Making an Impact on Healthcare Logistics

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Abstract This handbook provides our take on optimization of logistics processes in healthcare and on the gap that exists between theory and practice. We will bridge that gap as all theoretical results presented in this book have actually been implemented in the healthcare domain. We are driven by a desire to improve the healthcare system, by effectively making an impact with Operations Research (OR). We discuss specific projects that have addressed major challenges for healthcare Operations Research. We present our solution approaches, our approaches to implement the results in practice, and the impact on healthcare organizations. In addition, we discuss the problems we encountered when implementing the results in practice and how we addressed them. In this introductory chapter, we discuss the ecosystem of our research center CHOIR (Center for Healthcare Operations Improvement & Research) and demonstrate how we have an impact on healthcare logistics.

1 Introduction

This handbook provides our take on optimization of logistics processes in healthcare and on the gap that exists between theory and practice. We will bridge that gap as all theoretical results presented in this book have actually been implemented in the healthcare domain. We are driven by a desire to improve the healthcare system, by effectively making an impact with Operations Research. We discuss specific

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projects that have addressed major challenges for healthcare Operations Research. We present our solution approaches, our approaches to implement the results in practice, and the impact on healthcare organizations. In addition, we discuss the problems we encountered when implementing the results in practice and how we addressed them. This book is targeted at (a.o.):

- *Operations Research teachers and students* to have a standard reference text for state-of-the art Operations Research techniques that may be used in an advanced class on healthcare Operations Research;
- *Healthcare logistics researchers* to have a standard reference text for state-of-the art Operations Research techniques and valuable lessons on how to engage practice;
- *Healthcare logistics consultants* to have an overview of available methods;
- *Healthcare managers* to become aware of the potential, complexity, and (engineering) approach that come with applying healthcare Operations Research techniques;
- *Healthcare practitioners* to become aware of the opportunities for logistical improvements that may be obtained invoking Operations Research techniques.

In this introductory chapter, we will discuss the ecosystem of our research center CHOIR (Center for Healthcare Operations Improvement & Research) and demonstrate how we have an impact on healthcare logistics.

2 The Ecosystem of Education, Research, and Impact

Since the early 2000s, CHOIR has invested in building sustainable relationships with healthcare institutions. Together with our stakeholders, we facilitate the CHOIR ecosystem of education, research, and impact. In this section we first explain the ecosystem in Sect. 2.1, followed by the network of healthcare organizations and other involved stakeholders in Sect. 2.2. We furthermore discuss the three main activities of CHOIR, education, research, and impact, in Sects. 2.3, 2.4, and 2.5, respectively.

2.1 The Ecosystem

The CHOIR ecosystem is a unique collaboration between academia, healthcare organizations, and business partners. We leverage this collaboration from the onset of every project to ensure that (i) research starts from a question that is relevant to practice, (ii) research is executed as generically as possible, to advance its applicability to multiple healthcare organizations, and (iii) implementation is considered from the start of the project, to maximize the chances of actual implementation of the research results. Projects executed within the CHOIR ecosystem consist of five

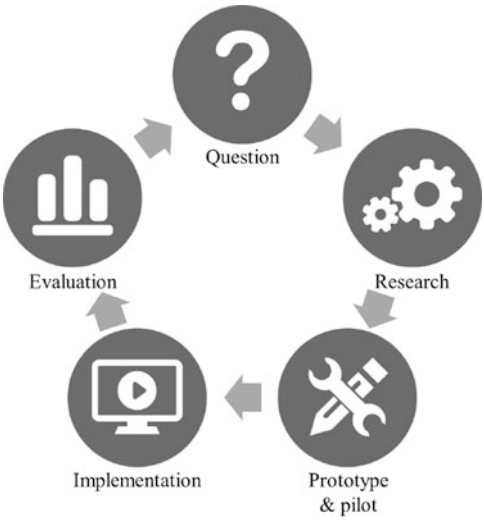

Fig. 1 The CHOIR ecosystem

phases, as shown in Fig. 1. Currently, CHOIR's predominant involvement is with the first two phases of the ecosystem, starting with a question, followed by research and possibly a pilot study. However, after a successful research project, impact in practice is not guaranteed. Therefore, the ecosystem continues with a prototype and pilot, implementation, and evaluation phase, in which our spin-off company Rhythm is involved.

Question: each project starts with a question, originating in healthcare practice. We stipulate involvement of clinical staff in every project, to ensure them taking ownership from the offset of the project. In many cases, an organization or department approaches us with a question, which is often formulated as a solution. This solution is regularly in the form of more capacity. For example, "The work pressure for our staff is way too high, can you calculate how much more capacity we need?" Most questions are raised on perceived issues, such as a high workload in our example. However, the human mind tends to remind those incidental situations over common situations in which no pressure was present. Furthermore, a rational interpretation of these issues is regularly not available, as performance is not quantitatively measured but subjectively interpreted.

To address a question from practice in a systematic way and to find the root cause problem, we follow a systematic problem-solving method, such as the managerial problem-solving method [3]. We first determine the core problem(s). Furthermore, we analyze the initial performance of the system using quantitative and qualitative techniques. This is required to objectify the perceived problems, to establish whether any operational data is present, and in order to establish after the project whether performance has improved. For this purpose, we define KPIs and gather target performance levels from administrators. Using these systematic analyses, the perceived problem becomes a quantified and objectified problem. This more often

than not causes a change in the research question. It is key to closely collaborate with the involved care providers, to make them aware of the (road to the) objectified problem and to maintain their ownership of the problem. Continuing the example, analysis might have shown that the work pressure for staff is indeed 20% above target in the mornings but below target in the afternoon. The research question then becomes: "How to allocate work over the day, to level the work pressure for staff?" or "How to optimally align the staff schedules to the workload over the day?"

Research: after the question is well designed, the research goals are clear, the target performance is known, and stakeholders are involved and commit ownership, research starts. This starts with a (literature) search for approaches that can overcome the gap between the current and the desired situation. After this search, solutions are generated using a systematic solution design process, or tooling can be developed to design a(n optimal) solution. Tools that visualize (redesigned) processes can provide much insight to practitioners and lower the barrier for acceptance. Particularly discrete event simulation can greatly assist to demonstrate the expected performance of the solution in practice and to convince healthcare employees of the solution's impact in practice.

Prototype and pilot study: after a valid solution has been chosen, a prototype is developed, and/or a pilot study is started. A prototype is developed when software is required to assist in decision-making and includes the design of the new decision-making process, including the control mechanism, governance, information structures, and tooling. A pilot study is started to evaluate the use of the new decision-making process in practice. A pilot study is always conducted in a small setting, in order to evaluate the requirements of the implementation phase, to analyze the needed support during a full implementation, and to analyze and overcome the shortcomings of the solution in practice.

Implementation: a successful prototype and pilot study is followed by a full implementation of the solution. This not only includes a well-designed implementation plan and support during the implementation but also aftercare and continuous development of the tooling to support the needs of practice.

Evaluation: after the implementation of the solution in practice, the evaluation takes place to empirically assess whether the solution resulted in the expected performance improvement. From the evaluation, new questions come up, which makes these five phases act as a cycle.

2.2 Stakeholders

Depending on the phase of the cycle, various stakeholders are involved to enable a successful impact in practice. Among these are the patients, frontline staff, healthcare administrators, business partners, bachelor, master, PDEng and PhD students, and faculty members.

Gathering *patient* preferences is essential input for system redesign but is rarely reported in Operations Management (OM) publications. Patient inquiries, for example, using discrete choice experiments, may uncover operational constraints and performance indicators.

Healthcare professionals are involved in all phases of the cycle, as the project is executed within the healthcare institute. Our network of healthcare professionals is involved after a first implementation and evaluation cycle in the healthcare organization under study, to show the results in practice and to enable further dissemination of the results among other healthcare institutes.

Business partners play an important role in the implementation phase, by providing a complete business solution based on the research and prototype. A fruitful relation with such a partner is potentially mutually beneficial, as well-implemented research leads to new research questions and more opportunities for implementation. Also, it may generate revenues, which preferably would (partly) flow back to fund research. For this reason, in 2014 CHOIR has started a spin-off company, called Rhythm. By collaborating with this spin-off, we may use part of the income of the partner for new research opportunities. The same can be obtained through a royalty or intellectual property contract with an external partner.

Student-researchers are a main driver of our research projects. We find it essential for CHOIR researchers to be present in healthcare organizations, to lower the barrier for practitioners to approach us, to ensure relevant topics of study, and to promote involvement of frontline staff. Therefore, we are convinced that student-researchers should be positioned in a healthcare organization for a major part of their research, ideally to be considered by practitioners as part of their own organization. Therefore, we follow the *researcher-in-residence model* in all stages of the research project. The researcher-in-residence model positions a student-researcher as a core member within a healthcare team of relevant care professionals [6]. In a context of process improvement, the researcher brings a new body of expertise, focused on data analysis, modeling, and structured decision-making, which is different from, but complementary to, the expertise of the existing team. Within CHOIR, we differentiate between three types of student-researchers, with their own skill set, related to the analytics framework of Gartner [2], as displayed in Fig. 2.

Bachelor students excel in descriptive and diagnostic activities. Within a project team, they perform a thorough problem definition, together with a root cause analysis. Based on this analysis, they present improvement opportunities to assist decision-makers. *Master students* not only assist in descriptive and diagnostic activities but can also take on a predictive or prescriptive aspect to enhance decision-making support, depending on the organization's need. *PhD students* collaborate in projects spanning all possible activities, including descriptive, predictive, and prescriptive activities. It is beneficial to include PhD students in projects from an early phase for a good understanding of the problem and its causes. Furthermore, the perception by clinicians and other healthcare staff that an outside person (the PhD student) is fully aware of all restrictions that apply leads to high acceptance and cooperation rates and therefore a better performance of the proposed solutions. As PhD students reside in a healthcare organization for a longer period of time,

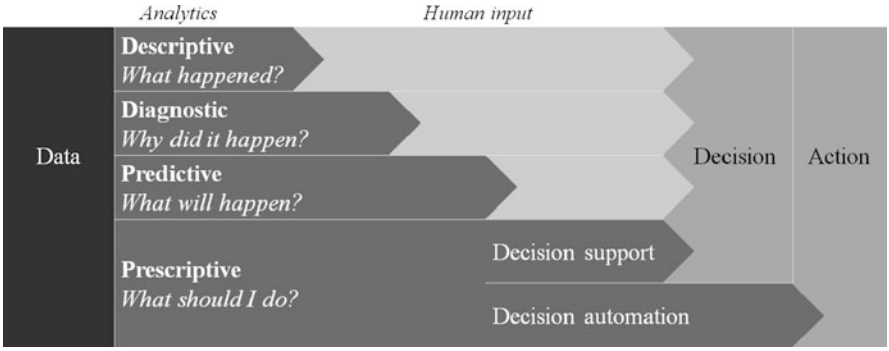

Fig. 2 Gartner's analytics maturity model [2]

prototype, pilot study, and early implementation results can be evaluated to prove impact in practice not only analytically but also in an empirical way.

Besides students that perform research activities, we employ *PDEng students* in the Professional Doctorate in Engineering (PDEng) program. This is a 2-year postgraduate program that focuses on applied research. Promising research results are translated into a prototype for a professional context, in close collaboration with a healthcare institute. A PDEng student focuses therefore on the prototype and pilot phase of the CHOIR ecosystem. PDEng students reside in a healthcare organization, in order to evaluate the requirements of the implementation phase, to set up the decision-making process, to analyze and overcome the shortcomings of the solution in practice, and to align this system with the institute's information systems.

Finally, *faculty members* are important contributors to the CHOIR ecosystem. They regularly visit healthcare institutes, and junior faculty members might even continue to participate in the researcher-in-residence model themselves. This prevents intellectual isolation of the junior staff and students, which is a common disadvantage of the researcher-in-residence model [6]. Being a researcher-in-residence requires great professional skills, which are best trained on site. Also, evidently it requires academic skills, which are best trained at the university, with faculty members and fellow researchers. The CHOIR researchers therefore reside at the university together for at least 2 days per week for this purpose and to share experiences and collaborate with other researchers-in-residence. Faculty members not only educate students and care professionals but also monitor the applied methodologies in the various projects, connect healthcare institutes with similar research questions, and link relevant people within the CHOIR network. Through their diverse activities, faculty members are involved in all three pillars of CHOIR (education, research, impact), which we elaborate upon in the upcoming sections.

2.3 Education

The first pillar of CHOIR is education. By educating both students and healthcare professionals, CHOIR aims to bridge the gap between theory and practice. As a research center within the University of Twente, CHOIR's main educational focus is on BSc and MSc students of industrial engineering and management, health sciences, and applied mathematics. The teaching activities encompass Operations Research in healthcare through lectures and practical sessions but also professional and academic skills training and practical experience, through graduation projects and internships. We aim to educate students to become independent researchers within an organization that speaks a different language. After their studies, many CHOIR alumni continue their career in healthcare and spread the knowledge throughout the organizations they work in, which results in a growing healthcare logistics community.

Aside from academic students, CHOIR also educates healthcare professionals, including managers, administrators, logistics staff, doctors, and (head) nurses. Most of them have an educational background in medicine or nursing and lack OM training. From experience, these professionals often know the practical constraints of process optimization but lack methodological knowledge and knowledge about theoretical (im)possibilities. Also, they typically find it hard to look at operational processes in an integrated way. Instead, they tend to only focus on their department or role in the system. The course encompasses not only theory. Parallel to the course, the participants have to perform a process improvement assignment within their own department, under supervision of CHOIR staff. In our experience, many former participants in the course become champions for our research approach. They often initiate new research projects, serve as in-company supervisors for our student projects, and guide the implementation of our research in practice.

2.4 Research

The second pillar of CHOIR is research. We take on complex logistical challenges that are driven by practice to design or optimize the organization of healthcare processes. Herein, we aim to improve the quality of care, the quality of labor, and the efficiency of processes. We find it important to emphasize this, as process optimization is quickly solely associated with efficiency and working harder. As it is evidently undesirable to try out interventions in practice, in our research we make use of mathematical models and discrete event simulation to prospectively assess the performance of an intervention before actual implementation.

We disseminate our research in the scientific community through two main channels. First, we present and publish our results in the OM/OR domain, where field experts can give us feedback on the methods used. Second, we present and publish our results in the medical domain, to show the potential of the use of

OM/OR tools for optimizing healthcare processes. CHOIR receives its funding for research and PhD and PDEng projects both from practice, e.g., through funding from healthcare organizations, and from funding agencies, e.g., through national science programs.

2.5 Impact

The focus of our education and research is to have an impact in practice, which is the third pillar of CHOIR. For a knowledge gathering and developing center such as CHOIR, impact is the dissemination and effective application of that knowledge in practice. We disseminate knowledge through the network of healthcare providers by the positioning of our students in healthcare organizations, through seminars and symposia at our university and at healthcare organizations, through teaching, through alumni, and through publications in professional and academic journals. By organizing meetings specifically targeted at professionals involved in capacity management and (patient) logistics, we collect new problems to work on but also share knowledge, tailored to the specific needs of this group.

We apply knowledge in practice in various ways. Through the projects of bachelor, master, PDEng, and PhD students, we contribute to process optimization in practice. Although not every project results in implementation, the presence of someone with a different background that questions regular protocols raises an awareness for improvement potential in organizations. Also our spin-off Rhythm makes an impact in practice through various activities, such as consultancy, training, and knowledge and software development. Over the years, we have gathered much experience in effective and less effective application of knowledge in practice. In the next section, we therefore discuss some conditions for making an impact.

3 Deliberations for Impact

In this section we reflect on the impact we have made in practice with CHOIR's research projects and educational program and analyze the critical success factors. We discuss four deliberations that we encounter in our research projects, which we illustrate using real-life examples:

1. Theoretical projects vs. practical projects
2. Theoretical solutions vs. solutions from practice
3. Building relationships
4. Bottom-up and top-down

3.1 Theoretical Projects vs. Practical Projects

The theoretical requirements for scientific research projects can be challenging. For example, modeling is one of the requirements for our BSc and MSc students in industrial engineering and management and applied mathematics to successfully finish their thesis projects. However, this theoretical requirement may contradict with the needs in practice, where a straightforward and easy-to-implement solution can have great impact already. Furthermore, there are projects with high potential for theoretical contributions to the scientific community, which are not relevant to practice. On the contrary, there are also projects with high practical relevance but with little significant contribution to science. For all our research projects, we always aim to combine a theoretical and practical perspective.

We realized a fruitful synergy between theory and practice when we were involved in the rebuilding of the surgical inpatient units in the Academic Medical Center in Amsterdam. We used the Erlang loss model to quickly answer the hospital's questions with respect to the number of beds required per unit given a prespecified blocking probability and simultaneously developed the much more detailed bed census prediction and flexible staffing models of chapter "Bed Census Predictions and Nurse Staffing". By providing practical advice quickly, we convinced nurses, physicians, and management of the usefulness of Operations Research methods. In response, they committed to supporting our research for developing the more detailed models.

Another example of finding the right balance between theory and practice is our work at the pre-anesthesia evaluation clinic at the University Medical Center in Leiden [7]. A mathematical model was developed to evaluate several alternative clinic designs, in order to overcome long patient waiting times, overcrowding, and high workload for staff. The model outcomes were discussed with clinic staff in several iterations, leading to improvement of the model and new scenarios to analyze. Already 4 months after the start of the project, an alternative clinic design, which was chosen unanimously by staff, was successfully implemented.

3.2 Theoretical Solutions vs. Solutions from Practice

When problems increase in frequency or size, we find that problem owners rapidly advocate the necessity of more capacity as the solution. However, in our experience with improvement projects in healthcare settings, in hardly a handful of cases there was a proven capacity shortage. Increasingly, healthcare providers realize that the rising expenditures need to be countered and that more capacity (especially nursing staff) is unavailable. Instead, new process designs and new planning and control models are sought after to overcome their challenges.

From a theoretical Operations Research perspective, exact methods to find or design an optimal solution are preferred over evaluation studies. Exact methods

determine the best possible decision for the project team. As the decision is optimal, it shows the best possible performance that can be reached, which can serve as a benchmark for the organization's performance. From a practical perspective, evaluation studies are preferred, for example, using computer simulation. Evaluation studies enable a researcher to test several interventions and scenarios. They give the involved healthcare staff more flexibility in testing those interventions which they consider promising to implement in practice. As evaluation studies often include a visual component, they are also relatively easy to follow and understand, which supports the acceptance of final recommendations even more.

As mentioned in Sect. 2.1, the question posed by a healthcare organization may be introduced in the form of a solution. This proposed solution is typically evaluated as one of the possibilities to solve the problem in the research phase. This is a practical perspective, wherein the possibilities for implementation are considered more important than finding the optimal solution. Note that in practice, a straightforward, near-optimal, planning solution most likely leads to higher impact than an optimal solution, as employees adhere better to easier-to-understand planning solutions than to more complex solutions.

In our experience, most successful studies from which one or more recommendations were implemented involved some kind of evaluation component. For example, in the histopathology laboratory of the University Medical Center in Utrecht, we were involved in a process improvement project [4]. During this project several interventions were evaluated. As decision-makers were involved in the design of the interventions themselves, they knew whether implementation of each intervention was realistic and possible. From a research perspective, it might be interesting to add several theoretically interesting solutions, or alternative solutions, for example, to serve as benchmarks for practice. Complex solutions, which are, for example, the outcome of an optimization study, have a higher chance of implementation when their implementation depends less on human input. An example is the schedule template in the outpatient clinics' agendas of the same hospital [5]. Based on this research, an optimized blueprint schedule was programmed into the computer system used for appointment planning, which reduces the possibilities of misuse and nonadherence.

3.3 Building Relationships

Research projects are not only successful due to the researcher but to a large extent also due to the project team surrounding the researcher. Many of the healthcare organizations that CHOIR collaborates with have a so-called champion. This champion supports the CHOIR ecosystem and is the connector between CHOIR researchers and the organization's board. Besides champion individuals, also champion departments or organizations are present. For organizations to benefit most from process improvement projects, it is essential to grow from a champion individual to a champion department or organization to ensure the continuity of

process improvement in the healthcare organization. This way, the implementation and continuation of the results of a project does not depend on a single individual. Collaborating with champion institutions allows for long-term relationships, which enables to take on larger research projects with long-term commitments. These projects can typically result in more impact, as not only quick wins are derived, and the project scope can be extended over multiple departments and hierarchical planning levels.

If an organization has evolved into a champion organization, it is key to further invest in this organization to create a long-term relationship, to ensure the continuity of process improvement in healthcare organizations. This requires an understanding from both sides that research projects are typically time-consuming and thorough, whereas healthcare organizations are typically in need of solutions on the short-term that work just fine, when they face logistical challenges. Champion organizations should be supported with both: thorough research for the long-term (re)organization of their logistical processes and support for short-term challenges. The investment required is also related to visibility: the researchers should be present in the organization and ideally work from there several days a week. It is important to set up training programs for staff and the C-suite, in order to enable the organization to ultimately successfully complete improvement projects themselves. From the organization's side, a financial investment is essential, since creating a financial relationship usually leads to enhanced commitment.

One of our champion organizations is Sint Maartenskliniek (SMK), a Dutch hospital for movement and posture. In 2014, we started our formal collaboration with SMK trough a PhD project, initiated by a champion individual, and have expanded our collaboration ever since. So far, one PhD and one PDEng student have graduated, and numerous MSc and BSc thesis projects have been executed in various departments of SMK. Rhythm B.V. support SMK in handling their logistical challenges. In SMK, we often work in close collaboration with Rhythm B.V. This collaboration has resulted in valuable outcomes, for example, regarding translating the bed census predictions of chapter "Bed Census Predictions and Nurse Staffing" into tooling that is used on a day-to-day basis to predict the occupancy of the wards and assist tactical operating room management decisions and major advances in their multi-appointment scheduling [1]. Furthermore, through the close collaboration and prior experience with their processes and data, we were able to support SMK with their short-term challenges faced during the COVID-19 crisis, for example, related to restarting their in- and outpatient care.

3.4 Bottom-Up and Top-Down

The bottom-up and top-down process improvement approaches are two complementary strategies for starting process improvement projects in practice. Bottom-up process improvement considers process improvement projects that are initiated by frontline staff and that focus on (iterative) process improvements on the

operational level of control, for example, to promote a culture of continuous quality improvement. Given that the healthcare process improvement field is still growing, there are a lot of process improvement opportunities. Therefore, it is important that healthcare organizations create a safe atmosphere for bottom-up quality improvement, in which all staff is involved in the improvement efforts. Top-down process improvement considers process improvement projects initiated by the management of an organization or department and is often executed by a project group. Top-down approaches revolve around the redesign and optimization of processes, planning, and control. Top-down process improvement projects enable organizations to make structural changes to their organization and to invest in new solutions, especially on the strategic and tactical level of planning and control. These projects are often well organized and (financially) supported by top management as the expected impact is large.

In a champion organization, the joint approach gives the highest probability of success. Bottom-up approaches aim to create an improvement culture, which creates a focus on operational processes and performance by frontline staff. Top-down approaches on the other hand can result in higher-level organizational changes. However, when operational level improvement opportunities are still abundant, frontline staff support for a top-down approach will be low. Therefore, the operational processes should operate sufficiently well before initiating a top-down approach. Furthermore, when top-down support is present, but problems are not perceived by frontline staff, implementation possibilities of project results are limited. Summarizing, it is essential to invest in champion individuals when starting research projects and to further extend this relationship to the development of a champion organization, to maximize impact.

The research project at the pathology department of the academic hospital in Utrecht was initially top-down initiated [4]. Through the top-down commitment, the results therefore benefited strategic decision-making – ultimately leading to the acquisition of additional laboratory work of a regional hospital in their laboratory. However, to deliver a successful project, much effort was needed into getting the frontline employees involved. For this, being a researcher-in-residence was the key to success. By incorporating the frontline employees into the problem finding and solution design phases, they supported the final recommendations of the project and were eager to implement the new planning rules in practice.

4 The Handbook of Healthcare Logistics

In this handbook of healthcare logistics, we highlight some of the results of the CHOIR ecosystem and demonstrate how our work has an impact on daily hospital operations. The book consists of three parts.

In Part I, we provide an overview of the state of the art, starting with a survey of literature reviews on patient planning and scheduling in healthcare. Following the

dominant patient routing in modern hospitals, we subsequently discuss outpatient clinic optimization, robust surgery scheduling, and hospital ward logistics.

In Part II, four examples of Operations Research applications in healthcare planning are given, related to surgical process analysis, emergency operating rooms, ward occupancy leveling, and nurse staffing.

In Part III, several case studies are presented: on clinical physiotherapy capacity planning, integrated emergency posts, master surgical scheduling, and the implementation of integral capacity management.

We hope to inspire ambitious researchers, showing that it is possible to make an impact with healthcare Operations Research.

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