

Dr. Segev Wasserkrug, Manager, Business Optimization Group IBM Haifa Research Lab Haifa University, Mount Carmel Haifa, 31905, Israel 972-4-8296337 segevw@il.ibm.com	Prof. Avishai Mandelbaum Professor of Operations Research and Service Engineering Industrial Engineering and Management Faculty, Technion, Israel Institute of Technology Haifa Israel 972-4-8294504 avim@ie.technion.ac.il	Yariv Marmor Engineering Industrial Engineering and Management Faculty, Technion, Israel Institute of Technology Technion City Haifa Israel 972-4-8292851 myariv@tx.technion.ac.il	Prof. Avi Shtub Industrial Engineering and Management Faculty Technion - Israel Institute of Technology Technion City, Haifa 32000 Israel 972-4-8294454 shtub@ie.technion.ac.il
Prof. Daniel Gopher Industrial Engineering and Management Faculty Technion - Israel Institute of Technology Technion City, Haifa 32000 Israel (972-4) 829-4456 dgopher@ie.technion.ac.il	Yael Auerback-Shpak Industrial Engineering and Management Faculty Technion - Israel Institute of Technology Technion City, Haifa 32000 Israel yael_au@tx.technion.ac.il	Dagan Schwartz MD Director, Emergency Department Rambam medical Center P.O.B 9602, Haifa,31096 Israel Tel: 972-4-8542309 E-mail: D_schwartz@rambam.health.gov.il	Fuad Basis MD Director public health services Rambam medical Center P.O.B 9602, Haifa,31096 Israel Tel: E-mail: f_basis@rambam.health.gov.il
Jacob Assaf M.D Director, Emergency Department Hadassah Hospital Kiryat Hadassah p.o.b 12000 91120 Jerusalem 972-2-6777221 Jassaf@hadassah.org.il	Boaz Carmeli Manager, IT for Healthcare & Life Science IBM Haifa Research Lab Haifa University, Mount Carmel Haifa, 31905, Israel 972-4-8296504 boazc@il.ibm.com	Pnina Vortman Manager, Industry Value Solutions Dept IBM Haifa Research Lab Haifa University, Mount Carmel Haifa, 31905, Israel 972-4-8296339 vortman@il.ibm.com	

Keywords: Service Science, Healthcare, Multi disciplinary, Process Improvement, Patient Care, Analytics

Acknowledgements

Acknowledgement of Support

Financial support for this research has been provided to the Technion mainly by IBM's OCR (Open Collaborative Research) grant to the IE&M Faculty at the Technion, as well as by the Technion funds for the promotion of research and sponsored research

Technical Acknowledgment

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 Rambam members of the project steering committee, - Prof. Shimon Pollack, Dr. Yaron Barel, Dr. Hana Adami, Sara Tsafrir and Amir Weiman;;

The dedicated professionals in the Rambam ED and trauma room, including Dr. Moshe Michaelson, 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 the people at 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.

We are also grateful to the following Technion students for their hard word and dedication: Tirza

Lauterman, Yulia Tseytlin, Galit Yom-Tov, Asaf Zviran, Shimrit Maman, Sharon Weismark, Yair

Giwnewer and Yael Ophir. Finally, we would like to acknowledge the contribution of Dr. Valery Trofimov

and Igor Gavako from the SEE lab at the Industrial Management and Engineering Faculty at the Technion.

Services Research in Hospitals, or The Multi-Disciplinary Science of Patients Care*

ABSTRACT

Hospitals are among the most complex service systems, providing service that must adhere to three often conflicting dimensions: Clinical, i.e. providing the best possible medical care, Operational – e.g. matching personnel staffing levels with demand, and Financial – i.e. controlling the cost of care.

To improve care processes in this complex environment, a partnership has been formed, between an academic institution, a large enterprise, and a government owned hospital. Within the scope of this partnership, a rigorous improvement approach has been defined, at the basis of which lie a scientific methodology, and utilization and fusion of established disciplines such as Operations Research, Human Factors Engineering and Information Systems Management.

This article describes the project, the improvement approach and its impact. The impact is far reaching in that it can potentially revolutionize the management of patient care processes. Moreover, this project continuously produces significant research that is relevant to Service Science in general.

1. INTRODUCTION

Hospitals are unquestionably among the most complex service organizations. Indeed, hospital operations require the coordination of complex processes, among highly skilled individuals, often in the face of literal life-

* The present paper describes a partnership based on Service-Research, with the partners being Rambam Hospital, Technion Institute and IBM Haifa Research Lab, all located in Haifa, Israel. It is an extended version of a paper submitted to the inaugural 2009 Service Science Innovation Partnership Award competition (see <http://media.einnews.com/article.php?pid=30540>), in which the project described was the winner.

and-death scenarios, and always under financial constraints. For example, a common challenge is the need to synchronize, in a timely fashion and typically within a rigid time horizon, the encounter between the patient, the caregiver, the data required to provide the care, and the equipment required for this care.

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 implement systems, methodologies and processes that 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 quality of care, efficiency of operations, medical practice and financial effectiveness. Due to the complexity of hospitals, a comprehensive approach for improving care provisioning by process management along and across multiple dimensions, there is the need to integrate methodologies and 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 the challenge of supporting such efforts with field-data, little research has been carried towards such comprehensive improvement that takes an overarching view of all these disciplines.

In order to address some of the challenges mentioned above, a collaborative, three-partner project has been created between the following parties: the Faculty of Industrial Engineering & Management (IE&M) at the Technion (<http://ie.technion.ac.il/>) – a world-class unit constituting of about 60 resident faculty (helped by 80 adjuncts) and over 1,500 students, within Israel's leading academic engineering institution; IBM's Haifa Research Lab (<http://www.haifa.il.ibm.com/research.html>) – IBM's largest research lab outside the U.S, employing over 500 employees, a large number of which have M.Sc. and Ph.D. degrees; and the Rambam hospital (<http://www.rambam.org.il/Home+Page/>) – a 1,000-bed government-owned teaching hospital – which is one of

Israel's largest medical centers, serving more than 2 million citizens (one third of Israel's population). Our partnership, of this wide variety of disciplines and organizations, has been formed towards designing new systems, methods, processes and techniques for managing patient care process. The ultimate goal of this project is to improve and optimize patients care processes at the Rambam hospital and beyond in the multiple dimensions described above, in a scientifically sound and data-driven manner that can be rigorously archived, readily applied and widely disseminated.

In terms of roles and responsibilities, each partner brings unique capabilities and advantages to the table. The Rambam hospital provides the comprehensive medical knowledge of their leading-edge staff, expertise regarding clinical procedures and processes, as well as logistical and financial aspects of hospital management. Moreover, the Rambam hospital offers an environment in which observations could be made and data could be gathered, actual improvements could be specified and carried out, thus ensuring that planned improvements are implemented. The IE&M Faculty contributes its deep academic research capabilities, in the wide variety of academic disciplines relevant to this project. In addition, the IE&M Service Enterprise Engineering (SEE) Laboratory (<http://ie.technion.ac.il/Labs/Serveng/>) has carried out the necessary rigorous data-analysis and provided a repository and analysis tool – SEEstat (http://ie.technion.ac.il/Labs/Serveng/SEE_Documents_List.php) – for complex hospital data. Finally, IBM adds not only complementary deep research knowledge in relevant disciplines, through its world renowned research organization, but also serves as an industrial partner who helps in turning research results into actual implementable products and services, both for the Rambam hospital and the healthcare industry as a whole.

The project began by charting the hospital territory. It was jointly decided to focus on the following units, that span diverse yet central hospital operations: the Emergency Department (ED) - the gate and window to the hospital, which operates 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 "project", whose hospitalization spans several months and requires significant resources (\$100K's); the 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 – being the most capital-intensive hospital unit (in terms of both cost and income) where the frontier of medical research is often charted; and an Internal Ward – representing the heart of the hospital's routine clinical practice.

We began with focusing on the Emergency Department (ED, or ER for Emergency Room, as it is often called). Similarly to most EDs world-wide, this is a facility where patients undergo complex care processes, often urgent ones, while suffering through excessive delays and deteriorating care quality. The ED is thus a natural candidate to benefit from applying Operation Research (OR), Human Factors Engineering (HFE), automated information capture, introduction of new processes, and reengineering of existing processes. In parallel to these ED efforts, we initiated pilot projects within the other wards we had planned on, as will be described later. We complemented it all with gathering and cleansing data from hospital data-bases, as well as performing measurements, field studies and observations by all parties involved.

Within our project, we have thus followed a rigorous scientific approach, starting with measurements and data analysis, continuing with modeling, followed by validation, leading to design, deployment and documentation of target improvements. Based on this approach, one can safely argue that 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 that include the design and deployment of a system for real time measurement, monitoring and control of these processes. Such a monitoring and control system would potentially result in revolutionizing the manner in which medical processes are designed and managed at hospitals. Our work has also had significant academic impact, as manifested by research papers, new course material (in fact new courses altogether), as well as novel techniques and tools that can be applied to other service domains.

The rest of this paper is organized as follows: Section 2 provides more details regarding the impact of our project. Section 3 details the methodology followed for obtaining the impact, Section 4 provides descriptions of several projects that followed the methodologies described in Section 3, through which part of the impact,

described in Section 2, was achieved. Finally, Section 5 concludes with a summary and a description of avenues for future research.

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 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 2.3 provides details regarding these techniques. Additionally, our project has significant academic impact, both in providing new material for academic courses and being the basis for several ongoing graduate theses, at the M.Sc. and Ph.D. level. Due to the novel techniques developed, the fundamental reliance on real-data and the fusion of multiple academic disciplines, the work in this project has already resulted in several research papers and, at the same time, is nurturing further promising academic research. This academic impact is described further in Section 2.4. Finally, this project is also expected to impact 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 metric in the operational dimension 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. (Note that when leaving the ED, patients are either discharged from the hospital or admitted to an inpatient ward; some patients, however, actually Leave Without Being Seen (LWBS) by medical personnel – indeed, LWBS is also an operational metric (Green 2008). Another example of a metric, belonging to

the clinical domain, is the *number of clinical errors* carried out within a certain time period (e.g. a month) and associated to a specific clinical routine.

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 several of these projects appear below, with additional details appearing in Section 4.

- The physical layout of the ED has a noticeable impact on the patient care process. This is due to the fact that, under some layouts, physicians and nurses must walk significant distances in order to treat their assigned patient, which could have negative operational and clinical impact. The operational impact arises since walking distances impose operational (time) load on the medical staff. The clinical impact may arise, for example, if a medical staff member has to walk a significant distance to treat a patient requiring non urgent medical attention - this staff member may then prefer to wait until there are several such patients seeking treatment in that distant location, thereby delaying medical treatment. The physical layout of the Rambam ED is currently undergoing significant renovations, and the ED is presently operating in a temporary location. One of our improvement projects, based on a detailed ED simulator that accounts for walking distances, as described above, provided recommendations for altering the physical layout of the temporary ED. This reduces the load on medical staff (e.g. by reducing about one mile per shift from their walking distances), as well as shortens the time that patients wait for treatment. Significantly, an increase in medical staff is not required to achieve these benefits¹.

¹ The above mentioned ED simulator has been, in fact, regularly used in improvement projects. Thus, another project seeks to make the simulator accessible online, through the SEE lab (<http://ie.technion.ac.il/Labs/Serveng/>) server, for use by managers, physicians, researchers and students.

- Through Human Factor Engineering, a new trauma room has been designed, and a project in the neonatal unit developed team-shared models of the patients, in order to improve information transfer between physicians and nurses.
- When patients from the ED must be admitted to one of the inpatient wards, appropriate resources (bed, nurse to patient ratio, etc.) must be allocated in a suitable ward. Currently, identifying such resources often takes a significant amount of time and effort, resulting in patients remaining unnecessarily in the ED. Such a delay has adverse operational, clinical and financial implications. Operational implications result from the fact that each patient in the ED must be checked upon at least once every fifteen minutes, resulting in additional load on the medical staff. Clinical implications are due, for example, to patients receiving sub-optimal treatment in the ED, as opposed to a ward that specializes in their needs. And financial implication arises from several factors, such as that increased workload results in the need for extra staff hence extra salaries; and a congested ED leads to blocking of incoming patients hence potential lost revenues (and, in the U.S., to the frequently arising phenomenon of ambulance diversion (Green 2008)); yet another financial implications stems from the reimbursement model in Israel that rewards admission to hospital wards as soon as possible.. Therefore, in another of our improvement projects, an algorithm for improving the ED-to-Wards flow was designed and implemented. This algorithm takes into account varying ward sizes and heterogeneous LOS, while catering to both operational (short ED delays) and fairness (work allocation among wards personnel) criteria; it also adapts to partial information regarding wards status, as the latter is updated only once a day.
- Yet another project enables the potential reduction of up to 20% in patient's waiting time in the ED, by implementing process reengineering methodologies (Karni and Shtub 2009). This is an example of a project which also impacts other hospitals, as some of the process changes proposed are being successfully implemented in the ED of the Hadassah hospital in Jerusalem.

A complete list of our partnership projects, with elaborate descriptions, appears in http://ie.technion.ac.il/Labs/Serveng/OCR_Documents.php.

2.2 Online Monitoring and Control of Patient Care Processes

In addition to the above mentioned improvement projects, there is also significant ongoing work and long term goals. For example, one major long term goal of the project is to design and provide a system for comprehensive monitoring and control of the patient care processes in the ED. This system, described in (Greenspan Et. Al. 2009), is composed of three main components, which are described below.

The first component in this system is an *Analytics Component* that enables various types of advanced analysis methods and algorithms. The first type of such methods is data consolidation, cleansing and correlation: it is needed since hospital data, collected and produced by IT systems, is often noisy and must be consolidated and correlated based on additional knowledge and/or assumptions. To exemplify this, consider the raw data produced by a tracking system providing information on location of patients at each point in time. Now consider two consecutive location-based events, one indicating that the patient entered a treatment room, and a successive even indicating that the patient left that room. If the time difference between the two events was say ten seconds, then obviously, the patient did not receive any treatment in the room, but may only have passed through this treatment room en route to another location. On the other hand, if the time difference between the two events was thirty minutes, one would tend to conclude that a treatment was administered. Such a conclusion can be drawn via techniques such as Complex Event Processing (CEP) (Etzion 2004).

The analytics component will include advanced data mining capabilities to turn the large amounts of data into useful information. Another type of methods included in the analytics components are forecasting algorithms for predicting future events (e.g., patient arrivals) or inferred knowledge (e.g., load on the ED staff) to support informed decision making. The analytics component will also include mathematical models, e.g. based on queueing theory (Green 2008), for modeling operational aspects, and Markov Decision Process (MDP) models in support of clinical decision making (Schaefer Et. Al. 2004; Hauskrecht and Fraser 2000). Model based data

completion algorithms will also be included in the analytics component. These algorithms are required for filling-in data that does not exist in the IT systems, but is required to ensure a complete picture of the ED state. Such data will be completed based on models (e.g. simulation models) of the environment, modified to take into account the data that is available. Finally, this component will include optimization algorithms that enable optimal decision making in various intersecting dimensions (clinical, operational and financial).

The second component of this system is a *Data Collection Component*. This component is responsible for data gathering and consists of a set of information systems installed in the ED. The Data Collection component will gather data of various types. It will first include all data being collected currently at the ED, and maintained in systems such as EMR (Mon 2004), imaging, and ERP. In addition, it will incorporate additional information systems, such as a Real-Time Tracking System (RTLS) (DAS 2005) which enables the tracking of patients and instruments (Miller Et. Al. 2006; Shin-Wei Et. Al 2006) as well as recording the interaction times between patients and medical staff. Such a tracking system would become an invaluable part of the data collection component, having the ability to increase efficiency, reduce cost and reduce medical errors, for example by reducing the erroneous identification of patients. In addition to data being collected within the ED, the Data Collection component will gather information that is imported from other healthcare providers (e.g., other hospitals and clinics), from adjacent organizations (e.g., insurance companies) and from patients (e.g., sensors collecting data). Besides these, the component will gather publicly available information from the web, such as relevant weather conditions, alerts on adverse drug reactions and so forth.

The third system component is the *User Interface (or Data Visualization) Component*. This component provides widespread accessibility, interaction and visualization of the advanced capabilities generated by the Analytics Component, to the different users in the ED (physicians, nurses, managers, etc.) It therefore includes the following: (1) A dashboard for displaying the minimal amount of information to support both quick decision making and longer term analysis. (2) Comprehensive reporting capabilities enabling complex queries. (3) Advanced analytics viewing and manipulation capabilities. (4) Adaptive mechanisms to dynamically change the data and applications being consumed.

Figure 1 describes this system and its components. This system's goal is to provide monitoring and control functions, spanning all relevant time horizons. Examples include optimal routing of patients to resources (i.e. medical staff, imaging device, etc.) during the day, deciding on 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 months into the future.

Current process management in EDs renders such a system no less than a revolution in current practices, both in real-time and, as importantly, in the design, reengineering and planning of ED processes.

While a large amount of work still remains to be done for creating a such complete end to end system, significant progress has already been made. For example, in the Data Collection component, work is underway for introducing a real time location tracking system into the ED, based on either RFID or ultrasound sensors (or both). In the Analytics layer, completed work includes: a detailed simulation model of the patient care process in the ED, forecasting algorithms, queueing formulae and rules of thumb relevant for various ED processes, and the development of several ED specific optimization algorithms, such as the assignment of ED patients to wards, and determining optimal staffing levels (Jabali and Sinreich 2007). Finally, with regards to the User Interface Component, a prototype business intelligence (BI) portal, specific to the ED, has been created using IBM's Cognos product (see <http://www.cognos.com>), and work using Web Mashups has enabled dynamic user interfaces (Altinel Et. Al. 2008).

2.3 Novel Services Research Techniques

During work on our project, many novel research techniques and approaches have been and are still 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 (Gopher 2004); and the concept of Lean Manufacturing (Basham Et. Al. 2007; Fillingham 2007), 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 is being created as a part of this work, and which can be applied to other domains, is the integration of formal operational and quality models. To elaborate, in our setting, it is necessary to integrate the simulation models of the ED processes with formal models describing the impact of time delays on clinical outcomes. Indeed, standard business process simulation models enable calculating metrics such as ED length of stay, or the probability distribution of waiting time until a patient is first seen by a physician. However, given a specific patient, such simulations leave unclear the impact of a specific patient's length of stay, or time to see a physician, on this patient's individual clinical status. Several works have proposed Markov Decision Process (MDP) models for modeling the impact of delays on clinical outcomes (Schaefer Et. Al. 2004; Hauskrecht and Fraser 2000). However, within the ED, it is presently hard-to-impossible to estimate the amount of time that a patient will await treatment, and here simulation comes to the rescue. To wit, our process simulation model and MDP techniques will be integrated into a more comprehensive simulation model, providing a holistic tool/model that takes into account the delays experienced by patients together with the explicit clinical consequences of these delays. This model will answer questions such as: If a patient arrives at 10:00AM, with a given medical condition, and displaying a specific set of symptoms, what will her medical condition likely to be at 03:00PM, given the overall ED load during that day (and the resulting waiting times), the natural progression of the medical condition and symptoms, the forecasted time that the patient is to be diagnosed/treated by the staff, and the diagnosis and treatments prescribed.

Besides enabling such advanced analysis, this combined simulation model can furthermore also serve as the basis for process based decisions (e.g., routing of patients) so as to directly near-optimize both clinical and operational measures. Moreover, combining such quality models and process simulation models is in fact a generic technique that can be applied to other service domains for analysis of sensitivity to response times. One such service domain is large service centers providing IT support, in which the damage caused due to an IT issue is not

just a function of the type of issue, but may also heavily depend on the **time** required to resolve it (Taub Et. Al. 2007).

Another example of a novel 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 phase of the ED process (e.g., waiting for treatment by a physician). Exact data regarding such operational measures cannot be obtained from the existing IT systems at the Rambam ED (and, we have good reasons to suspect, in most other EDs as well). However, knowing (or estimating) the values of these quantities is extremely important for real time management of the ED. Therefore, as a part of this project, we have developed techniques for estimating such lacking values, based on whatever data is available, and using the simulation model of the ED process. 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 hard/costly or impossible to get yet it is constantly required. For more details regarding the application of this technique to the ED – see (Marmor Et. Al. 2009).

2.4 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 <http://ie.technion.ac.il/serveng/>) – a well established course that discusses the application of formal models (mainly queueing-based) to the design of service systems. Prior to the beginning of our project, the main services application area discussed in this course was telephone call centers (mainly because it was possible to obtain reliable data for this application area through the SEElab <http://ie.technion.ac.il/Labs/Serveng/>). As a result of this project, significant new materials regarding the application of such models to hospital service has been 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, currently at its design stage,

is the creation of a new course, intended to teach students to apply a multi-disciplinary approach for solving 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; solving the problem, on the other hand, actually required, in many cases, that integration of different disciplines be carried out by project participants. However, only people with experienced in Services Research (e.g. IBM staff members), could actually apply such a multi disciplinary approach. Therefore, it is the purpose of the course to have academia and industry join forces, in order to teach advanced undergraduate level, or graduate level students, to apply a wider, multi disciplinary approach for solving problems that arise in service systems.

An additional academic contribution of our project is that it has provided a fertile ground for research of graduate students, culminating in several MSc and PhD theses – some completed and others still ongoing. For example, the IE MSc thesis in (Weismark 2009), dealt with the development of Rough Cut Capacity Planning (RCCP) procedures for the ED, in order to obtain a method for efficiently calculating expected load on ED staff. The RCCP methodology thus created was based on cluster analysis of the ED data base, over the period of January 1 2006 to September 21 2006, which clustered the patients into 10 major groups. Each such group had a similar process flow within the ED and required similar resources. By using standard time measurement methodology, the distribution of service time of each group members by each resource type was estimated. These estimates were used as a basis for the RCCP algorithm. The RCCP algorithm served as a planning tool with which the management of the ED allocated resources to shifts and assigned resources within each shift to different operations in the ED. Additional information regarding this work appears in Section 4.2.

Another thesis, a PhD in Human Factor Engineering, studies communication gaps and information transfer between doctors and nurses in Rambam's neonatal units, on the road to the development of a better shared information mapping of the patient care status. Patient care in Intensive Care Units (ICU) requires continuous and ongoing information transfer, collaboration and coordination between team members, at different times and

locations. Although extensive effort is made to maintain continuation of treatment, there are nonetheless unexpected events and gaps due to the dynamic nature of the process and the medical status of the patient, or at times works procedures and handovers that are not properly defined (Xiao, et al. 2003; Cook, et al. 2000). These failures, and in particular those associated to impaired information transfer, are a serious cause of adverse events in the medical work environment (Bates and Gawande, 2003). Improved communication and information transfer between physicians and nurses can improve decision making and patient care (Manias and Street, 2001). The aim of the present work is to examine the differences and gaps between physicians and nurses models of their task, its influence on creating a medical status map of the neonates they treat and the resulting gaps in these maps. The study of this problem may enhance our understanding of the ways to improve information transfer and create better shared maps among medical teams in health care procedures.

Yes another PhD thesis, in Operations Research and still ongoing (Yom-Tov 2008), studies queueing in hospitals. The focus is a Medical Unit (ED or a ward), the resources in which are nurses (dynamic capacity) and beds (static capacity), with the beds being occupied (partially or fully) by patients. Examples of some questions addressed are: How many nurses are required (staffing), and how many beds are needed (allocation) in order to minimize costs while sustaining a pre-given service level? Examples of performance measures which can be calculated explicitly are (i) the probability of a patient being blocked as all beds are full, (ii) the probability of waiting for a nurse, and (iii) the expected waiting time for a nurse. The analysis is first exact, namely the queueing models are analyzed in steady-state. Then approximations are developed (fluid and diffusion) in order to provide insight and simplify calculations. The ultimate goal is to have the tools developed be in fact deployed in hospitals, and possibly integrated into our ED simulator.

Two last examples of graduate thesis, both MSc in Statistics, are (Maman 2009) and (Reich 2007). These works develop models for the demand process to a service system that caters to time-varying loads – with the prime examples being EDs and telephone call centers. In (Maman 2009), the demand model accounts for the phenomenon of over-dispersion, which was discovered empirically – namely, stochastic variability in access of that usually employed in the literature. The importance of exact modeling is due to the fact that over-dispersion

comes as a cost – the larger it is the higher the staffing levels required to cope with it. In (Reich 2007), the focus is study is the offered-load process. This process combines the arrival process of patients with the work that each arrival brings to system's resources (e.g. work for nurses, physicians, imaging devices). This yields the so called offered-load process, which is the backbone for resource allocation (Zeltyn Et. Al. 2009). A part of the thesis in (Reich 2007) is the creation of a routine that calculates the offered load from actual data, which is to be incorporated into the SEEStat software (see <http://ie.technion.ac.il/Labs/Serveng/>).

Finally, several academic articles have already resulted from our work. These include (Greensphan Et. A. 2009), (Marmor Et. Al. 2009), and (Zeltyn 2009). Work on additional articles is currently in progress. For more details regarding future research directions, see Section 5.

3. METHODOLOGY

The methodology we have followed has been based on two main principles. The first is to have our work based on a wide variety of formal and structured disciplines (e.g., operations research, information systems management, human factor engineering, etc.) that have been proven useful in manufacturing and other service domains. As described in Section 2, in many cases our work resulted in scientific advancement of these disciplines, in some cases specific to healthcare, but in other cases applicable more generally. A brief description of the academic disciplines employed, as well as their applicability to our partnership, appears in Section 3.1.

The second principle is the application of the 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 their 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 Participating Disciplines

The various disciplines applied in this project cover medical and clinical knowledge provided by Rambam staff, Operations Research, Statistics, Industrial Engineering, Human Factors Engineering and Information Systems Management (with an emphasis on healthcare informatics).

Medical and clinical knowledge (as described in Section 1) 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 (OR), Statistics, and their interplay constitute quantitative methodologies that help transform, through formal 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. Data reliance makes Statistics an essential prerequisite for meaningful applications of OR; additional methodologies, all used in our OCR project, are Optimization, Simulation, Queueing Theory/Science and Game Theory. 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, and there are books on the subject - see (Green 2008) for further references. Hence, OR has a natural roles in our OCR project: modeling (mathematical, simulation) which also guides data acquisition and analysis of models (e.g. trading off efficiency of resources against queueing times of patients).

Industrial Engineering (IE) is the branch of engineering that is concerned with 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 (hence the term "industrial"). Industrial engineers often use computer simulation, especially discrete event simulation, for system analysis and evaluation. Examples of where industrial engineering might be used include designing a new loan system for a bank, streamlining operation and emergency rooms in a hospital by applying lean manufacturing concepts

(Bassham Et. Al. 2007, Fillingham 2007) to reengineer related processes, distributing products worldwide (referred to as Supply Chain Management), manufacturing cheaper and more reliable automobiles, and shortening lines (or queues) at a bank, hospital, or a theme park. **Lean manufacturing** is a philosophy derived mostly from the Toyota Production System (TPS), which focuses on *waste* reduction. In Lean manufacturing, seven kinds of waste are considered:

1. Overproduction (production ahead of demand)
2. Transportation (movement of products that is not actually required to perform the processing)
3. Waiting (waiting for the next production step)
4. Inventory (all components, work-in-progress and finished product not being processed)
5. Motion (people or equipment moving or walking more than is required to perform the processing)
6. Over Processing (due to poor tool or product design creating activity)
7. Defects (the effort involved in inspecting for and fixing defects)

One of the key steps in lean manufacturing is the identification of which activities add value and which do not. By classifying all the activities into these two categories it is then possible to begin improving the former and eliminating the latter. Special tools and methodologies have been developed and employed on these wastes to reduce or eliminate them.

In the past, the application of lean principles led to substantial improvements at the hospital level. As an example Virginia Mason Medical Center in Seattle, Washington, reported the results of using lean management principles between 2002 and 2005. By working to eliminate waste, Virginia Mason created more capacity in existing programs and practices so that planned expansions were scrapped, saving significant capital expenses, including: \$1 million for an additional hyperbaric chamber that was no longer needed; \$1 to \$3 million for endoscopy suites that no longer needed to be relocated; and \$6 million for new surgery suites that were no longer necessary (Miller 2005).

Previous use of lean principles has also led to substantial improvements at the health delivery system: ThedaCare, Inc., a health delivery system with three hospitals, 27 physician clinics, and a 300,000-member health

plan, based in northeast Wisconsin, reported the following results from the application of lean principles at ThedaCare, Inc.: \$3.3 million in savings in 2004; \$154,000 savings in the Catheterization Lab supply procurement processes; reduction of accounts receivable from 56 to 44 days equating to about \$12 million in cash flow; redeployed staff in several areas saving the equivalent of 33 FTEs; improved ThedaCare Physicians phone triage times by 35 percent, reducing hold time from 89 to 58 seconds; reduced ThedaCare Physicians phone triage abandonment rates by 48 percent (from 11.6 percent to 6.0 percent); 50% reduction of the time required to complete clinical paperwork on admission; and decreased medication distribution time from 15 minute/ medication pass (the amount of time it takes to pass one medication to one patient) to 8 min/ medication pass impacting 4.1 FTEs of staff time (Miller 2005).

Human Factors Engineering (HFE) is the scientific domain concerned with the application of basic science knowledge that pertains to the capabilities and limitations of humans, to the design of engineering systems, tools and machines to fit their users, as well as jobs and work procedures that assure efficient and safe performance. The key role of the human engineering professional is to evaluate the correspondence between demands of a task and the ability of the performer to cope with it. This is done by analyzing, evaluating and restating the engineering, environmental and procedural composites of a task in terms of the demands imposed on the performer. The outcomes of such analysis are then compared with the capabilities of the performer to assess the level of correspondence, match or mismatch between the two, which will influence performance levels and ability to cope with task demands. The larger is the mismatch the higher is the probability and severity of potential performance problems (Gopher 2004; Wickens and Hollands.2000).

Traditionally, Human Factors Engineering was applied to industrial systems and human computer interaction. But HFE started to be used in medical surroundings when problems of patient safety and the occurrence of medical errors became a prime focus and concern of the public and medical community (Carayon, 2007; Morrow, North and Wickens, 2006).

From the perspective of HFE, care givers (doctors, nurses and related personnel), are forced to work in hostile and poorly designed environments. Such environments are amenable to increased load, reduced efficiency

and are highly conducive to errors. As argued in (Gopher 2004), this is the major cause and contributor to human errors in medical systems, as opposed to low motivation or deliberate negligence of care givers. But only recently has there been a growing recognition of the severity and potential consequences of such environmental problems, which has lead to an increased focus on aspects of human factors and user friendly design of medical systems – this is the role of HFE in our project (Carayon, 2007; Morrow, North and Wickens, 2006).

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 this data by a variety of users in different organizational roles. Therefore, this discipline provides methods for efficient storage and retrieval of a wide variety of data, but also (and no less importantly) methods and systems that use and display this data to provide value to the business user. 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 that are intended to aid in managing the various processes of the enterprise, and Business Intelligence (BI) systems, aimed at extracting valuable and timely insights from the large amount of available data.

As in all other domains, the healthcare domain requires the ability to access and manage large amounts of data. Therefore, database management systems, BPM systems, and BI systems are all relevant to this domain. Moreover, in (Hersh 2002) it was claimed that healthcare is an information-based science – indeed, much of clinical practice involves gathering, synthesizing, and acting on information. Another aspect that is unique in healthcare, much more than any other domain, is the implications of an improper usage of the information or the danger in not seeing all relevant sources. The article in (Hersh 2002) discusses a growing concern that information is not being used as effectively as possible in healthcare. Recent reports from the Institute of Medicine have reviewed research findings related to information use and expressed concerns about medical errors and patient safety, the quality of medical records, and the protection of patient privacy and confidentiality. Due to these unique characteristics of information in healthcare, there exists a sub discipline of Information Systems Management, called Healthcare Informatics, sometimes also referred to as Medical Informatics. The Healthcare Informatics domain is often divided to two sub-domains. The first deals with informatics for research carried out in academia

and pharmaceutical companies. The second deals with informatics in practice, i.e. information being stored in hospitals and clinics. In (Winter Et. Al. 2001), several aspects reflecting the complexity of the latter informatics are described.

3.2 Scientific Approach

Throughout the course of our work, we have adhered to the scientific paradigm, as described in Figure 2. A detailed description of this approach now follows.

All improvement projects have begun with the Observation and Information Gathering phase. Observations are required for hands-on understanding of the current situation – activities, resources, processes and their interactions; information gathering aims at obtaining more detailed data regarding this current state, for example from hospital data-bases. All project partners participated in this extremely important phase, as it is the basis for the rest of the improvement work.

Taking our ED projects as a concrete example, it was mentioned in Section 2.1 that one of the first steps of our ED effort was to define a set of metrics that cover the clinical, operational and financial aspects that are to be measured and improved. 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, 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 multi-disciplinary partnership that was formed. Specifically, the **content** of the metric, namely which metrics are important, and how they should be measured, was characterized via specific knowledge of the Rambam partners. However, the knowledge of the other partners characterized the **form** of each metric definition, namely the precision required, data source definition, etc., which helped drive the definitions towards a desirable specificity.

The metrics' definition caters to several goals. First, present values of the metrics serve as a baseline measurement for improvements. Second, they serve to flesh out measurable quantities of interest in the ED. Third,

they help focus the improvement efforts in the ED, i.e., if the improvement effort is not intended to improve at least one of the metrics, this may serve as an indication that either the wrong improvement effort is being attempted, or that the set of metrics must be extended. Fourth, they serve to constrain the solutions, i.e., it will in many cases be unacceptable to improve some metrics while having a significant adverse effect on others. For example, it is unacceptable to improve waiting time by shortening treatment times to a point in which an unacceptable clinical outcome is reached. Finally, they serve to quantify both the goals and the outcomes of the improvement efforts. For example, it is possible both to state that the goal of the improvement effort is to reduce average patient length of stay (LOS) by at least 10%, and after the improvement effort is completed, it is possible to measure by how much the LOS was reduced.

Due to the importance of the Observation and Information Gathering stage, another part of the initial step in the ED was a set of detailed observations, intended to map and validate the patient care process in the Rambam ED. In general, the treatment process in the emergency department includes a generic process practiced in most EDs across the country. According to this process, a patient with non immediate life threatening conditions is initially registered, then evaluated by a nurse who then triages them according to various parameters such as urgency of the medical condition, expected length of ED evaluation, need for a bed, the probable nature of the underlying problem and the need for a specific consultant as well as other factors that depend on local ED management preferences (Wuerz, Fernandes and Alarcon 1998). The process then includes evaluation by one or more physicians, laboratory evaluation when needed, imaging evaluation when indicated and various treatment modalities. Simple cases may be discharged after a single physician encounter without requiring laboratory or imaging modalities while complex cases may necessitate multiple physician encounters from multiple disciplines, at times repeated laboratory and imaging modalities.

Although as described above, the high level form of the process is common across several EDs, it was necessary to map the intricacies and details specific to the Rambam ED. In preparation for this step, detailed questionnaires and observation forms were prepared. Moreover, the observation process required data relevant to all the disciplines described in Section 3.1 to be recorded as part of the direct observations. 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 patients' 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 proceed into the Understanding and Modeling phase. This phase consists of two stages, the first stage being Understanding, and the second stage being Modeling. In the Understanding stage, the data and information gathered in the Observation phase is analyzed. For example, with regards to the above metrics, it is important to find correlations between metrics: e.g. high rates of both medical errors and LWBS (patients who Leave the ED Without Being Seen by a physician), with possibly deteriorating health indicators of patients, all conceivably (but not necessarily exclusively) resulting from an over-congested ED. Based on the information gathered, it is then decided what is the problem (or problems) that must be addressed. Also some goal regarding future desired states is articulated. As described above, this goal should include quantitative statements regarding the set of defined metrics. 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 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* and *prototyping*. An example of a user review is a *Use Case*

(http://www.omg.org/technology/documents/modeling_spec_catalog.htm#UML.) review, which is used to ensure that all required usage scenarios of the required system are indeed provided. Another common review, the user interface review, enables ensuring that the functionality provided is convenient for the users, by showing to the users mockups of the screens and obtaining feedback. Prototyping is the practice by which small working parts of the system are created to demonstrate to the users how the system would behave, or to test other system characteristics. Another validation example, from the domain of human factors engineering, is performing usability testing on a product before it is distributed (Shneiderman, 1998). When using simulation, there is a prior step to validation, which is verification. The goal of this step is to ensure that no mistakes have been made in model implementation (Balci 1998).

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.

Note that the steps in Figure 2, are categorized into three types: Science, Engineering and Management. Science is generating new knowledge, engineering is then transforming this knowledge into tools, and these tools ultimately support Management practice.

4. APPLYING THE METHODOLOGY

In this section, it will be demonstrated how several of our improvement projects adhere to 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 partnership work included the detailed definition of a large set of metrics, and performing 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. For example very little data exists regarding the actual operational loads and bottlenecks in the ED at any given point in time, and no analytical tools are available to support decisions such as staffing decisions. This is in spite of the fact that monitoring and control of ED operations is complex, due to the large variation in patient flow and patient specific resource needs. Additionally many of the needed resources are not dedicated solely to the ED but rather serve the needs of multiple departments within the hospital (such as Imaging facilities, labs, ancillary personnel and specialty physicians). Currently, different monitoring and control mechanisms exist in different ED's and are historically the result of an evolutionary rather than an analytical process. Some EDs use computer generated control panels to aid with the monitoring and control of the processes while others use a non-computerized control board or a method of periodically carrying out patient rounds. Control measures include stratification of patients according to urgency or other variables, streamlining ED processes and obtaining additional resources.

Therefore, a goal was set to create a comprehensive system enabling such monitoring and control for EDs. Among the steps carried out in the Modeling stage of the Understanding and Modeling phase, work was done on characterizing a subset of the metrics defined in the Observation phase, to serve as the initial focus for these

management capabilities. Another step at this stage was the creation of a detailed component model of this perceived system (see Figure 1), which includes a dashboard that will constantly display values of the metrics of interest, especially for real-time monitoring and control.

In the Validation and Analysis phase, a prototype of the dashboard was created (see Figure 3), and was used to solicit feedback both about the concept as a whole, and the set of defined metrics. Feedback obtained from the intended users, including the physician who manages the ED and the Hospital's chief-manager, indicated that this concept is indeed extremely valuable, and has the potential to dramatically improve managerial capabilities of the ED. Also, in this phase gap analysis was carried out, which identified several major gaps. These included, among others, the design of the dashboard user interface (see Section 4.5), the need to better define the set of metrics displayed on the dashboard, and the inability of 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 complete the missing data, by providing estimates required regarding the detailed, real time operational state of the ED (Marmor Et. Al. 2009).

In terms of deploying this system within the ED, it is not the intent to wait until all of the components described in Figure 1 have all been implemented. Rather, once some of these components have reached a sufficient level of maturity, they will be introduced into the ED environment, to enable actual improvements, and also to obtain actual user feedback and measurements regarding the improvements they enable. 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 Short Term Capacity Planning in the Emergency Department

In this project, the process of patients' flow was considered, focusing on clinical and operational aspects. The goal of this project was to identify patient groups that share characterizing elements in the process they underwent in the ED and to differentiate between the relevant and non relevant information that has been collected

for each group. Such a differentiation will enable the ED team to cut down unnecessary tests improve the patient flow efficiency and shorten ED length of stay.

In the Observation and Information gathering stage, a large database that includes nine months of work was collected. The database was taken from "Hadassa Ein Karem" hospital ED, and included the dates 1/1/06–21/9/06. The original database included 51,914 records, where each record represents a patient. The records included the following information about the patient: age, sex, religion, entry and exit date and time from the ED, discharging doctor, tests (lab and imaging), verbal description of the patient state (if exists) and admitting department (if the patient was admitted).

In the Understanding and Modeling phase, each field was categorized in order to simplify the working conditions with that amount of data. After eliminating records with missing data items only 16,734 records were left for the final analysis. The original test fields contained 435 different tests; it was decided to cluster the tests into major groups. The criterion for clustering was the resource used to perform the test. Clustering resulted in 56 categories.

The next step in this phase was clustering of patients using Clementine 10.0 software from SPSS. The model used was the K-Means model. The resulting number of clusters was 10 clusters. All clusters were checked by the data expert and found logical in medical terms. Table 1 shows 3 patient types of the 10 found.

Following the above analysis, each patient type was modeled as a product type k and each ED resource type was modeled as a work station type s in the following rough cut capacity planning (RCCP) model:

$$L_s = \frac{\sum_{k=1}^K T_{ks} Q_k}{T_t R_s}, \text{ for } s = 1, 2, \dots, S, k = 1, 2, \dots, K$$

Where L_s is the total load predicted for resource type s , T_{ks} is the amount of work required for patient type k by resource type s , Q_k is the number of patients type k per period, T_t is the working time of a unit of resource type k per period, and R_s is the number of resource units of type s .

In the Validation and Analysis phase, statistical analysis was used to compare the RCCP models' results to the actual load in different resolutions. This analysis found no significant difference between the load as predicted by the Rough Cut Capacity Planning model and the load generated by a detailed simulation model. Our conclusion is that the RCCP model can be used to predict future load on the ED resources when detailed simulation is not feasible as a predicting tool without loss of accuracy.

With regards to implementation – The RCCP is currently being implemented in the Hadassah Hospital in Jerusalem. One interesting result of our clustering analysis is the observation that some tests are performed on most patients in all groups. Further analysis resulted in clinical guidelines on how and when to apply these tests. A one month pilot study demonstrated that these guidelines resulted in 73% - 80% reduction of several blood chemistry tests, saving 192,074 NIS .More details regarding this project can be found in the master thesis of Mrs. Sharon Weismark (Weismark 2009).

4.3 Developing a simulator for training new ED Physicians

This section describes a project which is currently in the initial stages, aimed at improving the training of emergency medicine physicians, and describes how the methodology will be applied to such a project.

In the Observation and Information gathering stage, the need for trained physicians in emergency medicine and the lack of formal courses was observed. This situation results in the implementation of on the job training, which is time consuming and risky, as errors during the learning process may impact the patients.

In the Understanding and Modeling phase the development of a training simulator will be carried out. This simulator will present specific cases of the 10 clusters of patient types found in the Hadassah hospital ED and will provide new physicians with a dynamic stochastic training environment. The first group of patients is currently being simulated using the *Wizard of Oz* approach. In this approach the trainee works on a computer that present patient data and accepts the trainee decisions. The results of these decisions are presented on the computer screen. These results trigger further decisions by the trainee and so on. The novel idea in this simulation is that an expert in Emergency medicine serves as a trainer who gets the input from the trainee and decides how to react to these

inputs given the specific scenario or patient type i.e. the simulator engine is not a computer program but rather the trainer who decide what to teach and how to react to the trainee decisions.

When enough data will be collected after several training sessions with different trainees and trainers, in the Validation and Analysis phase the results will be analyzed and used as a basis for the simulator logic to be developed in the future. Such logic when developed will make the training process significantly more efficient and effective.

4.4 Fair vs. Efficient Assignment of ED Patients to Internal Wards

Rambam has five internal medicine wards. Assignment of patients admitted from the emergency department is a complex and highly sensitive process due to the heavy patient load on all five wards. This process takes into account multiple factors including: a) bed availability in the ward; b) previous recent admissions of a specific patient (a patient who needs to be admitted and has been hospitalized in the preceding three months to one of the wards will be preferentially admitted back to that ward).; a software program which takes into account the number of patients admitted over the last 24 hours to the various wards; d) specific patient needs such as ventilation or isolation. e. Special circumstances such as patient preference, exceptional temporary burden on a specific ward and others. This process is also central to hospital operations, as a slowdown of this routing process could block the ED which, in turn, would have ample adverse ramifications, as already described: for example, it could lead to ambulance diversions and all its severe consequences (Green 2008), as well as clinical deterioration of delayed patients, due to the delay in receiving clinical care at the ED. Due to the complexity and centrality of this process, this project focused on the process of patients' routing from the Emergency Department (ED) to Internal Wards (IW), which is central to the operational well-being of a hospital.

In the Observation and Information gathering state, the process was carefully studied - this process starts with a physician in the ED who releases a patient for hospitalization in one of the internal wards (there are five such wards); the process is completed once the released patient is admitted to the designated ward. An important

ingredient of this process is the routing policy that seeks and identifies the ward to be admitted to, that takes into account the considerations described above.

In the Understanding and Modeling phase, it was found that the present routing algorithm of the Rambam hospital was not only somewhat inefficient but was also unfair in the sense of distribution of work among the wards. Indeed, careful measurements revealed that the ward that is “fastest” - shortest average LOS - which happens also to be the “smallest” in terms of number of beds, suffered the highest loads - as manifested by its highest bed occupancy. (We also made sure that patients' return-rate to this ward was no higher than at the other wards, thus at least indicating that short LOS did not come at the cost of medical quality.) Giving high priority to "fast" wards is efficiency-driven in that it minimizes waiting times, but then those fast wards "enjoy" increased workloads, which has in fact lead to its staff feeling, in some sense, "punished for being the best".

Thus, the goal of this project was determined to design a new routing algorithm to the wards, which will appropriately tradeoff efficiency with fairness. In order to do this, the ED to IW process was modeled as a queueing system. This queueing model was then analyzed under various queue-architectures and routing policies, in order to balance fairness (in terms of staff loads) with operational efficiency (least delays for patients). A routing algorithm that achieves these goals was identified, as described by the MSc thesis in (Tseytlin 2009).

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 (Tseytlin and Zviarn 2008) which, via simulation, gave rise to an implementable fair and efficient algorithm. This new algorithm also had a nice adaptive/learning capability as it is using only partial status-information about the wards, which is the one available in practice.

4.5 Specification and Human Factors Considerations in the Design of an ED Dashboard

The goal of this project is the development of a computer driven, user oriented dashboard for the supervision and management of flow and care procedures at the Rambam ED unit. This dashboard is intended to be the main on-line tool for the guidance of daily work in the unit. It aims to provide for each type of user (nurses,

doctors, administrative staff, directors, patients,) a coherent display of the specific information required for carrying out their daily routines, thereby increasing efficiency and reducing errors. Such a dashboard constitutes a cognitive aid that enhances users' performance and allows them to make the best use of their time, efforts and resources. It should also greatly improve each team member's situation awareness, i.e., the knowledge regarding each patient's situation, as well as the situational map, or knowledge, shared between the team members. Research on patient safety issues points to the clear advantages of using decision support tools to improve human performance (Nemeth, Cook, O'Connor and Klock 2004). Better digital cognitive artifacts, as provided by the dashboard, will also benefit team work processes, planning, communications, resource management and, by extension, patient safety. The dashboard is expected to also improve the distributed cognition of the team. Distributed cognition is the shared awareness of goals and plans (Nemeth, Cook, O'Connor and Klock 2004). Note that this aspect is 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 included a user centered task analysis of objectives. Task analysis identifies the overall objectives of a system and the allocation of responsibilities between human operators and engineering elements in fulfilling these objectives. It then maps and restates objectives and interactions in terms of their processing and response demands on the human, task workload, required knowledge and acquired skills (Gopher 2004). The result is a detailed description of the processes and tasks the user carry out, their expectations, the desired content, and the required information for each task. This process is done separately for each type of user. This stage also included a user centered design of the dashboard in which a concept 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 by using 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 (Shneiderman, 1998; Wickens, Gordon, and Liu, 1997).

5. SUMMARY AND FUTURE WORK

In this paper, we described a collaborative project carried out between the Rambam hospital in Israel, The Technion – Israel Institute of Technology and IBM, intended to comprehensively 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 on all partners involved, and on the future research agenda pertaining to healthcare, services science, and relevant disciplines such as Operations Research and Information Systems Management. In order to achieve this impact, a rigorous scientific methodology, detailed in the paper, was defined and practiced. In addition, a pre-requisite for such a project is that a true multi disciplinary approach must be applied, i.e., not only bringing together talented individuals with extremely varied background, but also carrying out research work in a truly integrated fashion. This is evidenced by the many improvement sub projects described in this paper, which address many facets of healthcare process improvements, from the view point of multiple disciplines it is this multi disciplinary approach which is at the heart of Service Science.

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. Examples of such work include completing the implementation of the monitoring and control system described in Section 4.1, and driving forward integrative research, e.g., achieving a true combination of models that capture the clinical, operational, and financial aspects of healthcare provision.

6. FIGURES & TABLES

cluster 3			cluster 2			cluster 1			number of patients
comment	probability	result	comment	probability	result	comment	probability	result	
	8.21	137		9.78	163		12.59	210	ag
65	28.17	9	65	51.89	9	18-	47.08	6	ED time
5.88	0%	9.16	5.43	0%	6.44	5.	0%	6.28	Se
	51.82	women		83.08	men		57.71	men	
	24.02	6		48.04	4-		48.89	3-	average test number
chest x-ray	55.24	1	chest x-ray	79.89	1	chest x-ray	22.07	1	test category
stomach x-ray	51.82	2		98.47	B		15.71	B	test category
	98.98	B		21.45	BA		99.34	B	test category
	17.69	B		20.42	BA		27.95	BA	test category
	98.54	B		98.29	1B		95.02	B	test category
stomach	93.45	BB		54.89	BB		51.73	BB	test category
	33.04	2		30.50	B		10.54	B	test category
CT chest	60.12	1UA		75.56	BB		31.75	1U	test category
	22.93	3		26.53	U		0%	U	test category
	11.21	BB		0%	2		0%	A	test category
US	18.78	BH		0%	A				test category
	14.26	U							releasing doctor
	89.08	surgeo		47.74	E		11.34	ENT	
	0%	M		35.76	internal		11.06	internal	
	0%	n		0%	n		9.87	neurologist	
							9.40	surgeo	
	64.70	surger		24.45	delay		60.65	mo admi.	admitting department
	14.56	no		41.93	internal		14.38	n delay	
	12.74	no delay		22.74	no		0%		
	0%	admi		0%					
fever	11.64	1	fever	12.90	admi	fever	15.14	1	complaint
vomitin	25.84	2	chest pains	31.54	1	stomach ache	20.17	2	
stomach ache	83.33	2	shortness of breath	27.51	2	throat ache	9.16	2	
	0%	o	weaknes	16.99	13	vomitin	12.58	2	
	0%	7	head	18.34	3	head	29.76	3	
			othe	10.70	o	head ache	10.39	4	
			trauma	0%	o	othe	10.16	o	

Table 1: Patient Data Analysis

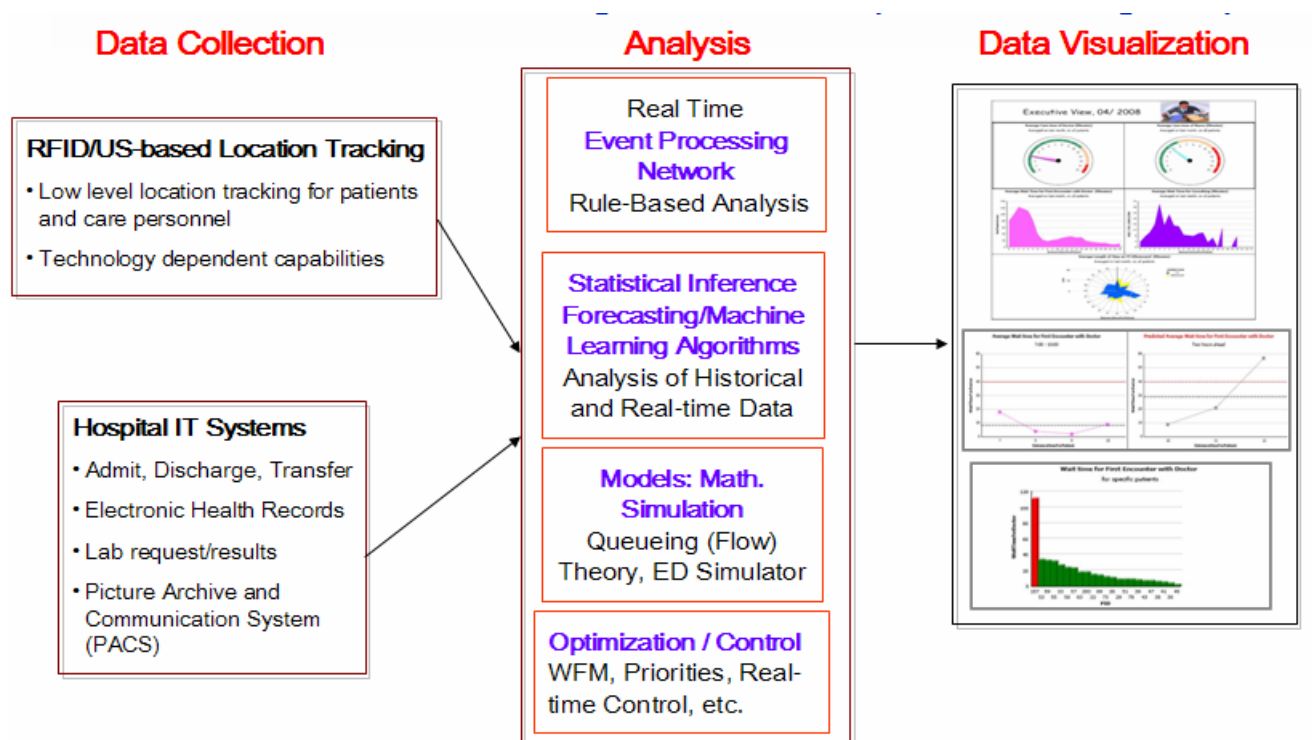


Figure 1: ED Monitoring and Control System

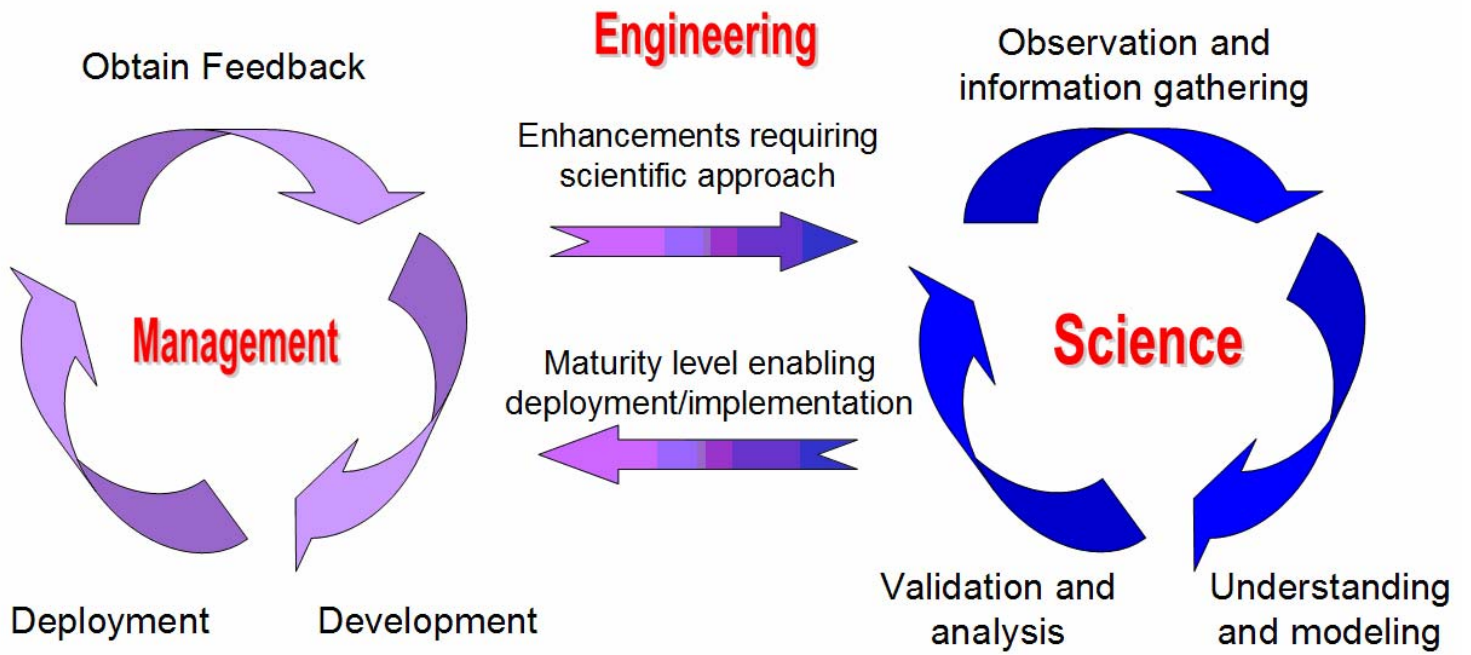


Figure 2: Scientific Service Improvement Approach

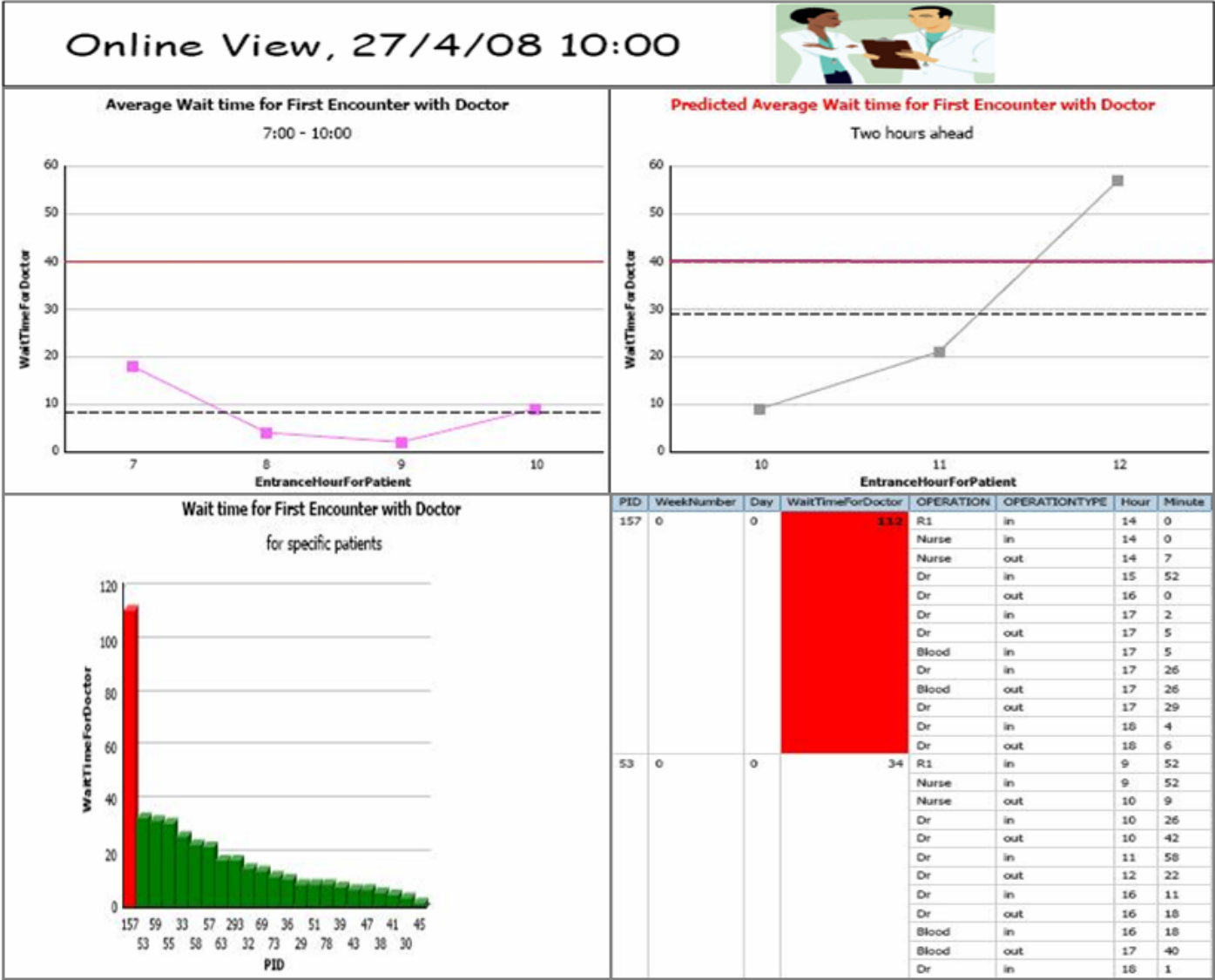


Figure 3: Prototype Manager Dashboard

7. REFERENCES

- Altinel, M., D. Simmen, et al. (2008), "Data Mashups for intranet applications", *SIGMOD 08*.
- Balci O. (1998), "Verification, Validation and Testing", *Handbook of Simulation*, Jerry Banks Editor, 335-393
- Bassham J. E., Ben-Tovim D. I., et al. (2007), "Lean thinking across a hospital: redesigning care at the Flinders Medical Centre", *Australian Health Review*, Sydney, 31, 1, 10-16.
- Bates, D.W. & Gawande, A.A. (2003), "Improving safety information technology". *The New England journal of medicine*. 348: 2526-2534.
- Berry, W. L., T. E. Vollmann, et al. (2004), *Manufacturing Planning and Control for Supply Chain Management*, McGraw Hill.
- Carayon, P. (Editor) (2007), *Handbook of Human Factors and Ergonomics in Health Care and Patient Safety*. Lawrence Erlbaum Associates, Hillsdale, NJ.
- Cook, I. R., Render, M. & Woods, D. D. (2000), "Gaps in the continuity of care and progress on patient safety". *British Medical Journal*. 320: 791-794
- Das, R. (2005): "An Introduction to RFID and Tagging Technologies" *Cambridge, UK: White paper, IDTechEx, 2002*.
- Etzion, O. (2004): "Complex Event Processing," *IEEE International Conference on Web Services (ICWS'04)*.
- Fillingham D. (2007), "Can lean save lives?", *Leadership in Health Services*, 20, 4, 231-241.
- Gopher, D. (2004), "Why it is not sufficient to study errors and incidents – Human Factors and Safety in Medical systems", *Biomedical Instrumentation and Technology*, 45:387-391.
- Green, L. V. (2008), "Using Operations Research to reduce delays for healthcare", *Tutorials in Operations Research*, INFORMS.
- Greenshpan, O., Y.N. Marmor, et al. (2009), "InEDvance: Advanced IT in Support of Emergency Department Management", *NGITS 2009*.
- Hauskrecht, M. Fraser H. (2000), "Planning treatment of ischemic heart disease with partially observed Markov decision processes", *Artificial Intelligence in Medicine*, (18), pg. 221-244
- Hersh WR. (2002), "Medical informatics: improving health care through information". *JAMA*. Oct 23-30, 288(16), 1955-8.
- Jabali, O., D. Sinreich, (2007), "Staggered work shifts: a way to downsize and restructure an emergency department workforce yet maintain current operational performance", *Health Care Management Sciences*, 10, 293–308.
- Karni, R., A. Shtub, (2009), *ERP and SCM: Integrated Operations and Process Management*, Forthcoming Springer 2009.

- Maman S. (2009), "Uncertainty in the Demand for Service: The Case of Call Centers and Emergency Departments." *IE MSc thesis*, Technion
- Marmor, Y. N., A. Shtub, et al. (2009), "Toward Simulation-Based Real-Time Decision-Support-Systems for Emergency Departments". *Accepted to WSC 2009*.
- Miller D. (2005), "Going Lean in Health Care", *Institute for Healthcare Improvement Whitepaper*.
- Miller, MJ., Ferrin, DM., Flynn, T., Ashby, M., White, KP., Mauer, MG. (2006), "Using RFID technologies to capture simulation data in a hospital emergency department"., *Proceedings of the 38th Conference on Winter Simulation* 1365-1370.
- Mon , DT. (2004): "Defining the differences between the CPR, EMR, and EHR", *J AHIMA*. Oct;75(9):74-5, 77.
- Morrow D., North R., Wickens C. D.,(2006). "Reducing and Mitigating Human Error in Medicine", *Reviews of Human Factors and Ergonomics*, Volume 1, The Human Factors and Ergonomic Association
- Nemeth, C.P., Cook, R.I., O'Connor, M., and Klock, P.A. (2004), "Using Cognitive Artifacts to Understand Distributed Cognition", *IEEE Transactions on Systems, Man and Cybernetics*, Part A.
- Reich M. (2007), "The Workload Process: Modelling, Inference and Applications" *IE MSc thesis proposal*, Technion.
- Schaefer A.J., Bailey M. D., Shechter S.M., Roberts M.S. (2004), " Modeling Medical Treatment Using Markov Decision Processes", *Operations Research in Healthcare*, Kluwer
- Shih-Wei L., Shao-You C., Jane YH, Polly H., Chuang-Wen Y. (2006): "Emergency Care Management with Location-Aware Services", *Pervasive Health Conference and Workshops*, 1-6.
- Shneiderman, B., (1998), *Designing the user interface: strategies for effective human-computer interaction*, 3rd Edition, Addison-Wesley publishers
- Taub, S., S. Wasserkrug, et al. (2007), "Shift Scheduling for Third Level IT Support: Challenges, Models and Case Study", *IEEE International Conference on Service Operations and Logistics, and Informatics*. Philadelphia.
- Tseytlin Y. (2009), "Queueing Systems with Heterogeneous Servers: On Fair Routing of Patients in Emergency Department", *IE MSc thesis*, Technion.
- Tseytlin Y. and Zviran A. (2008), "Simulation of Patients Routing from an Emergency Department to Internal Wards in the Rambam Hospital", *Technion Graduate Project*
- Weismark S. (2009), "Improving the quality of treatment in the emergency department", *Msc Thesis*, Technion, Haifa, Israel.
- Wickens, C.D., Gordon, S.E., & Liu, Y., (1997), *An Introduction to Human Factors Engineering*, Addison Wesley Longman Inc

Wickens D.C., Hollands, J.G., (2000), *Engineering Psychology and Human Performance*. Prentice-Hall, NJ

Winter AF et al. (2001), "Strategic information management plans: the basis for systematic information management in hospitals", *Int J Med Inform.* 64 (December), 2-3, 99-109.

Wuerz R, Fernandes CM, Alarcon J (1998), "Inconsistency of emergency department triage. Emergency Department Operations Research Working Group", *Ann Emerg Med.* Oct;32(4):431-5

Xiao, Y., Seagull, F., Faraj, S. & Mackenzi, C. F. (2003). "Coordination practices for patient safety: Knowledge, cultural and supporting artifact requirements". *Proceeding of International Ergonomic Association 2003*.

Yom-Tov G. (2008) "Queues in Hospitals: Semi-Open Queueing Networks in the QED Regime", *IE PhD thesis proposal*, Technion,

Zeltyn S., Marmor Y., Mandelbaum A., Carmeli B., Greenshpan O., Mesika Y., Wasserkrug S., Vortman P., Schwartz D., Moskovitch K., Tzafrir S., Basis F. , Shtub A., Lauterman T. (2009) "Simulation – Based Models of Emergency Departments: Real – Time Control, Operations, Planning and Scenario Analysis", *submitted to ACM TOMACS*.