46]

Garaix, T., Rostami, S., & Xie, X. (2018). Daily outpatient chemotherapy appointment scheduling with random deferrals. *Flexible Services and Manufacturing Journal*, 3(1): 1–25[27]

Goldberg-Hahn, S., Beck J. C., Carter, W, M., Trudeau, M., Sousa, P., & Beattie, K. (2014). Solving the chemotherapy outpatient scheduling problem with constraint programming. *Journal of Applied Operational Research*, 6(3), 135–144. [26]

Goldberg-Hahn, S., Carter, M., & Beck, C. (2012). Dynamic template scheduling to address uncertainty in complex scheduling problems: A case study on chemotherapy outpatient scheduling. *In Society for Health Systems Conference, Las Vegas, NV.* [28]

Gómez, A, T., Santos, J, V., & Poltosi, M, R. (2012). A meta-heuristics approach to the nurse rostering problem. *Journal of Applied Computing Research*, 2(1), 1-10. [96]

Chuma, K. G., & Ngoepe, M. (2022). Security of electronic personal health information in a public hospital in South Africa. *Information Security Journal: A Global Perspective*, 31(2), 179-195. [3]

Gupta, D., & Denton, B. (2008). Appointment scheduling in health care: Challenges and opportunities. *IIE Transactions*, 40(9), 800–819. [25]

Hakim, L., & Bakhtiar, T. (2017). The nurse scheduling problem: A goal programming and nonlinear optimization approaches. In *IOP Conference Series: Materials Science and Engineering* (Vol. 166, No. 1, p. 012024). IOP Publishing. [95]

Hamrock, E, 1., Paige, K, Parks, J., Scheulen, J., & Levin, S. (2013). Discrete event simulation for healthcare organizations: A tool for decision making. *Journal of Healthcare Management.* 58(2), 110-124. [35]

Han, J. H., France, D. J., Levin, S. R., Jones, I. D., Storrow, A. B., & Aronsky, D. (2010). The effect of physician triage on emergency department length of stay. *The Journal of emergency medicine*, 39(2), 227-233. [43]

Harries, A. D., Kumar, A. M., Satyanarayana, S., Thekkur, P., Lin, Y., Dlodlo, R. A., & Zachariah, R. (2019). How can operational research help to eliminate tuberculosis in the Asia Pacific region?. *Tropical Medicine and Infectious Disease*, 4(1), 47-59. [92]

Holm, L, B., Lurås, H., &Dah, F, A. (2013). Improving hospital bed utilization through simulation and optimization: With application to a 40% increase in patient volume in a Norwegian General Hospital. *International Journal of Medical Information*, 82(2), 80-89. [61]

Hoot, N, R., Epstein, S, K., Allen, T. L., Jones, S, S., Baumlin, K. M., Chawla, N., & Aronsky, D. (2009). Forecasting emergency department crowding: an external, multicenter evaluation. *Annals of Emergency Medicine*, 54(4), 514-522. [40]

Huggins, A., Claudio, D., & Pérez, E. (2014, May). Improving resource utilization in a cancer clinic: An optimization model. In *Proceedings of the 2014 Industrial and Systems Engineering Research Conference* (p. 1444). [29]

Jafari, H., & Salmasi, N. (2015). Maximizing the nurses' preferences in nurse scheduling problem: Mathematical modeling and a meta-heuristic algorithm. *Journal of Industrial Engineering International*, 11, 439-458. [100]

Jamom, M., Ayob, M., & Hadwan, M. (2011, June). A greedy constructive approach for nurse rostering problem. In *2011 3rd Conference on Data Mining and Optimization (DMO)* (pp. 227-231). IEEE. [101]

Kirigia J.M., Emrouznejad A., & Sambo L.G. (2002). Measurement of technical efficiency of public hospitals in Kenya: Using data envelopment analysis. *Journal of Medical Systems*, 26(1),10-20. [4]

Kirigia, J, M., Mensah, O, A., Mwikisa, C., Asbu E. Z., Emrouznejad A., Makoudode P., & Hounnankan A. (2010). Technical efficiency of zone hospitals in Benin. *The African Health Monitor*, 2(12). [9]

Latif, S., Rana, R., Qadir, J., Ali, A., Imran, M. A., & Younis, M. S. (2017). Mobile health in the developing world: Review of literature and lessons from a case study. *IEEE Access*, 5(1), 11540-11556. [76]

Levin, S. R., Dittus, R., Aronsky, D., Weinger, M. B., Han, J., Boord, J., & France, D. (2008). Optimizing cardiology capacity to reduce emergency department boarding: A systems engineering approach. *American Heart Journal*, 156(6), 1202-1209. [44]

Levin, S., Dittus, R., Aronsky, D., Weinger, M., & France, D. (2011). Evaluating the effects of increasing surgical volume on emergency department patient access. *BMJ quality & safety*, *20*(2), 146-152. [39, 24]

Levin, S., France, D. J., Hemphill, R., Jones, I., Chen, K. Y., Rickard, D., & Aronsky, D. (2006). Tracking workload in the emergency department. *Human factors*, 48(3), 526-539. [45]

Liberatore, M., Nydick, R. (2008). The analytical hierarchy process in medical and health care decisions making: A literature review. *European Journal of Operational Research*, 189(6), 194–207. [82]

Mahale, P., & Deshmukh, B, B. (2016). Analysis of delays due to waiting lines in healthcare delivery for sustainability. SAMVAD: *SIBM Pune Research Journal*, XII (II), 66-71. [18]

Mala, V, S, P. (2016). Waiting time reduction in a local health care centre using queuing theory. *IOSR Journal of Mathematics*, 12(1), 95-100. [64]

Malhotra, S., & Zodpey, S. P. (2010). Operations Research in Public Health, Public Health Research Methods, *Indian Journal of Public Health*, 54(3),145-150. [67]

Mbonigaba, J., & Oumar, S, B. (2014). The relative (in) efficiency of South African municipalities in providing public health care. *Economic Research South Africa* (ERSA), Paper 474. [10]

Mingzhu, Z., & Ershi, Q. (2016). A multi-type queuing network analysis method for controlling server number in the outpatient. *The Open Automation and Control Systems Journal*, 8(1), 21-33 [52]

Mobin, A. (2018). Applying operations research techniques to minimize delays in hospital operations. *IOSR Journal of Dental and Medical Sciences* (IOSR-JDMS), 17(2), 61-66. [59]

Mubiru, K, P. (2015). A markov decision model for hospital ward admission scheduling. *International Journal of Scientific Research in Science, Engineering and Technology*, 9(4), 188-195. [15]

Mujasi, N, P., Asbu, E, Z., & Puig-Junoy J. (2016). How efficient are referral hospitals in Uganda? A data envelopment analysis and tobit regression approach. *BMC Health Services Research*, 16(230), 1-14. [6]

Murugan, A. N., & Saratha, S. V. (2017). Minimizing the Total Cost in the Out Patient Department (OPD) of a Multispecialty Hospital. *World Journal of Research and Review*, 4(3), 50-53. [56]

Mwihia, F, K., Imunya, J. M., Mwabu G., Kioko U., & Estambale, B.,B., A. (2018). Technical efficiency in public hospitals in Kenya: A two-stage data envelopment analysis. *International Journal of Economics and Finance*, 10(6), 141-150. [5]

Olu, O. T., & Otonritsen, O, J. (2015). Waiting time analysis of a single server queue in an out patient clinic. *IOSR Journal of Mathematics*, 11(3), 54-58. [69]

Ozscan, E. (2005). Memetic algorithms for nurse rostering, international symposium on computer and information sciences. *ISCIS 2005: Computer and Information Sciences – ISCIS*, 3(2), 482-492. [62]

Parks, J. K., Engblom, P., Hamrock, E., Satjapot, S., & Levin, S. (2011). Designed to fail: How computer simulation can detect fundamental flaws in clinic flow. *Journal of Healthcare Management*, 56(2), 135-146. [38]

Priyna, S. (2017). Operations Research in Healthcare: A Review. *Juniper Online Journal of Public Health*, 1(3), 1-7. [66]

Puente, J., Gómez, A., Fernández, I., & Priore, P.(2009). Medical doctor rostering problem in a hospital emergency department by means of genetic algorithms. *Computers & Industrial Engineering*, 56(4),1232-1242. [63]

Quaglio, G., Ramsay, A, Harries, A. D., Karapiperis, T., Putoto, G., & Dye, C. (2014): Calling on Europe to support operational research in low-income and middle-income countries. *The Lancet*, 2(1), 308-310. [91]

Rais, A., & Viana, A. (2011). Operations research in healthcare: A survey. *International transactions in operational research*, 18(1), 1-31. [78].

Rao, D. R. (1974). Applications of operations research techniques in health administration-simulation. *Indian journal of public health*, 18(2), 58-67. [48]

Redd, V., Levin, S., Toerper, M., Creel, A., & Peterson, S. (2015). Effects of fully accessible magnetic resonance imaging in the emergency department. *Academic Emergency Medicine*, 22(6), 741-749. [33]

Reenberg, A, A., Nielsen, B, F., & Reinhardt, L, B. (2017). Optimization of hospital ward resources with patient relocation using Markov chain modelling. *European Journal of Operational Research*, 260(1), 1152-1163. [14]

Royston, G. (2011). Meeting global health challenges through operational research and management science. *Bulletin of the World Health Organization*, 89(6), 683-688. [87]

Saville, C. E., Smith, H. K., & Bijak, K. (2019). Operational research techniques applied throughout cancer care services: A review. *Health Systems*, 8(1), 52-73. [84]

Sheth, N., & Makwana, P. (2016). Application of queuing model on hospital OPD. *IJSRD - International Journal for Scientific Research & Development*, 3(11), 124-126 [55]

Shi, P., Chou, M. C., Dai, J. G., Ding, D., & Sim, J. (2016). Models and insights for hospital inpatient operations: Time-dependent ED boarding time. *Management Science*, 62(1), 1-28. [12]

Sloane, E. B., Liberatore, M. J., & Nydick, R. L. (2002). Medical decision support using the analytic hierarchy process. *Journal of Healthcare Information Management: JHIM*, 16(4), 38-43. [81]

Stop, T, B. (2011). Partnership, Global Fund to Fight AIDS, Tuberculosis and Malaria. *World Health Organization. Priorities in operational research to improve tuberculosis care and control. Geneva, Switzerland.*[88]

Tanga, J., & Pingping, C. (2014). Appointment scheduling algorithm considering routine and urgent patients. *Expert Systems with Applications*, 41(10), 4529-4541. [60]

Teixeira, A., & De Oliveira, M. J. F. (2015, May). Operations research on hospital admission systems: a first overview of the 2005-2014 decade. In *Journal of Physics: Conference Series* (Vol. 616, No. 1, p. 012009). IOP Publishing. [50]

Trilling, L., Guinet, A., & Magny, D, L. (2006). Nurse scheduling using integer linear programming and constraint programming. 12th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2006, Sep 2007, Saint-Etienne, France, 651-656. [94]

Toerper, M. F., Veltri, M, A., Hamrock, E., Mollenkopf, N. L., Holt, K., & Levin, S. (2014). Medication waste reduction in pediatric pharmacy batch processes. *The Journal of Pediatric Pharmacology and Therapeutics*, 19(2), 111-117. [34]

Tunc, S., Alagoz, O., & Burnside, E. (2014). Opportunities for operations research in medical decision making. *IEEE Intelligent Systems*, 29(3), 59–62. [77]

Vancroonenburg, W. (2015). *Operational decision support models and algorithms for hospital admission planning and scheduling* (Doctoral dissertation, PhD Dissertation, Katholieke Universiteit Leuven, Belgium). [65]

Vieira, B., Erwin, W., Hans, E. W., Corine, V. V, Kamer J., & Harten, W. (2016). Operations research for resource planning and -use in radiotherapy: A literature review, *BMC Medical Informatics and Decision Making*, 16(1),149-159. [75]

Waitzberg, R., Hernández-Quevedo, C., Bernal-Delgado, E., Estupiñán-Romero, F., Angulo-Pueyo, E., Theodorou, M., & Maresso, A. (2022). Early health system responses to the COVID-19 pandemic in Mediterranean countries: A tale of successes and challenges. *Health Policy*, 126(5), 465-475. [1]

Watermeyer, G., Awuku, Y., Fredericks, E., Epstein, D., Setshedi, M., Devani, S., ... & Katsidzira, L. (2022). Challenges in the management of inflammatory bowel disease in sub-Saharan Africa. *The Lancet Gastroenterology & Hepatology*, 7(10), 962-972. [106]

Wawer, M. J., McNamara, R., McGinn, T., & Lauro, D. (1991). Family planning operations research in Africa: Reviewing a decade of experience. *Studies in Family Planning*, 22(5), 279-293. [79]

Wonga, C., Xu, M., Chin, K, S. (2014). A two-stage heuristic approach for nurse scheduling problem: A case study in an emergency department. *Computers & Operations Research*, 51:99-110. [98]

Xu, M, Wong, T, & Chin K. (2012). A hybrid heuristic approach of nurse scheduling problem. *World Business Capability Congress*, 5-7 December 2012, Auckland, New Zealand. [97]

Yamin, A. E., & Maleche, A. (2017). Realizing universal health coverage in East Africa: The relevance of human rights. *BMC International Health and Human Rights*, 17(1), 1-10. [104]

Zachariah, R., Harries, A. D., Ishikawa, N., Rieder, H. L., Bissell, K., Laserson, K., & Reid, T. (2009). Operational research in low-income countries: What, why, and how? *The Lancet Infectious Diseases*, 9(11), 711-717. [90]

Zhang, J., Mason, J. E., Denton, B. T., & Pierskalla, W. P. (2011). Applications of operations research to the prevention, detection, and treatment of disease. *Wiley Encyclopedia of Operations Research and Management*, 4(3-4), 1-20. [85]

Zhong, X, Zhang, J., & Zhang, X. (2017). A two-stage heuristic algorithm for the nurse scheduling problem with fairness objective on weekend workload under different shift designs. *IISE Transactions on Healthcare Systems Engineering*, 7(4), 224-235. [99]

Zonderland, M, E., Boucherie, R, J., Carter, M, W., & Stanford, D, A. (2015). Modelling the effect of short stay units on patient admissions. *Operations Research for Health Care*, 5(2), 21–275. [17]