From Emergency Department to Hospitalization: Using Simulation, Empirical and Theoretical Models for the Operational Analysis of ED, IW, and their Interface

or

Emergency Department, Hospitalization (or IW), and everything in between: Using Simulation, Empirical and Theoretical Models for the Operational Analysis of Hospitals

January 8, 2009

Avishai Mandelbaum • Yariv Marmor • Yulia Tseytlin • Galit Yom-Tov

Faculty of Industrial Engineering and Management, Technion – Israel Institute of Technology, Haifa, 32000, ISRAEL

avim@ie.technion.ac.il • myariv@tx.technion.ac.il • yulia@tx.technion.ac.il • gality@tx.technion.ac.il

Abstract

Write an abstract...

Contents

1 Introduction and Literature Review 3
  1.1 Background: Hospital, ED and IW ............................................. 3
  1.2 Process Charts ................................................................. 4
    1.2.1 ED ................................................................. 4
    1.2.2 ED to IW .......................................................... 4
    1.2.3 IW ................................................................. 4
  1.3 Literature Review ............................................................ 13
  1.4 Measurements ............................................................... 13
  1.5 Data Description ............................................................ 13
2 Analysis of the collected data and validation of the empirical and simulation models

2.1 Empirical Analysis of Emergency Department

2.1.1 Arrival, Departure, and Occupied Beds rate in the ED

2.1.2 Length Of Stay (LOS) in the ED

2.1.3 The impact of Bed Occupancy on LOS

2.2 Empirical Analysis of Internal Wards

2.2.1 Length Of Stay (LOS) in the IW

2.2.2 Arrivals and Departures in the IW

2.2.3 Determining Length Of Stay in IW as a function of the work load (see Appendix A - 1)

2.3 Empirical Analysis of Transfers in the system

2.3.1 Waiting times from ED to IW

2.3.2 Waiting times from ED to ICU

3 Analysis of the system (using combined simulation and/or analytical models)

3.1 Two interesting questions for ED

3.2 Two interesting questions for IW

3.3 Two interesting questions for the transfer process from ED to IW

3.4 Two interesting questions for the whole process

4 Special events

A Meetings summary
1 Introduction and Literature Review

Health care systems in general, and hospitals in particular, represent a very important part
of the service sector. Over the years, hospitals have been successful in using medical and
technical innovations to deliver more effective clinical treatments while reducing patients’
time spent in the hospital. However, hospitals are typically rife with inefficiencies and delays,
thus present a propitious ground for many research projects in numerous science fields, and
in the Operations Research field in particular.

A hospital is an institution for health care, which is able to provide long-term patient
stays. Hospitals include numerous medical units specializing each in a different area of
medicine, such as internal, surgery, intensive care, obstetrics, and so forth. In most of the
large hospitals there are several similar medical units operating in parallel. In our research
we focus on an Emergency Department (ED), five Internal Wards (IW) and an interface
between them in Rambam/Anonymous? Hospital.

This report is structured as follows: first we provide a background on the hospital, the
medical units in question, the problems involved, and survey the relevant literature. Then...

1.1 Background: Hospital, ED and IW

Anonymous Hospital is a large Israeli hospital with about 1000 beds, 45 medical units,
and about 75,000 patients hospitalized yearly. Among the variety of its medical sections,
the hospital has a large Department of Emergency Medicine with a capacity of 40 beds; and
five Internal Wards, denoted from A to E.

The ED receives and treats more than 200 patients daily, and is divided into two major
subunits: Internal and Trauma (surgical and orthopedic patients), each of those is divided
into “walking” and “lying” subunits, according to the state of patients treated there. An
internal patient, whom the ED decides to hospitalize, is directed to one of the five Internal
Wards according to a certain routing policy - and this process is precisely our focus of
interest.

Internal Medicine Departments are responsible for the treatment of a wide range of
internal disorders, providing inpatient medical care to thousands of patients each year. Wards
A-D are more or less the same in their medical capabilities - each can treat multiple types
of patients. Ward E, on the other hand, treats only “walking” patients, and the routing process from the ED to it differs from the one to the other wards.

1.2 Process Charts

Below we describe the simulation models (ED, ED to IW, and IW) by using flow charts, such as Resources Flow charts, Information Flow charts, Activities Flow Charts, and Activities - Resources Flow Chart.

1.2.1 ED

When patients arrive to the ED, either walking or assisted by a stretcher or wheelchair, the first step is assessment, which is typically followed by directing the patients to an appropriate bay where they wait for their next stage of treatment. This stage of the medical-process is called Triage if performed by the medical staff (nurse or physician). There are possibly procedures prior to the Triage, which include an initial assessment, by medical and non-medical personnel, such as clerks and ambulance officers (Brentnall 1997), and/or the initiation of diagnostic tests, by a (registered) nurse (Cheung et al., 2002). Such pre-Triage steps aim at accelerating patients flow.

In the following figures, we depict the overall patient’s process within the ED, from some varying point of views: a precedence diagram of activities, patients’ flow among the resources, a combined activity-resource diagram, and information flow.

1.2.2 ED to IW

One can fully appreciate the complexity of the process in the Integrated (Activities - Resources) Flow Chart (see Figure 5) and other flow charts (see Figures 6, 7 and 8).

1.2.3 IW
Figure 1: Activities Flow Chart in the ED
Figure 2: Resources Flow Chart in the ED
Figure 3: Information Flow Chart in the ED
Figure 4: Activities - Resources Flow Chart in the ED
Figure 5: Integrated (Activities - Resources) Flow Chart
Figure 6: Activities Flow Chart

Hospitalization decision

"Walking" patient?

Yes → Assigned to Ward E

No

Assigning Ward (A-D) with the Justice Table

Management approves skipping

Yes

Ward requests skipping

Yes

No

Transferal time decision

Patient's status updating

Wards A-D

Bed preparation

Coordination with medical staff

Ventilated patient?

Yes

Coordination with medical staff in the ED

No

Initial measurements collection

Initial physician check

* Processes in broken line occur in the IW

- Ending point of simultaneous processes
Figure 7: Resources Flow Chart

- ED physician
- ED nurse in charge
- Receptionist
- IW nurse in charge
- General Nurse
- IW nurse
- Help force
- Stretcher Bearer
- IW physician
- Ventilated patient
- Measurements
- Transferal
- Medical check
- Coordination

Resource Queue -  Synchronization Queue -

- Ending point of simultaneous processes
Figure 8: Information Flow Chart

- **ED medical file**
- **ED physician**
- Type (regular, special care, ventilated)
- **ED nurse in charge**
- Allocation: Ward A-D
- **Receptionist**
- **Type + medical information**
- **ED nurse in charge**
- **General nurse**
- Skipping granted/not granted
- **Skipping request + reasons**
- **Patient’s status updating**
- **Transfer time**
- **Bed readiness check**
- **Initial measurements results**
- **Medical check results**
- **Clinical information**
- **Ventilated patient**
- **ED physician or nurse**
- **Ventilated patient**
- **IW nurse in charge**
- **Availability check**
- **Ventilated patient**
- **Help force**
- **Availability check**
- **Availability check**
- **Ventilated patient**
- **Ventilated patient**
- **Transfer time updating**

- Ending point of simultaneous processes
1.3 Literature Review

OR in health care - general (Green): [4], [5]
Yariv’s simulation: [7]
The Impact of Work Load on LOS: [3]
Some more on hospitals...: [1], [6], [2]
Add: Galit’s thesis, paper about measures, Yulia’s and Asaf’s project, more?

1.4 Measurements

As it was shown in above, the ED presents a very complicated service system. As we know, every patient that enters the hospital implies a certain amount of workload on the system. The uniqueness of the ED emerges from several facts (but these facts are true for all the wards?):

1. Each patient undergoes few processes in the ED, and some of them are recurrent. For example, a typical walking patient’s routing might be: nurse, doctor, blood test, nurse, doctor.

2. There are several types of patients (internal, surgical, walking, lying etc.), and each type requires different resources of the ED.

3. The arrival process to the ED is time-dependent.

These facts might arouse difficulties in using the typical OR measurement - some measurements require adjustments. From the literature we learn about several measurements that were designed exclusively for measuring ED workload, such as EDWIN, NEDOCS, READI and Work Score (add reference).

1.5 Data Description

This documentation describes patient-level data at Emergency Department of “Anonymous” Hospital in Israel. The data was recorded over the following periods: 1/1/2004 - 1/12/2008. There are four compatible tables, that describe the hospital operations. The first table (ED) contains the following individual patient’s arrivals data records: The details of the patients and time stamp of his arrival and his departure. The second table (Justice_Table) contains the details of the patients transferred from ED to IW. The third table
(Hospital_Transfers) contains individual patient’s arrivals and departures records from hospital’s wards. The fourth table (OR) contains individual patient’s arrivals and departures records from hospital’s operation rooms.

We now present the field descriptions for each of the tables.

1. ED Table

- key - a unique number identifies each patient. The hospitals replaced the patients ID numbers with a unique generate number.
- AdmissionNo - Patients in "Anonymous ED" are identified by a serial number starting with the year and continued by sequential 6 digits number (e.g. 1999000001)
- AdmissionDate - The patient’s arrival time and date. It is recorded when the admission secretary type the patient into the system. The format is ”dd/mm/yyyy hh:mm:ss”.
- Discharge - The patient’s departure time and date. It is recorded when the admission secretary type the patient into the system. The format is ”dd/mm/yyyy hh:mm:ss”.
- SubUnitID - The code type of ward where the patients are admitted in the ED (as typed by the admission secretary). The explanations of the codes are given in the next column. (5 digits)
- UnitName- The name of the ward where the patients are admitted in the ED.
- BirthDate - The patient’s day of birth.
- Gender - The gender of the patient (”M” for male and ”F” for female).
- AdmissionCode - The code describing the patients general cause of admitting (as typed by the admission secretary). The description of the code is listed in the next column.
- AdmissionDesc - The description of the patients general cause of admitting.
- SendByCode - The code describing the authority that sends the patients to the ED (as typed by the admission secretary). The description of the code is listed in the next column.
• SendByDesc - The description of the authority that sends the patients to the ED.
• SendLetter - The presence / absence of an application letter from the authority that send the patients to the ED. ("Y" for presence and "N" for absence).
• ComplainRsnCode - The code describing the patient’s complains in his arrivals to the ED (as typed by the admission secretary). The description of the code is listed in the next column.
• ComplainRsnDesc - The description of the patient’s complains in his arrivals to the ED.
• BodyPartCode - The code describing the patient body part on which he complained for admitting (as typed by the admission secretary). The description of the code is listed in the next column.
• BodyPartDesc - The description of the patient body part on which he complained for admitting.
• ArrivalStateCode - The status code of the patient arrivals (as typed by the admission secretary). The description of the code is listed in the next column.
• ArrivalStatusDesc - The description of the patient’s status arrivals to the ED - wheelchair / stretcher.
• ProcedureCode - The code describing the procedures the patient went through while in the ED (the procedures that the staff typed into the patient’s log). The details are listed just for the patients that released from the ED. The description of the code is listed in the next column.
• ProcedureDesc - The description of the procedures the patient went through while in the ED.
• ReleaseStatCode - The status code of the patient departure from the ED (as typed by the admission secretary). The description of the code is listed in the next column.
• ReleaseStatDesc - The description of the patient departure from the ED.
• Ward - The ward where the patient is hospitalized to.
2 Analysis of the collected data and validation of the empirical and simulation models

2.1 Empirical Analysis of Emergency Department

As we started investigating the database that we have on the ED, we have found four different patients types: Internal (Int), Surgical (S), Orthopedic (O), and Trauma (Trauma) patients. We also know from the hospitalization data, which of the patients were sent to ICU, and which of the patients were sent to semi-intensive care units. We have marked those patients by their future severity classes as 'ICU' and 'V' respectively. Those not belong to ICU nor to V classes were marked as regular patients (R). In Figure ?? we can see the number of patients in each category.

<table>
<thead>
<tr>
<th>ED_Type</th>
<th>R</th>
<th>ICU</th>
<th>V</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Int_ED</td>
<td>257,708 (97%)</td>
<td>5,915 (2%)</td>
<td>2,782 (1%)</td>
<td>266,405 (59%)</td>
</tr>
<tr>
<td>Ort_ED</td>
<td>109,941 (100%)</td>
<td>212 (0%)</td>
<td>49 (0%)</td>
<td>110,202 (25%)</td>
</tr>
<tr>
<td>Surg_ED</td>
<td>67,045 (98%)</td>
<td>1,194 (2%)</td>
<td>65 (0%)</td>
<td>68,304 (15%)</td>
</tr>
<tr>
<td>Tra_ED</td>
<td>2,237 (56%)</td>
<td>1,687 (42%)</td>
<td>52 (1%)</td>
<td>3,976 (1%)</td>
</tr>
<tr>
<td>Total</td>
<td>436,931 (97%)</td>
<td>9,008 (2%)</td>
<td>2,948 (1%)</td>
<td></td>
</tr>
</tbody>
</table>

In the following subsections we shall show the arrivals, departures, and occupied beds rate. We shall analyze the Average Length of Stay (ALOS) of the different types of patients. Finally, we shall try to show how the crowdedness in the ED can influence the patients’ ALOS.

2.1.1 Arrival, Departure, and Occupied Beds rate in the ED

We shall start by analyzing the arrivals rate from a database of about four years. In Figure 9 we can see the minor fluctuation of the arrivals over time, except in a distinguished period of two months around June 2006. It seems that a war fought in the north of Israel had an influence on the arrivals rate. From Figure 10 we can see more clearly that in the two months of war the regular patients rate (Int, Ort, and Sur) dropped rapidly, while the rate of patients that need more intense care, such as Trauma patients, dramatically increased.

The next step is to look on the time variation during a day. As the day of week is influencing the patient’s arrivals patterns, we have analyzed those separately. Figure 11
Figure 9: ED Arrival rate by Time

Figure 10: Percentage of ED Arrival rate by Time
shows us the arrival, departure and occupied beds pattern of Orthopedic (O) patients during Sunday. We can see that all measurements have low rate during the night. The arrival rate is getting to its first peak at 11 AM, while the number of beds and departure rates are keep climbing until late afternoon. The same pattern we can see with Internal (Int) patients during Sundays on Figure 12.

Figure 11: Arrivals, Departures, and Occupied Beds for Orthopedic patients on Sundays

2.1.2 Length Of Stay (LOS) in the ED

Figure 13 shows the LOS distribution of the four ED patients. It can be seen that, excluding some very short stays, the gamma and log-normal distributions fit the data well.

We have further investigate the influence of the severity of the patients on the LOS distribution. In Figure 14, and Figure 15, we can see that the higher the severity the shorter the patient stays in the ED.

2.1.3 The impact of Bed Occupancy on LOS

Figure 16 shows the ALOS of the four ED patients type by their Regular Severity Beds Occupancies. We see that ALOS is starting to increase when the Occupancy rate is rising, until a certain point when it stopped influencing the LOS, and when the occupancy is in its peak, the LOS start to decrease. We can provide the following psychological explanation: When the ED is empty, each patients adds to the staff load, and the patients waiting times
Figure 12: Arrivals, Departures, and Occupied Beds rate for Internal patients on Sundays

Figure 13: LOS (hours) in the ED by Patient Type
Figure 14: LOS (Minutes) of Internal Patient by Severity

Figure 15: LOS (Minutes) of Trauma Patient by Severity
start to increase. When the ED start to be overcrowded, the staff gives high priority to the patients that are waiting to leave the ED and promote them in the queues.

Figure 16: ALOS (hours) in the ED by Regular Beds Occupancy for each Patient Type

Figure 17 shows the ALOS of the four ED patients type by the average amount of ICU cases the patients saw while in the ED. It seems that Internal and Surgical patients LOS decrease while the amount of ICU cases the ED exposed to while in the system. The explanation could be that the staff knows in advance when ICU patients are expected to arrive. It could force them to give high priority for preparing patients for departure. Figure 18 shows the ALOS of the Internal patients by the average amount of V cases the patients saw while in the ED. It seems that Internal ICU patients are not influenced by the amount of V cases, while both V and Regular Internal patients mostly go faster out of the ED when the number of semi-intensive cases are in the ED. Since these last two figures are not easily explained, we can provide kind of mathematical explanation: The ICU and V patients are relatively sparse, and seeing on average couple of cases during patients stay is more rare. The shorter the stay the higher the chance of catching more rare events on average, and not vice versa. Therefore, more investigation is needed before making any assumption on the influence of ICU and V beds occupancy on the ALOS.
Figure 17: ALOS (hours) in the ED by ICU Beds Occupancy for each Patient Type

Figure 18: ALOS (hours) in the ED by V Beds Occupancy for each Patient Type
2.2 Empirical Analysis of Internal Wards

2.2.1 Length Of Stay (LOS) in the IW

As a first stage we would like to investigate the distribution of LOS in the various departments of the hospital. We can find various patterns in the LOS distribution. Figures 19 and 20 show the LOS distribution in one of the Internal Wards. It can be seen that, when considering daily resolution, the gamma and log-normal distributions fit the data well. The second graph is on hourly resolution and illustrates the impact of the discharge policy: the decision on discharging patients is done once a day, hence the stay distribution has peaks in jumps of 24 hours.

![Figure 19: LOS (days) in internal ward A](image)

![Figure 20: LOS (hours) in internal ward A](image)

2.2.2 Arrivals and Departures in the IW

Patients arrive to the hospital on random times according to Poisson process with time dependent arrival rate (prove!!). Most patients arrive to the ED during the day (see Figure ??). The process of admissions to the wards (transfers from the ED) has the following pattern: most of the patients arrive between 15:00 - 24:00, and depart between 13:00-17:00. Thus, the number of patients in the ward during the afternoon hours (when the rate of
arrivals and departures is high) is significantly lower than the average number of patients during the whole day or during the patients’ stay. For example Figure 21 illustrates such pattern in Ward A - it shows average of all week days. Figure 22 illustrates such pattern in Ward A by week days for days 1, 2, and 7, and Figure 23 illustrates the same pattern in Ward A during the entire week.

![Figure 21: Arrival, Departures, and Number of Patients Patterns in Ward A](image)

2.2.3 Determining Length Of Stay in IW as a function of the work load (see Appendix A - 1).

We want to determine the impact of workload on the LOS in Internal Wards. The similar attempt was done at [3]. There are few ways to define workload. The simplest way is to look at the patient-load, for example, the number of patients in the ward or the percentage of occupied beds. A more sophisticated view is to look at the workload on the service providers (i.e. nurses and doctors). These two workloads are connected; we shall examine both.

**Length of stay as a function of patients load in the ward**

When considering the LOS versus the patient load in the system, we find that during one patient’s stay the load can be changed dramatically.

Figure 24 illustrates the number of patients a random patient sees in the ward during his/her stay, and the workload on nurses s/he sees. The work load on nurses is calculated using Formula 1 assuming $T_s = 0.25, T_{INI} = 0.5$ hours and $f_s = 0.4$ requests per patient.
Figure 22: Arrival, Departures, and Number of Patients Patterns in Ward A for Days 1, 2, and 7 in the Week

Figure 23: Arrival, Departures, and Number of Patients Patterns in Ward A During the Weekdays
per hour. (WE MUST ESTIMATE IT AGAIN) One can observe the same patterns of the number of patients in the ward. It is important to notice that, while the number of patients drops between 13:00 and 23:00, the workload does not decrease but increases. (remark: can we add the waiting probability or averages he observes?)

![Chart1](image)

**Figure 24:** Number of patients and workload during the LOS of a random patient

Summarizing the above, we conclude that although one usually measures the load that patient sees at his/her entering time to the system, in our case this will underestimate the real load that the patient observes. In order to overcome this problem, we calculate the average number of patients in the ward during each patient’s stay. Figure 25 shows the ALOS [in days] of patients as a function of the average beds occupancy rate. Occupancy rate is calculated relatively to the maximal number of beds in the ward.

We also need to calculate it by average number of people at 7:00.

**Length Of Stay as a function of nurses work load in the ward**

In order to define the workload that each patient brings to the ward, we use a model that is close to the one described in Galit’s thesis (reference). Each patient during his stay alternates between “needy” and “content” states. When a patient is needy he requires service from a nurse. A patient starts and ends his stay in a needy states. The average time
Figure 25: ALOS as a function of bed occupancy in wards A-E
of the first and last services (when she is admitted or discharged from the ward) could be
different from the average service time of regular service (we don’t have data on that, but it
is reasonable to assume that, and that is what the IW B nurse has told us). Thus, in order
to define the workload that a specific patient sees during his stay, we shall count the number
of patients that arrive and depart during his stay and the number of patients hospitalized
in his ward in every hour, and multiply them in the service time they require.

Define \( A_t \) - The total number of customers that entered the system till time \( t \),
\( D_t \) - The total number of customers departed from the system till time \( t \), \( A^{-1}(i) \) - The arrival time of
customer \( i \), \( D^{-1}(i) \) - The departure time of customer \( i \). \( Q_t \) - The number of customers in the
system at time \( t \), therefore \( Q_t = A_t - D_t \). Define \( E_i[Q] \) - The average number of customers in
the system when customer \( i \) is in the system, and \( LOS(i) \) - The Length of Stay of customer
\( i \), \( LOS(i) = D^{-1}(i) - A^{-1}(i) \), therefore:

\[
E_i[Q] = \frac{\int_{A^{-1}(i)}^{D^{-1}(i)} Q_t dt}{LOS(i)}.
\]

Define \( INI_i \) as the average number of admissions and discharges during the stay of customer
\( i \), and \( Load_i \) as the average load customer \( i \) sees during his stay. Therefore:

\[
INI_i = \frac{A(D^{-1}(i)) - A(A^{-1}(i)) + D(D^{-1}(i)) - D(A^{-1}(i))}{LOS(i)},
\]

and

\[
Load_i = INI_i * T_{INI} + E_i[Q] * T_s * f_s, \tag{1}
\]

where \( T_{INI} \) is the average time that admission or discharge takes, \( T_s \) is the average service
time , and \( f_s \) is the frequency of service requirements of customer per hour (?). We assumed
\( T_s = 0.25, T_{INI} = 0.5 \) hour and \( f_s = 0.4 \).

Figure 26 shows ALOS of patients as a function of their \( INI_i \) for each ward.

Figure 27 shows ALOS of a patient as a function of the total service work load s/he
observes during his stay - \( Load_i \).

In order to account for the influence of ward size the Figure 28 shows ALOS as a function
of \( \frac{E_i[Load_i]}{N_j} \), where \( N_j \) is the maximum number of beds in ward \( j \) and \( E_j[Load_i] \) is the average
load of customers in ward \( j \).
Figure 26: LOS as a function of INI by ward
Figure 27: ALOS as a function of working load of a nurse

Figure 28: LOS as a function of working load of a nurse
2.3 Empirical Analysis of Transfers in the system

2.3.1 Waiting times from ED to IW

Empirical analysis of waiting time for transferring from ED to the IW (see Appendix A - 3) by customer type (patients that are given artificial respiration or not).

2.3.2 Waiting times from ED to ICU

is there blocking? maybe we should transfer this to the next chapter?
3 Analysis of the system (using combined simulation and/or analytical models).

Answering what-if questions. Two for each part; the first will consider an operational issue (such as pooling or priority), and the second will try to explain an interesting empirical findings.

3.1 Two interesting questions for ED

For example capacity analysis of ED:

a. Resources (staff, beds, and supported activities) utilization
b. How many patients’ arrival per day can the system handle?
c. The impact of time-varying arrivals and the impact of mass casualty events (e.g. car accident or terrorist attack).
d. What is the bottleneck of the process?
e. Staffing policy - the use of analytical models (see Appendix A - 6a).
f. input control - ambulance diversions.
h. Using simple analytical model for the ED.
i. Replacing simulation sub-models with analytical models (see Appendix A - 4)
j. Using priorities (see Appendix A - 9).
k. Designing of teams (pooling decisions as in Appendix A - 6c).

3.2 Two interesting questions for IW

Investigating the connection between Lambda, Mu, Q and time in IW

3.3 Two interesting questions for the transfer process from ED to IW

For example:

justice
heterogenic wards?

a. How do different routing schemes affect system’s performance (fair allocation)?
b. Where the queue should be: IW or ED (see Appendix A - 5).
c. Using incentive (auction) mechanism (game theory -Pulling method)?
3.4 Two interesting questions for the whole process

For example:
The impact of IW/OR/ICU work load on the capacity analysis of the ED (see Appendix A - 1).

4 Special events

a. The war. b. Moving to the temporary location. c. Special days (with many Multi Trauma). d. Months with flu patients.
References


A Meetings summary

1. The impact of load (workload per server per time unit) on the length of service (in Internal Wards - LOS, in ED - treatment time (nurse, physician), in Call Center - duration).

Remark: one need to consider the influence of ward size and the number of nurses and doctors.

(a) Empirical model (statistical approach): from the Hospital Database and observations.

(b) Compare with other fields (call centers). Explanation based on psychological / economical model. We would look on papers from Health care (Yulia) or in OR/MS.

(c) Influences on Analytical model (call centers staffing; health care staffing, bed allocation and routing policy).
   1. Compare simulation with changing service time ($M/M_\rho/N/(K)$) to $M/M/N$, $M/M/N/K$ models check the accuracy of probability of blocking and beds’ utilization.
   2. Can we estimate LOS function in such a way that one can develop a closed form solution to ($M/M_\rho/N/(K)$)?

Challenges: how to define Load.

2. Support mathematical basis for the QED model: check empirically that the probability of waiting, in the meaning of the probability for an empty bed, is between 0 and 1. Check it for different seasons.

3. Modeling waiting time for moving from ED to IW (accounting for constrains in the IW). The possible approaches are:

   (a) As currently in the simulation - the delay is exponentially distributed with empirically found average (does not account for congestion in Internal Wards).

   (b) Empirical model possibly based on the database from Rambam.

   (c) Green and Yancovitch model which accounts for blocking that are caused by lack of nurses, physician, or beds.
(d) Combined with Galit’s model (use the probability of blocking and waiting to predict nurses’ availability).

(e) Procedural constrains in the IW, such as shift changing periods, meals times, cleaning patients time and so on.

4. Comparison of Simulation Model of the ED+IW to Erlang-C, Erlang-B, or M/M/? or Galit’s model:

(a) What is the meaning of ”the number of servers” in such models, and how to estimate the right one as the combination of Nurses, X-Ray, Beds, or Physicians?

\[
\begin{align*}
M/M/S + M \\
S = W_P \times P + W_N \times N
\end{align*}
\]

where \( P \) is the Number of Physicians and \( N \) is the Number of Nurses

(b) Different measures: LOS pdf, waiting times, occupancy, patients’ departures from the ED etc.

(c) Influences of the model on operational decisions (e.g. staffing, bed allocation, and routing).

5. Moving patients from the ED to the IW: Compare between policy in which patients are waiting in the ED for their placement (Rambam) vs. in which patients are waiting in the IW for their admission (Nahariya or Pnimit Hei in Rambam). (Could be relevant to ED vs. ER). Green also mentioned this conflict in the US.

6. Using the Simulation for interesting questions:

(a) Determine staffing policy for Beds, Nurses, and Physicians (developing staffing algorithm and use of Analytical Model vs. Simulation).

(b) The influence of IW congestion on the ED.

(c) Treatment times are influenced by learning and forgetting. Forgetting is influenced by congestion (time between treatments of the same patient) and by amount of patients per staff member (information overload problems). Can one estimate these influences and their impact on staffing decisions?
(d) Using shared X-Ray or dedicated X-Ray to the ED. If shared, then how the priorities are determined.

(e) The operational strategies impact on the LWBS/abandonment-rate and the Returns rate.

(f) DEA (Data Envelop Approach).

7. Combination of incentives mechanism (in IW) and routing policy (ED to IW) in a way that encourages operational improvement (e.g. reduce LOS, increase staffing and bed efficiency) without interfering with the clinical aspects (as quality of care). Remark: patient allocation can be in Push-mode or by Pull-mode (e.g. auction-like).

8. Clinical aspects: building a connection between quality of treatment (urgency of treatment needed) and waiting time using known clinical procedures for different cases and their frequency in population. The outcome would be the quality of service function that can be used for staffing decisions instead of the regular waiting time function, or in order to define appropriate waiting time standards for staffing in EDs (optimal "cost/profit as opposed to constraint satisfaction). Return rate as a quality of treatment measure.

9. The impact of using priority on operational decisions and measures:

   (a) Triage and priority schemes.

   (b) Imaging priority (can be used to reduce the load in the ED).

Our hypotheses for 1 and 5c: