Service Science in Hospitals:  
A Research-Based Partnership for  
Innovating and Transforming Patients Care

ABSTRACT

Hospitals are among the most complex service organizations. Indeed, operating a hospital entails the coordination of complex processes among highly skilled individuals, often in the face of literal life-and-death scenarios, and always under financial constraints. When providing care, hospitals are thus challenged along three main dimensions: Clinical – i.e., providing the best possible medical care, Operational – e.g. matching staffing levels with demand, and Financial – i.e. controlling the cost of care.

Due to the interdependence of these dimensions, the need hence arises for an integrated process management approach that brings together professionals from varied disciplines, including medical professionals, operations researchers, IT professionals, human factor engineers, financial specialists and process improvement experts. To address these needs, a partnership has been formed between the Industrial Engineering Faculty at the Technion – a world class unit within one of Israel's most prominent academic institutions, the Rambam hospital – the largest hospital in the north of Israel, and IBM's Haifa Research Lab. This partnership is in order to collaborate on the design of new systems, methods, processes and techniques, to improve and optimize care processes at the Rambam hospital and beyond. Following a rigorous data-driven scientific approach, and relying on, expanding and fusing established disciplines such as Operations Research, Industrial and Human Factors Engineering, and Information Systems Management, significant improvement work has already been carried out, with additional such work in process and being planned for the future.

This article describes the project, its impact, and the methodologies supporting it. The impact is far reaching in that it can not only revolutionize the management of patient care processes at the Rambam hospital, but it is likely to propagate to other hospitals and care providers, e.g., through IBM's products and services, publications and new teaching material. Moreover, this project has already produced, and is expected to continue to produce, deep research that is relevant to both healthcare in particular and Service Science in general. Needless to say, such outcomes could not have been achieved without the true partnership formed between the three parties involved.

1. INTRODUCTION

Hospitals are unquestionably among the most complex service organizations: hospital operations require the coordination of complex processes, among highly skilled individuals, often in the face of literal life-and-death scenarios, and always under financial constraints. For example, a common challenge is the need to synchronize, in a timely fashion, typically within a rigid time interval, the encounter between the patient, the caregiver, the required data and equipment.

When providing care, hospitals address challenges along three main dimensions: Clinical – i.e., providing the best possible medical care, Operational – e.g. matching staffing levels with demand, and Financial – i.e. controlling the cost of care. Moreover, balancing these dimensions is becoming increasingly demanding due to factors such as population aging and inflating costs. Despite these complexities, scarcely few hospitals comprehensively manage these interdependent dimensions. As a result, and notwithstanding the involvement of highly skilled and highly motivated individuals (e.g. doctors, nurses, engineers), there is much room for improvement in terms of medical care quality and practice, efficiency of operations, and financial effectiveness. Due to the complexity of hospitals, as well as the need to improve care provisioning by holistic process management along multiple dimensions, there is the need to follow an approach that integrates professionals from a multitude of disciplines, including medical professionals, operations researchers, IT professionals, human factor engineers, financial specialists and process improvement experts. In addition, applying the above disciplines in a scientifically sound manner requires actual data, observations, and empirical evidence. As a result of the need to both pull together this variety of disciplines and using a data driven approached, little
research has been carried out that takes an overarching view of all these disciplines.

In order to address some of the challenges mentioned above, we partnered together: the Faculty of Industrial Engineering & Management (IE&M) at the Technion ([2]) – a world-class unit within Israel's most prominent academic engineering institution, IBM's Haifa Research Lab (see [7]), and the Rambam hospital ([9]) – a government-affiliated hospital – which is Israel’s largest northern medical center, serving more than 2 million citizens (one third of Israel’s population). Our partnership has been formed towards designing new systems, methods, processes and techniques. The ultimate goal is to improve and optimize patients care processes, at the Rambam hospital and beyond, based on scientifically sound and data-driven principles that can be rigorously applied and widely disseminated.

In terms of roles and responsibilities, each partner brought unique capabilities and advantages to the table. The Rambam hospital provided the comprehensive medical knowledge of their leading-edge staff, as well as expertise regarding clinical procedures and processes, logistical procedures and processes and the financial aspects of hospital management. Moreover, the Rambam hospital offered an environment where actual improvements could be specified and carried out, and in which observations could be made and data gathered, thus ensuring that planned improvements are implemented. The IE&M Faculty contributed their deep academic research capabilities, in the wide variety of academic disciplines relevant to this project, as well as carrying out necessary rigorous data-analysis and provided a repository and analysis tool. Finally, IBM added not only complementary deep research knowledge in relevant disciplines, through its world renowned research organization, but also served as an industrial partner who could help in turning research results into actual implementable products and services, both for the Rambam hospital and the healthcare industry as a whole. Additionally, IBM contributed significant funding to the project, within its Open Collaborative Research (OCR) framework ([1]), in order to support academic research of Technion faculty and graduate students.

We began the project by charting the hospital territory. It was jointly decided to focus on the following units, that represent diverse yet central hospital operations: the Emergency Department (ED) - which is the gate and window to the hospital, and which must operate in a mass-customized mode – i.e., follow a structured care process while providing to each individual the specific care required; the Neonatal Intensive Care - in which each infant represents a unique complex medical case whose hospitalization requires significant resources; the neo-natal trauma unit - where a team of physicians and nurses are often challenged with saving a life within typically a time-window of about 40 minutes; the operating rooms - which is by far the most capital-intensive hospital unit (in terms of both cost and income); and an internal ward – representing the heart of the hospital's routine clinical practice.

We started with focusing on the ED (or ER, as it is often called) – similarly to most EDs world-wide, this is a facility where patients undergo complex care processes, while suffering through excessive delays and deteriorating care quality. The ED is thus a natural candidate to benefit from this project. In parallel to these ED efforts, we initiated pilot projects within the other focus wards. All projects were driven and supported by detailed observation and data gathering.

Within our project, we have thus followed a rigorous scientific approach (see Section 3). We are indeed on the path of improving patient care processes at the hospital. Specifically, we have completed several significant projects, intended to achieve measurable improvements in patient care processes, with longer term goals which would potentially result in a revolution of the manner in which care processes are designed and managed at the hospital. Our work has also had significant academic impact, as manifested by research papers, new course material, and novel techniques and tools that can be applied to other service domains.

2. IMPACT

The impact of this wide-arching project encompasses all partners, and is both practical and foundational. The first type of impact, described in Section 2.1, is real significant improvement in the design and management of patient care processes within the hospital. Another significant impact of our project is the development of new scientific, engineering and managerial techniques, the potential influence of which reaches beyond healthcare in that they are applicable to a variety of service domains. Section 2.2 provides details regarding these techniques. Additionally, our project has
significant academic impact, which is described further in Section 2.3. Finally, this project is also impacting IBM's offerings in the healthcare domain. Unfortunately, due to business confidentiality reasons, no additional details regarding this type of impact can be provided in this present work.

2.1 Improvements to Care Processes

In order to ensure that it would be possible to quantify the impact of our work, initial project steps included both detailed metrics definitions, and detailed baseline observations and measurements (see Section 3.1 for further details). An example of a defined operational metric is the Length Of Stay (LOS) in the Emergency Department (ED): this is the time duration between the entrance of the patient to the ED, and the time the patient leaves the ED (either being discharged from the hospital or admitted to an inpatient ward). An example of a clinical metric is the number of clinical errors carried out within a certain time period (e.g. a month) and associated to a specific clinical routine. An example of a financial metric is the total cost of imaging tests within a month.

Under the scope of this project, a large number of improvement works have already been completed, and are expected to have a positive impact on the defined metrics. Brief descriptions regarding two of these projects appear below, with additional details appearing in Section 4.

- The physical layout of the ED has a significant impact on the patient care process. This is due to the fact that in some layouts, a physician or nurse will have to walk a significant distance in order to treat a patient. If the need to walk such distances arises frequently enough, it has both an operational impact and a clinical impact. The operational impact arises due to the fact that this walking distance may impose an additional significant load on the medical staff. The clinical impact may arise due to the fact that if a medical staff member has to walk a significant distance to treat a patient requiring non urgent medical attention, this staff member may prefer to wait until there are several such patients in the distant location which require treatment, thereby delaying medical treatment. As the physical layout of the Rambam's ED is currently undergoing significant renovations, in one of the improvement projects, recommendations for changing the temporary ED physical layout based on a detailed simulation model that took into account these walking distances. The implementation of these recommendations is expected to reduce the load on medical staff (e.g. by reducing about one mile per shift from their walking distances), as well as shorten the time patients wait for treatment. Note that an increase in medical staff is not required to achieve these benefits.

- Potential reduction of up to 20% in patient's waiting time in the ED, by implementing process reengineering methodologies [17]. This is an example of a project which also impacts another hospital, as some of the process changes proposed are being implemented in the ED of the Hadassah hospital in Jerusalem.

A complete list of the improvement projects, with full descriptions, appears in [4].

In addition to these completed improvement projects, there is also significant ongoing work and long term goals. For example, one of the major long term goals of the project is to provide a system for comprehensive monitoring and control of the patient care processes in the ED. The system's goal is to provide monitoring and control functions across all relevant time horizons. Examples of such monitoring and control functions include optimal routing of patients to resources (i.e. medical staff, imaging device, etc.) during the day, deciding on the required staffing changes at 3PM given the status of the ED at 10AM, and deciding what would be the required staff size, and the relevant skills, several years into the future.

This system shown in Figure 1, is based on advanced analytics. These analytics include, among others: Data consolidation, cleansing and correlation; forecasting algorithms to predict future events (e.g., patient arrivals) to support smarter decision making; mathematical models, such as queueing models, simulation models, and Markov Decision Process (MDP) models, which are useful for modeling both operational aspects and clinical decision making; data completion algorithms for filling-in data which cannot be provided by the existing IT systems, to ensure a complete picture of the state at the ED; Optimization algorithms which enable optimal decision making in various intersecting dimensions, i.e. clinical, operational and financial.
The above analytics component needs to be supported by a Data Collection component, responsible for gathering of all relevant data. It will include all data being collected by existing ED IT systems, (e.g., electronic records, imaging, ERP), and will incorporate new information systems, such as real time location systems, which enables constant tracking of patients and instruments, as well as recording the interaction times between patients and medical staff, as these interactions occur.

Finally, in order to provide convenient access to the data and analytics, the system is rounded off by a Data Visualization component. More details regarding this system is given in [13].

2.2 Novel Services Research Techniques

During the work on this project, many novel research techniques and approaches were developed. Two important categories of such work are adapting and enhancing research techniques from other service/production domains to healthcare, and the development of new methods that could be applied to other service domains.

Examples of methods adapted from other domains to healthcare include a variety of human factors engineering techniques such as task analysis techniques, observational studies, interviews, simulation, and mockup development ([12]). Another example is the concept of Lean Manufacturing ([10],[11]), which was adapted to the hospital environment in an effort to reduce the Length Of Stay (LOS) and to increase the staff and resource efficiency.

An example of a technique that was created as a part of this work, and which can be applied to other domain, is the integration of formal operational and quality models. To elaborate, in our setting, it was necessary to integrate the simulation models of the ED processes with formal models describing the impact of time delays on clinical outcomes. This is as standard business process simulation models enable calculating metrics such as ED length of stay, or probability distribution of waiting time until a patient is first seen by a physician. However, given a specific patient, it is unclear what the impact of, e.g., the patients' specific length of stay has on the patients individual clinical status. On the other hand, several works have proposed Markov Decision Process (MDP) models for modeling the impact on delays on clinical outcomes. However, within the ED, it is very difficult to estimate the amount of time that a patient will await treatment without a process simulation model. Therefore, within this work, the process simulation model and the MDP models will be integrated, providing a holistic model that takes into account the delays experienced by patients together with the explicit clinical consequences of these delays. This combined model can then serve as the basis for process based decisions (e.g., routing of patients) so as to directly optimize both clinical and operational measures. Moreover, combining such quality models and process simulation models is a generic technique that can be applied to other service domains for sensitivity to response times. One such service domain is large centers providing IT support, in which the time...
required to solve an IT issue has a significant impact on the cost (for some of the details and issues in providing service from such centers, see [21]).

Another example of a technique that has widespread applicability is simulation based data completion. To understand this, consider data such as waiting times and queue lengths at a specific point in time in the ED. Exact data regarding such quantities cannot be obtained from the existing IT systems in the Rambam ED. However, knowing (or estimating) the values of these quantities is extremely important for efficient real time management of the ED. Therefore, as a part of this project, we have developed techniques for estimating these values, based on whatever data is available, together with the simulation model of the ED process (see [15]). This technique – model based data completion, is potentially applicable to any scenario in which only partial (and possibly inaccurate information is available), and in which additional data is constantly required.

2.3 Academic Impact
With regards to academic impact, new materials have been introduced into academic courses at the Industrial Engineering and Management faculty at the Technion. One example of such influence is the Service Engineering course (see [3]) – a well established course that discusses the application of formal queuing models to the design of service systems. As a result of this project, significant new materials regarding the application of such models to hospital service was added.

This work also resulted in completely new courses being created. An example of such a course is a seminar regarding the use of Operations Research techniques in Healthcare. Another example is the creation of a new course, intended to teach students to apply a multi-disciplinary approach in order to solve services related issues. The need for such a course became apparent during the project work, as it was observed that even in cases in which a multi disciplinary approach would have been beneficial, students at the Technion (both undergraduate and graduate) tended to apply only a single discipline to the solution of any particular problem in an isolated fashion. This isolated approach required, in many cases, that integration between different disciplines be carried out by project participants who have more experience in services research (e.g. IBM staff members). Therefore, it is the purpose of the course to teach students to apply a wider, multi disciplinary approach.

This work has also been the basis for several theses: The thesis in [22], dealt with the development of a novel method enabling the quick calculation of expected load on ED staff. This method could then serve as a planning tool with which the management of the ED could quickly allocate resources to shifts, and assign resources within each shift to different operations in the ED. Another thesis focused on studying communication gaps and information transfer between doctors and nurses in neonatal units, on the road to the development of a better shared status map. This study facilitates improvement of information transfer between team members and the creation of better shared cognitive maps among medical teams, thereby enabling better decision making and reducing medical errors.

This project is fertile ground for additional significant research, including more graduate theses. Finally, several academic articles have already resulted from this work. These include [13], [15], [4] and [17]. The work on additional articles is currently in progress.

3. METHODOLOGY
The methodology we have followed in the project is based on two main principles. The first principle is to base the work on a wide variety of formal and structured disciplines (e.g., operations research, information systems management, etc.) that have been proven useful in manufacturing and other service domains (see Section 3.1). As described in Section 2, in many cases our work resulted in the scientific advancement of these disciplines.

The second principle is the use of a scientific approach. This principle is important in order to ensure, as much as possible, that the research carried out in this project follows a rigorous scientific method, and that proposed changes indeed have the desired improvement, can be integrated into the hospital's challenging environment, and will not result in any undesirable additional side effects. This approach is described in Section 3.2.

3.1 Applied Disciplines
The varied disciplines applied in this project includes medical and clinical knowledge provided by the Rambam hospital staff, Operations Research and Statistics, Industrial Engineering, Human Factors Engineering and Information Systems Management.
(with an emphasis on healthcare informatics). The rest of this section provides additional details regarding these disciplines.

As described in Section 1, medical and clinical knowledge refers not only to the clinical aspects of specific ailments and their treatments, but also to treatment process and protocols, best practices, and relevant dependencies/constraints in the hospital environment.

Operations Research, statistics, and their interplay constitute quantitative methodologies that help transform, through modeling, data into information. The ultimate goal is support of decision making (e.g. resource allocation, analysis of complex tradeoffs), often in the face of uncertainty. The Data reliance makes Statistics an essential prerequisite for meaningful applications of OR. For over 50 years, OR has been applied within a broad range of scientific, engineering and managerial contexts. Examples of OR applications are prevalent in government, military, transportation, manufacturers and service providers. OR also has a long history of applications in health care, e.g., in creating a queuing model for ER processes. Examples of additional methodologies used this project, are optimization and Simulation.

Industrial Engineering (IE) is the branch of engineering that is concerned with the efficient production of industrial goods as affected by elements such as plant and procedural design, the management of materials and energy, and the integration of workers within the overall system. Whereas most engineering disciplines apply skills to very specific areas, industrial engineering is applied in virtually every industry. Examples of where industrial engineering might be used include designing a new loan system for a bank and streamlining operation and emergency rooms in a hospital by applying lean manufacturing concepts ([10],[11]) to reengineer related processes.

Human Factors Engineering (HFE) is the applied scientific domain concerned with the design of engineering systems, tools and machines to fit their users, as well as jobs and work procedures, to assure efficient and safe performance. Human factors engineering started to be used in medical surroundings since the problem of patient safety and the occurrence of medical errors became in the prime focus and concern of the public eye and the medical community. Applying such techniques to the medical domain enabled not only the realization that care givers (doctors, nurses and related personnel), are forced to work in an environment which is poorly designed to their role, but also provided methods for correcting this design, thereby reducing medical errors.

Information Systems Management is the discipline that deals with the creation of systems that store the data required for the organization, and enable accessing and manipulating, and analyzing this data by a variety of users in different organizational roles. Therefore, the term "Information System" covers a wide variety of systems, and include database management systems (such as DB2 and Oracle), Business Process Management (BPM) systems, intended to aid in managing the various processes of the enterprise, and Business Intelligence (BI) systems, intended to extract valuable and timely insights from the large amount of available data. Needless to say, these systems are all relevant to healthcare providers such as hospitals. In addition, unique data related concerns in healthcare environments is the implications of improper usage of the information or the danger in not having all relevant information (see [14]). Due to these unique characteristics of information in healthcare, there exists a sub discipline of Information Systems Management, called Healthcare Informatics, which deals both with the informatics required for medical research and the sensitive information being stored in hospitals and clinics (see [23]).

To close this section, it is important to note that it is only possible to apply the variety of disciplines appearing in this section within the scope of a collaborative project such as this one, which ensures the availability of individuals with in depth knowledge in each of the required disciplines.

3.2 Scientific Approach

Throughout the course of this work, we've adhered to the scientific approach described in Figure 2. All improvement projects have begun in the Observation and Information gathering stage. In this phase, observations and information gathering are carried out to understand the current state. This phase is extremely important, as it is the basis for the rest of the improvement work. Therefore, as described in Section 2.1, one of the first steps of the work in the ED was to define a set of metrics that cover the clinical, financial and operational aspects that needs to be measured and
improved in the ED. The definition of each such metric included a detailed definition of how it would be measured, as well as a definition of the data source used to calculate the value for this metric. For example, for the length of stay (LOS) metric defined in Section 2.1, the definition included the exact definition of the two time points that define the length of stay for each patient, as well as the information system from which this data was obtained. Moreover, the process for obtaining the metrics was quite interesting, and demonstrated some of the benefits of the partnership that was formed. That is as the content of the metric, i.e., which metrics are important, and how they should be measured, were defined based on the specific Rambam staff’s knowledge. However, the knowledge of the other partners defined the form of each metric definition (i.e., the precision required, data source definition, etc.), and helped drive the definitions towards the required specificity.

Due to the importance of the Observation and Information gathering stage, another initial step in the ED was a set of detailed observations, intended to map and validate the patient care process in the ED. This observation process required data relevant to all the disciplines described in Section 3.1 to be recorded. For example, the specific information required in various steps of the process was recorded in order to plot the gap in existing information systems, detailed time measurements were carried out in order to obtain data required for creating operations research models, and patient medical records were reviewed retrospectively by senior ED physicians in order to obtain data related to the clinical aspects of the process.

In the approach described in Figure 2, once the Observation and Information Gathering phase is complete, we pass into the Understanding and Modeling phase. This phase is composed of two stages: The Understanding stage and the Modeling stage. In the understanding stage, the data and information gathered in the Observation phase is analyzed. Based on this information, it is then decided what is the problem(s) that needs to be addressed. Also some goal regarding the future desired state is articulated, which includes quantitative metric improvements.

In the Modeling stage of this phase, models and methods relevant to the disciplines described in Section 3.1 are created in order to enable reaching the goal defined in the Understanding stage. Examples of such models may be clinical models defining new/modified medical protocols or practices, information systems models describing how data regarding the patient care processes should be stored and monitored, operations research models such as queuing formulae describing waiting times in the ED, IE models used to estimate the load on resources at the ED, and human factors engineering models ([12]) such as patient treatments flow or modeling the information needed for staff members.

After the models and methods are created, they are validated, and the results provided by them are analyzed. This is carried out in the Validation and Analysis phase. Such validation and analysis is based on established methods in each of the disciplines.
described in Section 3.1. For example, in Information Systems Management, if the purpose is to create a new information system, established practices for such validation are user reviews. An example of a user review is a *Use Case* ([8]) review, which is used to ensure that all required usage scenarios of the required system are indeed provided. Another validation example, from the domain of human factors engineering, is performing usability testing on a product before it is distributed.

Another activity that is carried out in this stage is **Gap Analysis**. The purpose of gap analysis is to understand if there are any gaps between the current state (e.g. lack of existing information, current policies/practices) and the desired state, which must be addressed. Note that at this point, if the goal is very ambitious, or the gap is too large, reaching the goal may be partitioned into sub projects, such that each new sub project will follow the approach described in Figure 2 (resulting in the loop appearing in the figure).

As shown in Figure 2, once the models and methods reach a certain level of maturity, development and deployment is carried out to ensure that the models are incorporated into the hospital environment. Note that in this context, development and deployment refers not only to the development of new information systems, but may also refer to introducing or changing the actual work processes or protocols in the hospital environment. Once these changes are introduced, feedback regarding the results must be obtained. This feedback can be of several types. For example, quantitative feedback can be obtained by measuring the values of the targeted metrics. In addition, qualitative feedback can be obtained by conducting surveys, or by additional observations. Based on this feedback, it may be necessary to either change some of the deployed functionality (resulting in a return to the development stage), or a follow on, deeper, improvement project may be needed – which dictates the need to return to the Observation and Information gathering stage.

### 4. APPLYING THE METHODOLOGY

In this section, it will be demonstrated how several of the improvement projects carried out followed the approach described in Section 3.2.

#### 4.1 Monitoring and Control of ED Operations

As described in Section 3.2, initial steps in the project included the detailed definition of a large set of metrics, and carrying out the detailed observations in the ED as part of the observation and measurement phase. When analyzing these observations in the Understanding stage of the Understanding and Modeling phase, it was noticed that very little support exists for real time management of the ED processes. Therefore, a goal was set to create a comprehensive system enabling such monitoring and control. Among the steps carried out in the Modeling stage of the Understanding and Modeling phase, work was carried out on defining a subset of the metrics defined in the Observation phase, to serve as an initial focus for these management capabilities. Another step in this stage was the creation of a detailed component model of this system (see Figure 1), which includes a dashboard that will constantly display the values of the metrics of interest.

In the Validation and Analysis phase, a prototype of the dashboard was created (see Figure 3), and was used to solicit feedback.

![Figure 3: Prototype Dashboard](image)

Feedback obtained from the intended users, which included Dr. Dagan Schwartz, the manager of the ED, Dr. Fuad Basis from the ED and Prof. Rafi Barel, the director of the Rambam hospital indicated that this concept is indeed extremely valuable, and has the potential to dramatically improve the management capabilities of the ED. Also, when carrying out gap analysis, several major gaps were found. These included, among others, the need to better define the dashboard design (see Section 4.4), the set of metrics displayed by the dashboard, and the inability of the existing ED information systems to provide the required information regarding the current state of the ED in terms of the care process. As a result, several sub projects were initiated. These sub projects included
additional metric definitions and modeling, and using simulation based models to provide estimates required for understanding the real time state of the ED (see [15]).

Deployment of this system is planned to start once some of these components have reached a sufficient level of maturity. Additional components, once they reach the required level of maturity, will be continuously added, until the overall vision described by Figure 1 is reached.

4.2 Improving the Quality of Treatment in the Emergency Department
In this project, the process of patients' flow was considered, focusing on the subject of prediction and capacity planning.

In the Observation and Information gathering stage, a large database that includes nine months of work was collected. This data included detailed information about the patient's sex, age, medical tests carried out, releasing physician, complaints, and hospitalization department.

In the Understanding and Modeling phase, the goal of this project was determined to be finding a method for quick calculation of load and ED staff. Data analysis of the patient data was, based on which a capacity planning model was created. Then, based both on this data and a preexisting model of the patient care processes, a model enable quick calculation of the load was created.

In the Validation and Analysis phase, statistical analysis was used to analyze the models'. This analysis showed that it is possible to use this model for the forecast of future load on the ED resources.

With regards to implementation – parts of this project are currently being implemented in the Hadassah Hospital in Jerusalem. More details regarding this project can be found in [20].

4.3 Fair vs. Efficient Assignment of ED Patients to Internal Wards
This project focused on the process of patients’ routing from the ED to Internal Wards (IW), which is central to the operational well-being of a hospital. Indeed, a slowdown of this routing process could block the ED which, in turn, would have negative ramifications: for example, it could lead to ambulance diversions which in turn may lead to clinical deterioration of delayed patients, due to the delay in receiving clinical care at the ED.

In the Observation and Information gathering state, the existing ED to IW process was carefully studied.

In the analysis phase, it was determined that the present routing algorithm of the Rambam hospital was unfair, as far as distribution of work is concerned. I.e. the ward that was fastest (in terms of shortest average LOS), suffered the highest loads. Thus the goal of this project was to determine a new routing policy. A routing policy was indeed defined in this stage, which balanced fairness (in terms of staff loads) with operational efficiency (least delays for patients). This algorithm was created based on queueing model analysis (see [5]).

In the Validation and Analysis phase, feedback from the field necessitated the relaxation of some key constraints that the theoretical models had imposed. To this end, an additional sub project was carried out, which, via simulation, gave rise to an implementable fair and efficient algorithm.

4.4 Specification and Human Factors Considerations in the Design of an ED Dashboard
The goal of this project was the development of a computer driven dashboard for the Rambam ED unit, based on human factor engineering principal. This dashboard is intended to be the main device for the daily management of its work, in that it will provide each type of user (nurses, doctors, etc.) the specific information required for carrying out their roles while reducing errors. Note that this was one of the sub projects defined by the project described in Section 4.1.

In the Observation phase, interviews and observations were conducted to learn about the current way in which the team gathers information and makes decisions regarding the care processes. The Understanding and Modeling phase, task analysis was carried out. Task analysis is a technique which identifies the overall objectives of a system and the allocation of responsibilities between human operators and engineering elements in fulfilling these objectives. The result is a detailed description of the processes and tasks the user do, their expectations desired content and required information for each task. This stage also included a user centric design of the dashboard is built taking in consideration the user demands and needs gathered in the task analysis. Finally, the Validation and Analysis phase included beta testing of the dashboard via usability testing methods on a prototype of the
Dashboard. Input from the test will help to redesign the dashboard so it will fit the user cognitive demands.

5. SUMMARY AND FUTURE WORK
In this paper, we described a collaborative project carried out between the Rambam hospital in Israel, The Technion and IBM, intended to improve patient care processes at hospitals from the clinical, operational and financial aspects. The significant practical and academic impact was described, as well as the rigorous approaches and methodologies used. As was described in this paper, this work has had, and is expected to continue to have, impact both on the hospital, and on future research agendas pertaining to healthcare, services science, and relevant disciplines. Also, much work still remains to be done, both in continuing the actual improvement of the patient care processes at the Rambam hospital, and advancing on the wide variety of research topics resulting from this work.

Obtaining the impact described required the true partnership that exists between the three parties involved in this project. This is as achieving this impact required bringing together talented individuals with extremely varied background, skills and knowledge. Needless to say, such a set of individuals could not have been found within a single organization. Moreover, obtaining actual benefits which improve the patients' quality of care on a day to day basis could only be achieved with the involvement of relevant academic and industrial partners, together with the involvement of a hospital that provides constant data and feedback, and in which observations could be carried out and improvements could be implemented.

6. REFERENCES

Acknowledgement: This work would not have been possible without the hard work and dedication of the following people: Prof. Rafi Beyar, the head of the Rambam hospital; Oded Cohen, head of IBM Haifa Research Lab; Prof. Boaz Golany, Dean of Technion's IE&M Faculty; The project steering committee, first and foremost the Rambam Members - Prof. Shimon Pollack, Dr. Yaron Barel, Dr. Hana Adami, Sara Tsafir and Amir Weiman; Prof. Avishai Mandelbaum, Prof. Avi Shhtub and Prof. Danny Gopher, the Technion members of the steering committee; and Pnina Vortman, Segev Wasserkrug and Boaz Carmeli, the IBM members of the steering committee.; The dedicated professionals in the Rambam ED and trauma room, led by Dr. Moshe Michaelson, Dr. Dagan Schwartz, Dr. Fuad Basis and head nurse Hagar Baruch; The dedicated professional in the operating rooms, neonatal, trauma and inpatient wards. We would also like to express our gratitude to Dr. Kobi Assaf, head of the Hadassah ED, who made it possible for us to disseminate the results of this work outside the Rambam hospital, and with whose help and dedication we demonstrated that the potential impact of this work is indeed widespread.