



# Operations Research in Telemedicine

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## Abstract

Telemedicine is the delivery of healthcare, where distance is an issue. This paper explores the use of operations research techniques to contribute to the successful implementation of telemedicine systems. A study of literature concerning the application of operations research together with telemedicine, showed research gaps, but also identified a few examples with respect to linear programming, simulation modelling, Markov decision-making processes, Bayesian networks, queuing theory and meta-heuristics. There are many areas in telemedicine where operations research can be used to ensure the success and sustainability of telemedicine as a viable alternative to providing specialist healthcare that is economically feasible.

**Key words:** telemedicine, operations research, health systems, healthcare

## 1 Introduction

Telemedicine is the delivery of healthcare, where distance is an issue. Broens (2007) found in a study of 50 international telemedicine projects that most of these projects failed. This observation is confirmed by the low success rate in the implementation of telemedicine projects in the public health sector of South Africa. Health systems engineering is an academic discipline where researchers and practitioners treat the healthcare industry as complex systems, and further identify and apply engineering applications in healthcare systems. Health Systems Engineers make use of - amongst others - operations research techniques. Operations research allows us to solve complex decision-making problems, a common phenomenon when developing and implementing a telemedicine system. This paper explores the use of operations research techniques to contribute to the successful implementation of telemedicine systems.

**Methodology:** The first part of this paper is devoted to the study of literature pertaining to the use of operations research techniques within the context of health systems engineering, with a specific focus on telemedicine. This is followed by a qualitative and quantitative evaluation of a selection of techniques. A few examples of operations research techniques used within the context of healthcare is also given to support findings from the literature study and technique evaluation.

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## 2 Literature Review

Two main components play a vital role when developing and implementing a telemedicine system, namely the telemedicine system itself and the project management team who is responsible for the successful implementation of the system. Both of these components can be supported by operations research individually and also simultaneously. Operations research provides the project management team with decision support and the telemedicine system with operating support.

A multiple keyword search is used to identify the availability of literature containing operations research in telemedicine. eHealth, mHealth, and telehealth, are just some of the words that are associated with telemedicine. SciVerse Scopus was used as the search engine to gather articles containing the key words and phrases.

SciVerse Scopus is a bibliographic database containing abstract and citations for scholarly journal articles. The results returned from Scopus is of a scholarly nature excluding advertisements and irrelevant articles. Scopus searches both the internet and its local (scholarly) database of article. A summary of the results obtained from the Scopus search is discussed in the following section.

### 2.1 Scopus Search Result - Scholarly Database

**Table 1:** Summary of Search Results - Scopus Scholarly Database

Keyword	Keyword	Found	Date
Operations Research	-	30 371	1947 - 2011
Operations Research	health	1 374	1952 - 2011
Operations Research	health care	883	1964 - 2011
Operations Research	decision support	882	1974 - 2011
Operations Research	project management	778	1968 - 2011
Operations Research	health systems	56	1966 - 2011
Operations Research	telemedicine	6	1994 - 2007
Operations Research	electronic health	1	2007

Table 1 shows the keywords entered into the search space and the number of articles that contain those keywords. This table is a summary of the local Scopus database. This database only contains scholarly articles and does not include any results obtained from the internet. Operations research was used as the fixed variable in all of the searches. From the results it is clear that there is a multitude of articles containing operations research literature. However, as soon as the search is tweaked to be more specific, focusing on the medical field, the number of scholarly level articles decreases dramatically.

## 2.2 Scopus Search Result - Internet

Table 2 shows the summary of the results obtained with the exact same keywords as mentioned in the previous section. The difference is that the results include data obtained from the internet. The only filter applied in this instance is that the results returned must be articles. This is done to avoid corrupting the data with advertisements or irrelevant website data. Also, note all the results returned from the internet contains dates, hence it is omitted from the table.

**Table 2:** Summary of Search Results - Scopus Internet

Keyword	Keyword	Found
Operations Research	-	766 469
Operations Research	health	256 870
Operations Research	health care	55 381
Operations Research	decision support	74 279
Operations Research	project management	63 200
Operations Research	health systems	9 054
Operations Research	telemedicine	2 199
Operations Research	electronic health	896

It is interesting to note that a much larger portion of the articles pertain to the health environment. This implies that operations research is indeed being used extensively in the health sector, however the documentation and implementation of the operations research techniques used in the healthcare sector are not being documented academically and is mostly personal research. Another point of interest is the fact that the same ratio applies in the case of telemedicine related searches. Few articles of any nature exist which clearly makes use of operations research in telemedicine.

## 2.3 Search Conclusion

The Scopus search engine indicated that few works about the use of operations research in the telemedicine field have been published. This can be contributed to the fact that telemedicine is a relatively new branch in the medical field and also that the use of operations research techniques to support decision making in the telehealth industry is a modern trend that is only now starting to gain popularity in the profession.

From the search results it can also be seen that early attempts have been made to incorporate operations research into healthcare, but the focus was more on clinical support rather than health support.

This is an indication that more research is required to identify appropriate uses of operations research which will benefit the medical field and in this manner improve the success of health and telemedicine projects. The next section describes some of the operations research techniques and possible application of these techniques to support healthcare, especially telemedicine.

A summary of the search results obtained from Scopus is shown in figure 1:

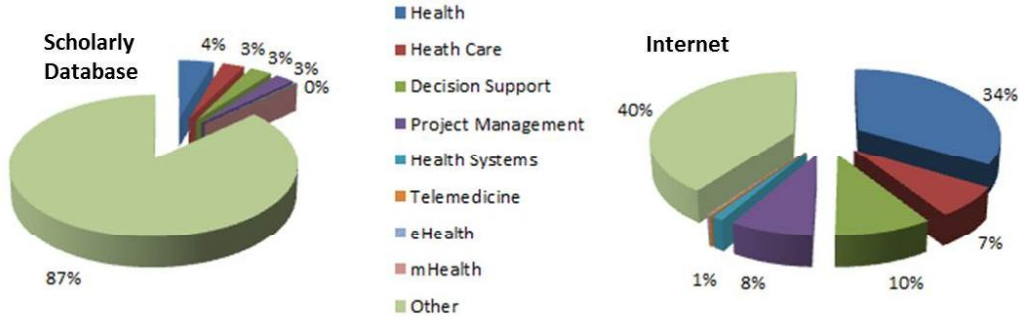


Figure 1: Summary of Scopus Search Results

### 3 Operations Research Applications in Telemedicine

This section describes some operations research techniques used in the telemedicine field. A brief discussion and a relevant example is also given for each operations research technique.

#### 3.1 Linear Programming

Linear programming (LP) is a tool for solving optimization problems and is used in industries as diverse as banking, education, healthcare, etc. [2]. Linear programming has proved useful in modelling diverse types of problems in planning, scheduling, assignment, and design [7].

An example of the use of linear programming to aid the cause of telemedicine in South Africa is the development of a decision support framework for telemedicine by Treurnicht [8]. A telemedicine workstation was developed as a first step in addressing the need of specialized healthcare in rural communities in South Africa. This was followed up by the development of a decision support framework that will assist telemedicine decision makers with a scientifically based needs assessment [8].

Integer programming was implemented to find the best alternative given the utilization and cost of the telemedicine devices, by maximizing the benefit or utilization while reducing the costs involved. The outcome of the project was that devices could be recommended for the workstation given patient data and cost of devices.

#### 3.2 Simulation Modelling

The complexity of many organizations in today's society is such that the totality of the effects of the interacting elements includes sometimes cannot be captured adequately through mathematical model. This is particularly evident when many of the factors affecting the performance of the organization cannot be predicted with certainty. In cases like these, the analyst will often turn to simulation modelling as an alternative approach to the problem [3].

An example of simulation used in telemedicine is the project by Lach [5] that provides people living in poverty conditions in Mexico with medical care. A mobile unit is sent to location, fully equipped with telecommunications gear and satellite connection, where a patient can be diagnosed by a specialist located hundreds of miles away in a hospital. The program's processes were simulated on a computer model. This allowed for various scenarios to be tested and to identify any possible problems. The results were used to assist decision making procedures that lead to increased performance and efficiency of the program [5].

In this instance, simulation modelling was used to analyse a new process. Simulation modelling can also be useful when an already existing process with a lot of variables and constraints need to improved. The popularity of simulation as an optimization tool has lead to many software developers developing powerful simulation packages such as Arena and more recently Simio (a powerful simulation modelling tool with an extensive three dimensional library for visualization).

### 3.3 Markov Decision Processes

Diagnosing a patient more often than not requires sequential decision making in an uncertain environment. Most of these decisions are made relying on the skill of the practitioner and his ability to make the correct assumptions. Due to the fact that the decision made can be the difference between life and death, a support tool to aid the practitioner in his decision making process is crucial. The use of mathematical decision models can reduce the burden on the practitioner as well as increase the likelihood of a successful diagnoses. Markov decision processes (MDPs) are one such technique for aiding the practitioner with certain types of treatment decisions [4].

A serious problem in the medical field is that patients with dementia often cannot remember how to do simple, everyday task. Boger [6] proposed the use of a computerized guidance system that can support a person with dementia, reducing the person's reliance on a caregiver. A planning system that uses MDPs to assist a person with dementia perform the simple task of washing hands was developed. Results from the study gives a clear indication that MDPs can be used to great effect in this type of guidance problem [6].

### 3.4 Bayesian Networks

A Bayesian network is a graphical representation of a probabilistic model of conditional dependencies using variables of interest [4]. A Bayesian network could for example represent the probabilistic relationship between diseases and symptoms.

A model of a real-world application which aim is giving a daily diagnosis on the hydration state of kidney disease to people is used as an example. Based on a collaboration with the ALTIR and the C.H.U. of the Nancy Center for the Treatment of Kidney Disease Patients and the University Hospital of Nancy, the Diatelic project aims to monitor kidney disease patients at home who are waiting for a kidney transplant. These patients must have a substitution process in order to replace the kidney before the transplant. To improve the performance of the system and enhance the interaction of the telemedicine system with the specialist and patients, a Dynamic Bayesian Network is used. The goal of the model is to predict a

problematic situation before it happens rather than discovering them as they occur [9].

The approach to model such a domain in terms of data fusion using the dynamic Bayesian network was successful and it is possible to detect pathological situations by directly using the results issued from the dynamic Bayesian network, which allow a synthetic view of the possibility that the patient is in an abnormal hydration state [9].

### 3.5 Queueing Theory

Queueing theory is a mathematical model approach to describe queues. This mathematical technique allows for the derivation and calculation of several performance measures. Queueing theory is applied in various fields, including telecommunications, traffic engineering, and hospitals. It is considered an operations research technique since the results are often used when making decisions about the resource needed to provide the service.

An example of the application of a queueing system in telemedicine is the study done by Tarakci [10] of the optimal strategy to provide traditional face-to-face consultation via experts and remote medical services via tele-specialists to a remote hospital. The whole system is modelled as a queueing problem and the optimal staffing policy for this hospital is provided by taking into account the various cost components, such as those for staffing, mistreatment, and waiting. An optimal investment in telemedicine technology that offers the best trade-off between the quality and accuracy of telemedicine services is also found. The outcome is that the queueing system determines the optimal tele-specialist policy of which patients to treat remotely via telemedicine and which patients to refer to the experts for a face-to-face consultation [10].

### 3.6 Meta-Heuristics

Meta-heuristics are ways to go about searching for the optimal solution in a structured and logical fashion. It is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regards to certain user defined constraints. A candidate solution and a method to test whether the solution is good or bad, better or worse is required. Normally, a meta-heuristic is applied in situations where there is very little heuristic information available and a brute force search is out of the question because the search space is too large. There are many different meta-heuristics such as particle swarm, ant colony, and genetic algorithm. Each technique has its strong- and weak points and the use of the correct technique is subject to research and experience.

Telemammography and telemedicine requires that the characteristics of an image, such as the image resolution, bit-depth and intensity response are standardized to ensure the integrity of the diagnosis. Qian [11] developed a method based on the genetic algorithm to allow for the standardization digital mammography images. The techniques that are used to standardize the image are based on geometric and intensity transformations that are discovered by using calibration images. The result of the study was that the genetic algorithm method improved the detection sensitivity rate (true positive%) from 60% to 87% while the false positive was successfully reduced from 3.5 per image to 1.9 per image [11].

## 4 Conclusion

Few articles on a scholarly level exist that illustrates the use of operations research techniques in telemedicine. This should be seen as an opportunity for operations research specialists to contribute to the field of telemedicine and the use of operations research in Telemedicine. The previous section showed that there are people using operations research techniques to facilitate the development and implementation of telemedicine systems. It also indicated that there are many areas in telemedicine where operations research can be used to ensure the success and sustainability of telemedicine as a viable alternative to providing specialist healthcare that is economically feasible.

The growing need for specialist healthcare in the developing countries due to economic growth has pressured governments and health institutions to increase its capacity and reach when providing healthcare. Telemedicine provides an economically feasible solution to one man's most basic rights; a right to proper healthcare. It is thus worthwhile to invest in telemedicine, not only financially, but also academically.

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