ED simulation overview

Seminar in Service Engineering
Winter 2009

Outline

- Can We Make Simulation More Accessible. To Emergency Department Decision Makers.
  - Sinreich, D. and Marmor. Y. (2005), "Emergency Department Operations: The Basis for Developing a Simulation Tool", *IIE Transactions*, Vol. 37, No. 3, pp. 233 – 245.
  - Sinreich, D. and Marmor, Y. (2005), "Ways to Reduce Patient Turnaround Time and Improve Service Quality in Emergency Departments", Journal of Health Organization and Management. Vol. 19, No. 2, pp. 88-105.
- Resource Scheduling in Emergency Departments.
  - Sinreich, D. and Jabali. O. (2007), "Staggered work shifts: a way to downsize and restructure an emergency department workforce yet maintain current operational performance ", *Health Care Management Science*, Vol. 10, No. 3, pp. 293-308.
- Rough Cut Capacity Planning (on going work).
- Offered Load (on going work).
- בחינת היבטים תפעוליים של המעבר למלר"ד הזמני בבית החולים רמב"ם (פרויקט שנתי).

Can We Make Simulation More Accessible To Emergency Department Decision Makers

David Sinreich and Yariv Marmor

The Healthcare Industry and Numbers

- The ICBS reports that the annual healthcare spending in Israel in 2003 reached \$10.1 billion (~\$1700 per person), which accounts for 8.8% of the GDP.
- This level of expenditure is similar to other OECD countries such as Germany 10.9%, France 9.7%, Sweden 9.2% and Australia 9.1% (number reflect expenditure in 2002)
- Hospitals accounted for 26.1% of the national expenditure on healthcare in 2001.

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The Healthcare Industry and Numbers

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These numbers are a clear indication that increasing the efficiency and productivity of hospital and ED operations is critical to the success of the entire healthcare system

The Emergency Department

- The ED serves as the hospital's "gate keeper" and is the most difficult department to manage.
- The ED has to handle efficiently and effectively a random arrival stream of patients.
- The ED has to be highly versatile and flexible.
- The ED is required to have the ability to react quickly to fast unfolding events.

The Emergency Department

- There are 2.5 million patient visits each year at the 25 EDs in Israel. This translates to about 270 patient visits on average per day.
- On average there 30 - 40 beds in these EDs.
- Based on these number, there are around 7 - 8 patient turnarounds a day, this translates to an average length of stay of 3 - 3.5 hours.
- In reality there are 4 - 6 times more patient arrivals during pick hours (between 11 – 13 and 19 – 22) compared to other hours of the day.

Simulation of Healthcare and ED Systems

- Hospital management is reluctant to accept change, particularly if it comes from a 'black-box' type of tool.
- Management often does not realize the benefits of using simulation-based analysis tools.
- Management is well aware of the time and cost that have to be invested in building detailed simulation models.
- Management believes that spending money on operational issues only diverts funds from patient care.
- Lack of experts with experience in modeling large, complex systems.

Increasing Acceptance of Simulation in Healthcare

It is essential to build up the models' credibility:

- Hospital management should be directly involved in the development of simulation projects.
- The development of simulation projects should be done in-house by hospital personal.

Increasing Acceptance of Simulation in Healthcare

- **General, and flexible**
- Include **default values for most of the system parameters**.
- **Simple** to use
- Include a **decision support system**

Essential Basic Condition

For the tool to be general and flexible

The process patients go through when visiting an ED has to be determined mainly by the patient type (Internal, Orthopedic, Surgical etc.) rather than by the hospital in which it is performed.

The Field Study

- Funded by the Israel National Institute for Health Policy (NIHP).
- 5 out of the 25 – 27 general hospitals operating in Israel participated in the study.
- Hospitals 1 and 3 are large (over 700 beds). Hospital 5 is medium (400 - 700 beds). Hospital 2 and 4 are small (less than 400 beds).
- Hospital 5 is a regional hospital and the rest are inner-city hospitals.
- Hospitals 1 and 3 are level 1 trauma centers and the rest are level 2 centers.

The Field Study

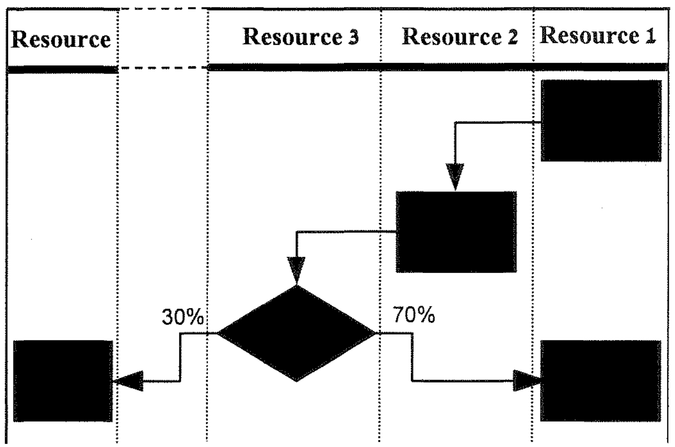
- Teams of supervised students equipped with standardized code lists of the different process elements conducted time and motion studies in the selected hospitals.
- Data was also gathered from each hospital's information system.
- Additional data was gathered trough interviews with the hospital top management, ED chief physician and ED head nurse.

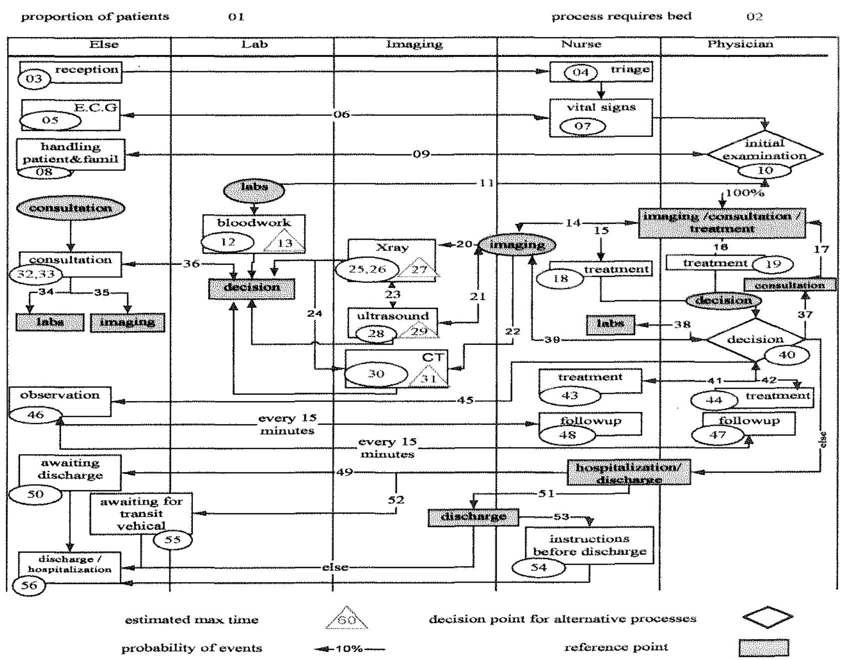
Processes and Patient Types

- Through observations, gathered data and interviews, 19 individual process charts each representing a typical patient types were identified.

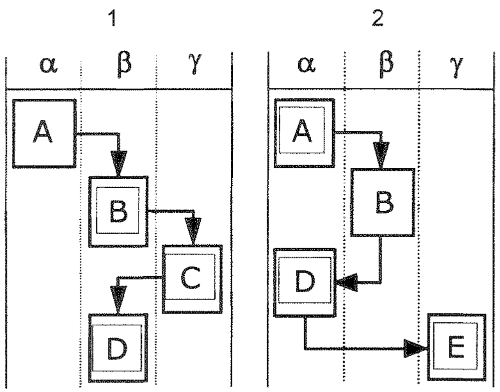
Hospital	Patient Type
1	Fast-Track, Internal, Surgical, Orthopedic
2	Internal, Surgical, Orthopedic
3	Walk-In Internal, Walk-In Orthopedic, Walk-In Surgical, Internal, Trauma
4	Internal Acute, Internal/Surgical Minor, Orthopedic
5	Fast-Track, Internal, Surgical, Orthopedic

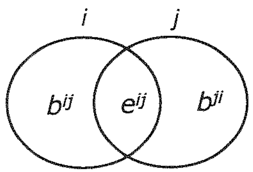
Process Chart





The Similarity Measure - Activities

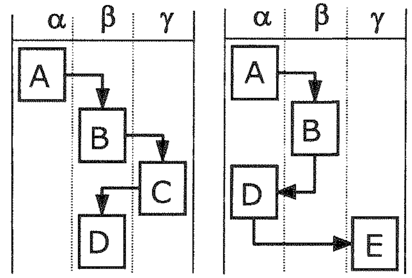




$$a^{ij} = \frac{e^{ij}}{e^{ij} + b^{ij} + b^{ji}}$$

$e^{12}=2, b^{12}=2, b^{21}=2 \longrightarrow a^{12}=0.33$

The Similarity Measure - Relationships



$$\begin{cases} h^{i}_{kl} = f^{i}_{kl} \times \omega_k \times \omega_l \\ c^{ij} = \sum_k \sum_l \min\{h^{i}_{kl}, h^{j}_{kl}\} \\ d^{ij} = \sum_k \sum_l \left| h^{i}_{kl} - h^{j}_{kl} \right| \\ r^{ij} = c^{ij} / (c^{ij} + d^{ij}) \end{cases}$$

$$H^1 = \begin{pmatrix} 0 & 1\times2\times1 & 0\times2\times1 \\ 0\times1\times2 & 0 & 1\times1\times1 \\ 0\times1\times2 & 1\times1\times1 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 2 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \quad H^2 = \begin{pmatrix} 0 & 2 & 2 \\ 2 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \omega_k = (2,1,1)$$

c^{12} = 0+2+0+0+0+0+0+0+0 = 2

d^{12} = 0+0+2+2+0+1+0+1+0 = 6

r^{12} = 2/(6+2) =0.25

The Sensitivity of the Similarity Measure

The similarity measure is sensitive to:

- The absence of an activity or to additional activities a resource is expected to perform.
- The absence of a relationship or to an additional relationship between activities.

The similarity measure is not sensitive to:

- The order in which activities are expected to be performed.

Clustering the Patient Processes

5 FT	5 S	5 O	5 I	4 I_A	4 O	4 I_S	3 T	3 I_W	3 S_W	3 O_W	3 I	2 S	2 O	2 I	1 FT	1 S	1 O	1 I	
88	55	24	66	70	46	89	43	32	23	32	59	52	33	64	80	52	43		1 I
53	62	77	32	36	86	35	59	12	37	60	14	74	89	40	40	66			1 O
79	89	42	37	39	61	58	68	31	47	58	31	74	59	49	61				1 S
94	56	23	48	43	57	67	45	28	29	37	44	51	32	56					1 FT
66	40	23	89	73	25	59	38	39	18	25	63	53	44						2 I
46	51	72	32	50	71	30	45	6	23	43	9	67							2 O
64	71	51	37	45	55	46	62	32	38	45	31								2 S
52	23	1	53	51	7	57	27	27	9	10									3 I
46	51	25	14	15	52	28	88	16	84										3 O_W
37	41	2	5	5	31	16	100	30											3 S_W
45	19	0	23	26	3	29	36												3 I_W
54	64	22	23	24	46	34													3 T
79	54	27	61	72	39														4 I_S
57	56	53	18	26															4 O
59	27	32	77																4 I_A
55	25	16																	5 I
32	52																		5 O
65																			5 S
																			5 FT

Average Similarity Level – 0.44

3

Clustering the Patient Processes

- Full enumeration and ranking was used to determine the best way to divide the processes into:

Two clusters | Three clusters | Four clusters

Clustering the Processes Into Two Groups

- The first group included all the internal patient types from all 5 hospitals: 1Int, 1FT, 2Int, 3Int, 3W_Int, 4Int_S, 4Int_A, 5Int, 5FT.
- The best combined average similarity value for two clusters (0.579, 0.571) was 0.575.

Clustering the Patient Processes

- Full enumeration and ranking was used to determine the best way to divide the processes into:

Two clusters | Three clusters | Four clusters

Clustering the Processes Into Three Groups

- The best combined average similarity value for three clusters was 0.638.
- The chosen clustering option was ranked as number 17 with a combined average similarity value of (0.656, 0.746, 0.544) 0.623.

"When good is better than best" (Petroski 1994)

5 FT	5 S	5 O	5 I	4 I_A	4 O	4 I_S	3 T	3 I_W	3 S_W	3 O_W	3 I	2 S	2 O	2 I	1 FT	1 S	1 O	1 I	
88	55	24	66	70	46	89	43	32	23	32	59	52	33	64	80	52	43		1 I
53	62	77	32	36	86	35	59	12	37	60	14	74	89	40	40	66			1 O
79	89	42	37	39	61	58	68	31	47	58	31	74	59	49	61				1 S
94	56	23	48	43	57	67	45	28	29	37	44	51	32	56					1 FT
66	40	23	89	73	25	59	38	39	18	25	63	53	44						2 I
46	51	72	32	50	71	30	45	6	23	43	9	67							2 O
64	71	51	37	45	55	46	62	32	38	45	31								2 S
52	23	1	53	51	7	57	27	27	9	10									3 I
46	51	25	14	15	52	28	88	16	84										3 O_W
37	41	2	5	5	31	16	100	30											3 S_W
45	19	0	23	26	3	29	36												3 I_W
54	64	22	23	24	46	34													3 T
79	54	27	61	72	39														4 I_S
57	56	53	18	26															4 O
59	27	32	77																4 I_A
55	25	16																	5 I
32	52																		5 O
65																			5 S
																			5 FT

Average Similarity Level – 0.656

Average Similarity Level – 0.746

Average Similarity Level – 0.544

Combined Average Similarity Level – 0.623

Clustering the Patient Processes

- Full enumeration and ranking was used to determine the best way to divide the processes into:

Two clusters | Three clusters | Four clusters

Clustering the Processes Into Four Groups

- The best combined average similarity value for four clusters was 0.683.
- The chosen clustering option was ranked as number 76 with a combined average similarity value of (0.669, 0.746, 0.654, 0.558) 0.666.
- The first group included all acute internal patient types: 1Int, 2Int, 3Int, 4Int_S, 4Int_A, 5Int.
- The second group included most orthopedic patients types: 1O, 2O, 4O, 5O.
- The third group included most surgical patients types: 1S, 2S, 3O_W, 3S_W, 3T, 5S.
- The forth group included all ambulatory patients types: 1FT, 3Int_W, 5FT.

Conclusions

Based on this analysis it is safe to argue that in the hospitals that participated in this study, patient type has a higher impact in defining the operation process than does the specific hospital in which the patients are treated.

Increasing Acceptance of Simulation in Healthcare

- **General, and flexible**
- Include **default values for most of the system parameters**.
- **Simple** to use
- Include a **decision support system**

The Relative Precision of the Time Elements

- Since a time study is basically a statistical sampling process, it is important to estimate the precision of the gathered data.

$\hat{\mu}_{ip}, \sigma_{ip}$ — Average Duration and Standard Deviation over all observed elements i for patient type p at all the hospitals

m_{ip} — The number of times element i was observed for each patient type p

ϑ_p — The maximum number of times patient type p goes through an element that is only performed once during the ED process

Precision as a proportion of the gathered element $d_{ip} = \frac{z_{(1-\alpha/2)} \cdot \hat{\sigma}_{ip}}{\sqrt{m_{ip}} \cdot \hat{\mu}_{ip}}$

The Relative Precision of the Time Elements

The contribution of element i to the total process time of patient type p $\quad \tilde{t}_{ip} = \frac{\hat{\mu}_{ip} \cdot m_{ip}}{\vartheta_p}$

The relative weight of element i for patient type p $\quad w_{ip} = \tilde{t}_{ip} \Big/ \sum_{\forall i} \tilde{t}_{ip}$

The relative precision of element i $\quad d_{i\bullet} = \frac{z_{(1-\alpha/2)} \cdot \hat{\sigma}_i}{\sqrt{m_i} \cdot \hat{\mu}_i}$

The relative precision for patient type p $\quad d_{\bullet p} = \sum_{\forall i} d_{ip} \cdot w_{ip}$

Over 20,000 process elements were observed and recorded.

Precision of the Different Time Elements

Element Precision $d_{i\bullet}$	Patient Types					
	Fast-Track	Trauma	Orthopedic	Surgical	Internal	Element
2.2%	3.2%	6.7%	5.5%	6.7%	3.6%	Vital Signs
3.9%	6.7%	13.1%	16.0%	11.3%	3.5%	E.C.G. Check
3.5%	15.6%	10.8%	11.1%	12.6%	5.5%	Treatment Nurse
7.9%	50.1%	19.7%	43.0%	47.5%	10.1%	Follow-up Nurse
11.9%	43.2%	25.2%	29.1%	30.7%	16.5%	Instructions Prior to Discharge
2.6%	10.2%	7.4%	4.4%	[illegible]	4.5%	First Examination
4.3%	30.2%	11.8%	5.0%	11.4%	6.7%	Second or Third Examination
5.6%	----	32.9%	26.0%	27.8%	6.5%	Follow-Up Physician
7.5%	15.0%	32.9%	19.3%	13.0%	11.0%	Hospitalization /Discharge
4.5%	18.4%	5.5%	5.5%	15.9%	6.6%	Handling Patient and Family
7.1%	49.9%	21.2%	15.4%	12.9%	11.3%	Treatment Physician
	7.6%	9.5%	5.1%	8.4%	6.2%	Patient Precision $d_{\bullet p}$

Delighted outcome of the analysis: Finding critical elements

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Table XI.
The three most critical elements in each of the six hospitals and their average duration (minutes)

Component	Hospital 1	2	3	4	5	6
Average waiting time for the first physician's examination (PC 30)			3 (8.9)	2 (9.9)	2 (14.8)	3 (7.5)
Average time away for an x-ray examination (PC 60)	1 (30.9)	1 (32.9)	1 (23.5)	1 (46.2)	1 (29.7)	1 (37.5)
Average waiting time for regular blood results (PC 69)	2 (54.2)	2 (66.6)	2 (54.6)			2 (55.5)
Average time away for checkup in one of the hospital departments (PC 73)					3 (57.8)	
Average waiting time for logistics aid personnel (PC 84)	3 (19.9)			3 (16)		
Average duration of the patient's delay for observation (PC 85)		3 (93.8)				
Total impact of the top three components (%)	30.8	28.8	36.8	29.7	29.7	32.7

The contribution of element *i* to the total process time of patient type *p*: $\tilde{\iota}_{ip} = \frac{\hat{\mu}_{ip} \cdot m_{ip}}{\vartheta_p}$

Conclusions

The combined precision values indicate, that aggregating element duration regardless of patient type and the hospital in which the patients are treated, improves the precision levels of all the different elements.

Increasing Acceptance of Simulation in Healthcare

- **General, and flexible**
- Include **default values for most of the system parameters**.

[redacted]

Increasing Acceptance of Simulation in Healthcare

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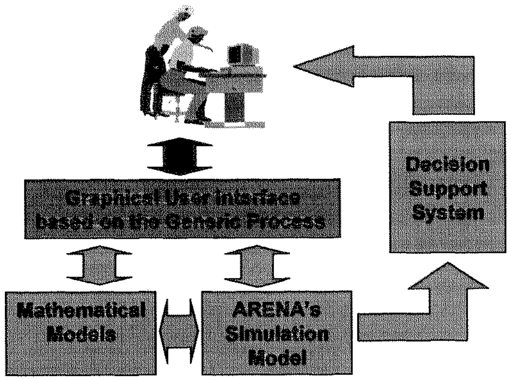
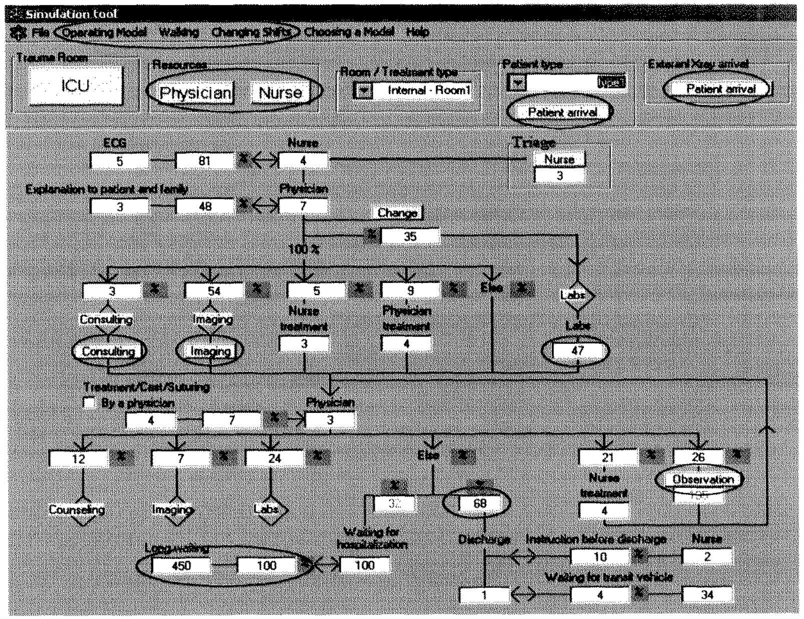
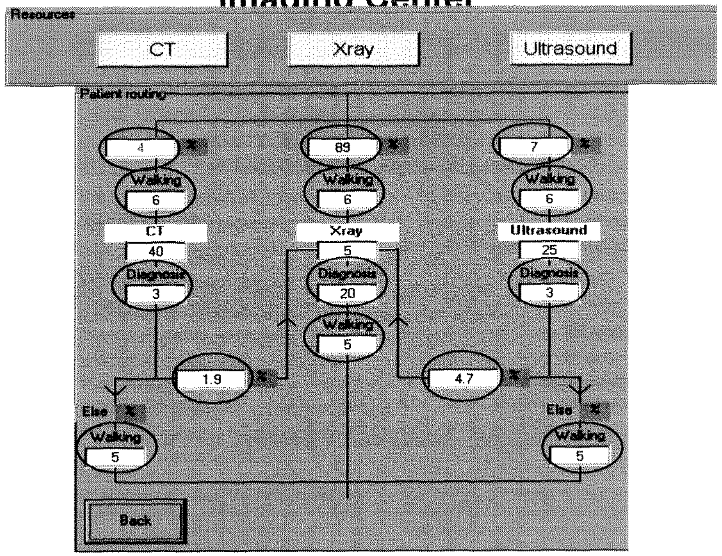
5

The Structure of the Simulation Tool

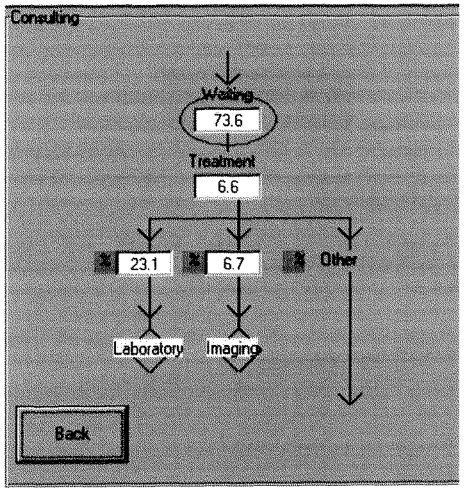




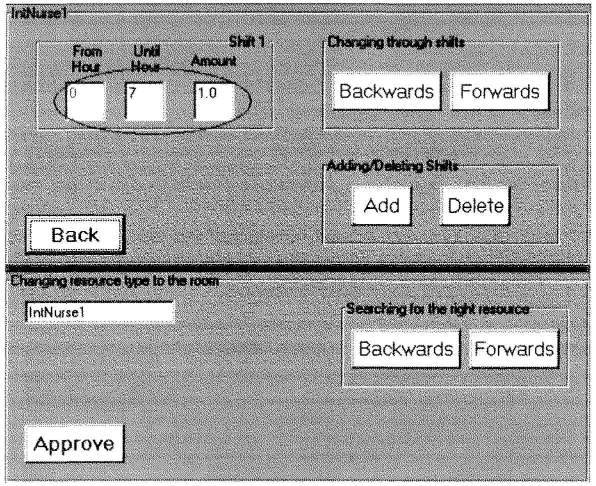
Imaging Center



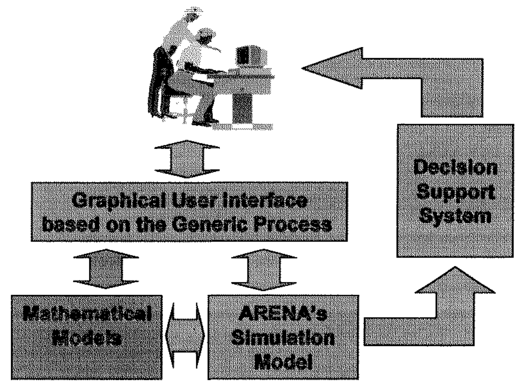
Specialists



Scheduling Medical Staff



The Structure of the Simulation Tool



Mathematical Model Development

The following mathematical models were developed based on the gathered information:

- Patient arrivals to the ED
- Patient Arrivals at the Imaging Center
- Staff's walking time

Estimating the Patient Arrival Process

- The gathered data reveals that the number of patients arriving at the ED differs from hour to hour and from day to day
- Statistical tests reveal that the square-root of the patients' arrival process can be described by a normal distribution.
- Let X_{pihd} be a random variable normally distributed with a mean of μ_{pihd} that represents the square-root of the number of patients of type p who arrive at the ED of hospital i at hour h on day d.

Estimating the Patient Arrival Process

The patient arrival process is similar for all the hospitals surveyed therefore it was decided to combine the gathered data from all hospitals

n_{pihdw} - The square-root of the number of patients of type *p* who arrive at the ED of hospital *i* at hour *h* on day *d* in week *w*

$\hat{\mu}_{pi}$ - The average square-root estimator of the number of patients of type *p* arriving at hospital *i* per hour

W, H - Number of data weeks received from the hospitals' information systems and number of hospitals

$\hat{F}_{pi}$ - The patient arrival factor

$\hat{n}^a_{pihdw}$ - The estimated adjusted arrival data values of patients of type *p* who arrive at hospital *i* at hour *h* on day *d* in week *w*

$\hat{\mu}_{phd}$ - The number of patients of type *p* who arrive during hour *h* on day *d*

Estimating the Patient Arrival Process

$$\hat{\mu}_{pi} = \sum_{w=1}^{W}\sum_{d=1}^{7}\sum_{h=1}^{24} n_{pihdw} \Big/ W \cdot 7 \cdot 24$$

$$\hat{F}_{pi} = \frac{\hat{\mu}_{pi}}{\sum_i \hat{\mu}_{pi} \Big/ H}$$

$$\hat{n}^a_{pihdw} = n_{pihdw} \Big/ \hat{F}_{pi}$$

$$\hat{\mu}_{phd} = \sum_{i=1}^{H}\sum_{w=1}^{W} \hat{n}^a_{pihdw} \Big/ H \cdot W$$

$$\hat{\mu}_{pihd} = \hat{\mu}_{phd} \cdot \hat{F}_{pi} \longrightarrow X_{pihd} \sim N(\hat{\mu}_{pihd}, 0.6)$$

The number of patients of type *p* who arrive at hospital *i* at hour *h* on day *d* $\quad \theta_{pihd} = \left\langle x^2_{pihd} \right\rangle$

Estimating the Patient Arrival Process

In the case a new hospital whishes to use the simulation tool all that is needed are the n_{pihdw} values obtained from the hospital's computerized information systems.

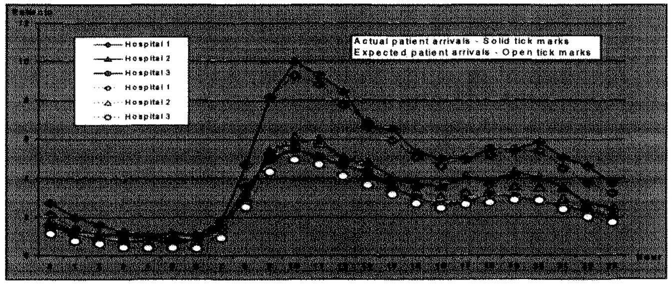
The rest of the process, which includes calculating the formulas, is performed automatically by the simulation tool.

Patient Type			
Orthopedic	Surgical	Internal	Hospital
1.187	1.293	1.180	1
0.840	1.038	0.958	2
0.974	0.669	0.862	4

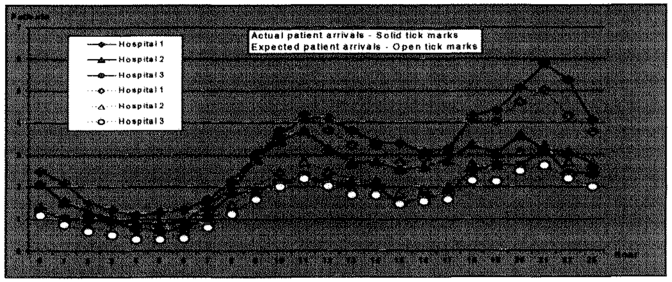
It is clear from these factors that hospital 1 is larger than the other two hospitals

Validating The Model

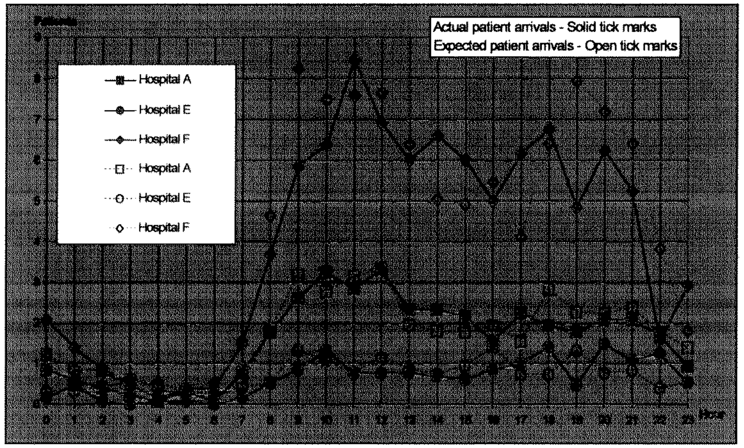
Internal Patients on Monday



Internal Patients on Saturday



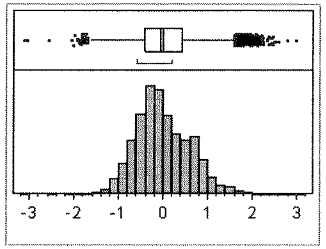
Validating The Model



Surgical Patients on Wednesday

Validating The Model

The distribution of the residuals between the predicted patient arrivals and the actual patient arrivals.



Moments	
Mean	0.0000844
Std Dev	0.6003367
Std Err Mean	0.0025241
upper 95% Mean	0.0050316
lower 95% Mean	-0.004863
N	56571

Shapiro-Wilk goodness of fit tests reveal that the residuals can be described by a normal distribution with a mean close to 0, and a standard deviation of 0.6 .

Mathematical Model Development

The following mathematical models were developed based on the gathered information:

- <u>Patient arrivals to the ED</u>
- <u>Patient Arrivals at the Imaging Center</u>
- <u>Staff's walking time</u>

The Patient Arrival Process to the Imaging Center

- To accurately estimate the turnaround time ED patients experience at the imaging center it is important to estimate the following:
  - patients' walking time
  - Waiting time at the imaging center
  - the time it takes to perform an X-ray
  - the time it takes the radiologist to view the X-ray to return a diagnose
- Imaging centers (X-ray, CT and ultrasound) are not always ED-dedicated. In some cases these centers serve the entire hospital patient population.

The Patient Arrival Process to the Imaging Center

- In these cases two different patient types are sent to the imaging center for service:
  - patients who come from the ED
  - patients who come from all other hospital wards
- These two streams interact and interfere with each other and compete for the same resources
- In these case it is imperative to estimate the hospital patient arrival process.

Estimating The Imaging Center Arrival Process

- The gathered data reveals that the number of hospital patients arriving at the imagining center differs from hour to hour and from day to day and from month to month
- Statistical tests reveal that the square-root of the hospital patients' arrival process can be described by a normal distribution.

Estimating The Imaging Center Arrival Process

- A linear regression model was used to estimate the stream of hospital patients. In order to maintain the model's linearity, four separate regression sub-models were developed.
  - A sub-model to estimate the arrivals between 6 AM and 12 midnight on weekdays.
  - A sub-model to estimate the arrivals between 6 AM and 12 midnight on weekends.
  - A sub-model to estimate the arrivals between 12 midnight and 6 AM on weekdays and weekends.
  - A sub-model to estimate the arrivals between 12 noon and 5 PM in the cases the central imaging center only operates part of the day.

Estimating The Imaging Center Arrival Process

$\hat{\mu}$ - The square-root of the average number of patients arriving to the imaging center

α_i - The hospital effect

β_h - The hour effect

γ_d - The day effect

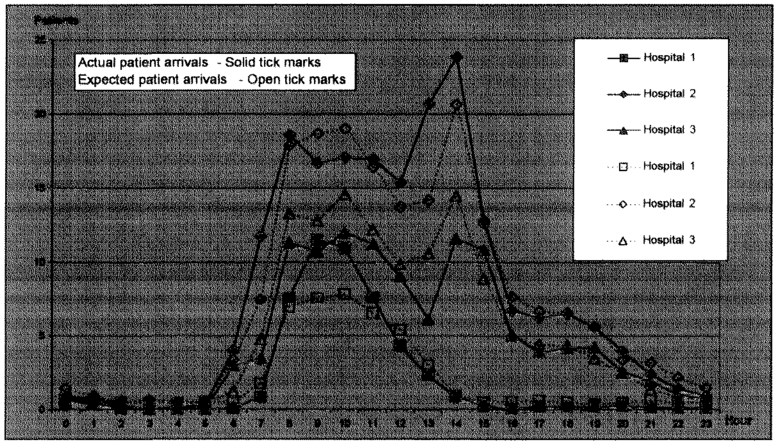
δ_m - The month effect,

$$\hat{\varphi}_{ihdm} = \hat{\mu} + \alpha_i + \beta_h + \gamma_d + \delta_m + \varepsilon$$

The number of hospital patients of type *p* who arrive at imagining center of hospital *i* at hour *h* on day *d* and on month *m*

$$\pi_{ihdm} = \left\langle \varphi_{ihdm}^2 \right\rangle$$

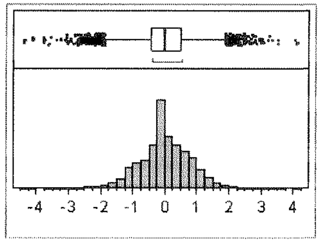
Validating The Model



Hospital Patient Arrivals to the Imaging Center on A Tuesday

Validating The Model

The distribution of the residuals between the predicted patient arrivals and the actual patient arrivals.



Moments

Mean	-1.62e-14
Std Dev	0.8030956
Std Err Mean	0.0075429
upper 95% Mean	0.0147854
lower 95% Mean	-0.014785
N	11336

Shapiro-Wilk goodness of fit tests reveal that the residuals can be described by a normal distribution with a mean close to 0, and a standard deviation of 0.8.

Mathematical Model Development

The following mathematical models were developed based on the gathered information:

- Patient arrivals to the ED
- Patient Arrivals at the Imaging Center
- Staff's walking time

Estimating the Staff's Walking Time

- Observations show that the medical staff spends a considerable amount of time, during each shift, walking between the different activity points in the ED.
  - patient beds
  - medicine cabinet
  - nurse's station
  - ED main counter
- The estimation model is based on the following parameters:
  - The distances between the different activity points
  - The number of beds each staff member is in charge of
  - The ED space dimensions each staff member operates in.

8

Estimating the Staff's Walking Time

$\hat{T}_p^D$ - Physician's mean walking time when treating patient type *p* (sec)

$\hat{T}_p^N$ - Nurse's mean walking time when treating patient type *p* (sec)

W, L - Width, Length of the space in which the medical staff operates (cm)

d_c - Walking distance from the area's centroid to the ED counter (cm)

d_r - Walking distance from the area's centroid to the procedure room (cm)

d_m - Walking distance from the area's centroid to the medicine cabinet (cm)

d_s - Walking distance from the area's centroid to the nurse's station (cm)

N - Number of patient beds in the ED room

Estimating the Staff's Walking Time

Physician's Walking Model

$$T_p^D = \left[-461.37127 + 0.50041 W + 0.12628\, d_c + 0.13354\, d_r + 0.00047 \cdot (d_c - 703.5) \cdot (W - 596.5) + 0.00034 (d_r - 20438125) \cdot (W - 596.5) + \varepsilon(0, 150^2)\right] / N$$

Nurse's Walking Model

$$T_p^N = \left[-7695.81994 + 6.61123 \cdot W + 5.1936 \cdot d_s + 1.50267 \cdot d_m + 0.02921 \cdot (d_m - 499.44444) \cdot (W - 806.66667) + 0.00875 \cdot (d_m - 1176.66667) \cdot (W - 806.66667) + \varepsilon(0, 150^2)\right] / [N \cdot L/W]$$

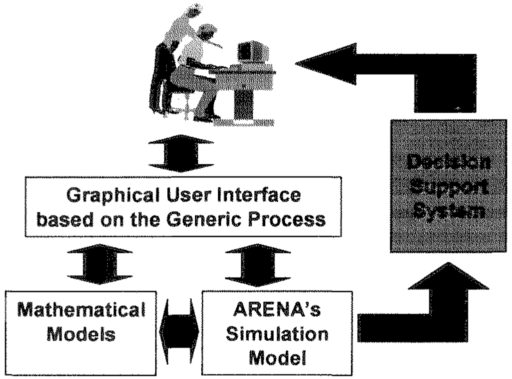
Validating The Model

- The fit of the above models as indicated by R^2 is 0.737 for the physician's walking model and 0.675 for the nurse's walking models.
- The variance analysis shows the both models and all their parameters are significant.
- The residual analyses of the physicians' and nurses' estimation walking models reveal that in both cases residuals are normally distributed with a mean of 0.
- The models have been used in a setting different from the ones that were used in the initial development.

Validating The Model

- The single factor ANOVA in both cases reveals that the null hypothesis, (there is no statistical difference between the model and observation results) can not be rejected.
- P-value for the physicians' model was 0.28
- P-value for the nurses' model was 0.74

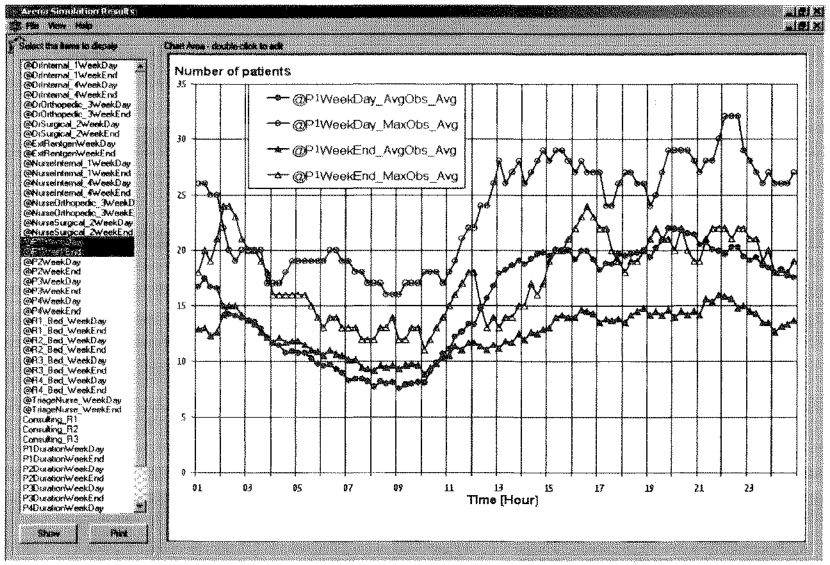
The Structure of the Simulation Tool



Increasing Acceptance of Simulation in Healthcare

- **General, and flexible**
- Include **default values for most of the system parameters**.
- **Simple to use**
- Include a **decision support system**

The Decision Support Module

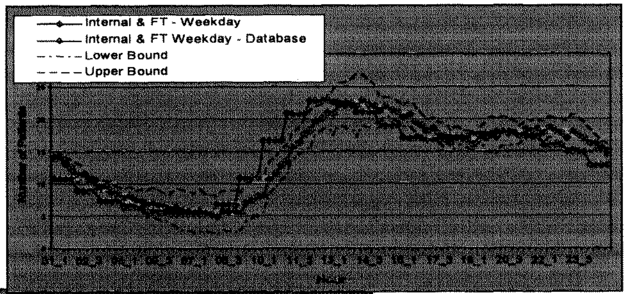


Model Validation

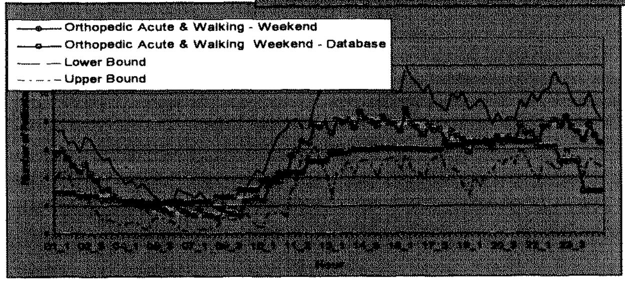
The validation process is comprised of two stages:

- Five simulation models were created using the developed tool in conjunction with the suggested default values and the other specific values for each of the five EDs that participated in the study.
- Ten 60-day simulation runs were performed for each of the five EDs.
- The performance of each of these models was compared to the actual data that was obtained from each of hospital's information systems (250,000 data entries that represent around 2.5 years of data).

Model Validation

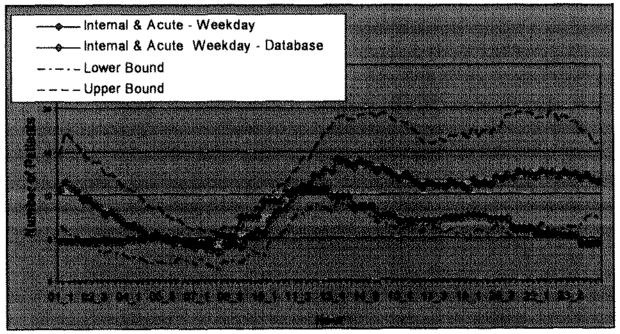


Internal Patients During a Weekday in the ED of Hospital 1



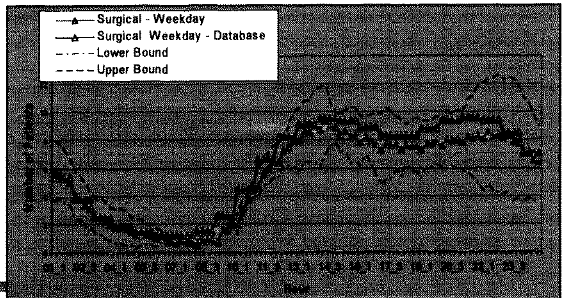
Orthopedic Patients During a Weekend day in the ED of Hospital 3

Model Validation

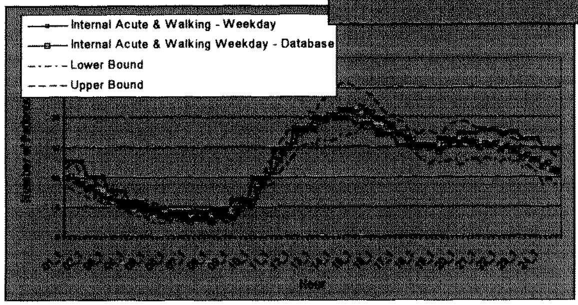


Internal Patients During a Weekday in the ED of Hospital 4

Model Validation



Surgical Patients During a Weekday in the ED of Hospital 6



Internal Patients During a Weekend day in the ED of Hospital 6

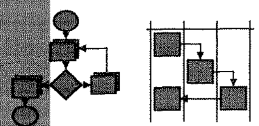
Conclusions

If we use the statement

"<u>The suggested unified generic process can be used to model any arbitrary ED</u>"

as a scientific hypothesis and try to find a system for which the statement is not true, each failure increases our confidence in the model.

So far we have failed to reject the statement eight times



Resource Scheduling in Emergency Departments

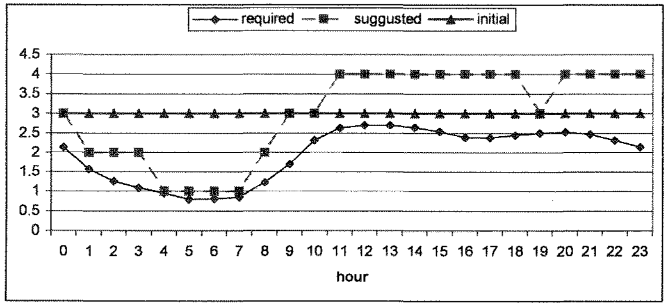
Sinreich David & Ola Jabali

The Focus and Concern of the ED Management

- Staffing levels directly impact the workload and congestion in the ED.
- High workload and congestion impair the quality of care. Therefore, staffing levels have an indirect impact on the clinical outcome of the medical procedures performed at the ED.

Currently the ED resources are scheduled into predetermined shifts that do not comply with the system's congestion

Physicians' Availability



- A better fit between patient demand and physicians' availability may lead to:
  - reduction in the physician workload during peak hours.
  - reduction in patient length of stay.

Problem and Solution Approach

Resource Scheduling in Emergency Departments

Efficient Scheduling	Downsizing and restructuring
WSSA-1	SWSSA
WSSA-2	
Varying shift start times	Varying shift start times and duration

10

WSSA-1

1. Run the simulation in its initial state.
2. Choose the bottleneck resource by using the highest delay factor.
3. Run rescd-opt for the chosen resource.
4. run the simulation using the solution obtained from rescd-opt and calculate all the new delay factors.
5. If improvement is detected then continue to the 2nd stage. Otherwise, choose the resource with the next highest delay factor that was not addressed in the previous step and reschedule it (3rd stage).

Identifying The Bottleneck by Δ_r

- Although the different patient types have different clinical pathways these paths are not mutual exclusive as they share some of the ED resources (labs, imaging center, logistic personal, some of the nurses and physicians)
- To improve patient flow in the ED it is necessary to identify first which of the resources is the bottleneck resource that impedes the patient flow
- The bottleneck resource is the one that on average accumulates the most waiting time

The Delay Factor

Notation:

Process - 1,…, p,…,P

Hour of the day – 1,…,i,…,I

Resource type – 1,…,r,…,R

W_{pi} – Average waiting time for process p at time i

N_{pi} – Average number of patients waiting for process p at time i

S_{ri} – Number of resource unit of type r available at time i

$$Z_{pr} = \begin{cases} 1 - \text{If process } p \text{ is performed by resource } r \\ 0 - \text{Otherwise} \end{cases}$$

Δ_{ri} – The patient delay factor for resource type r at time i

$$\Delta_{ri} = \frac{\sum_{p \in P} W_{pi} N_{pi} Z_{pi}}{S_{ri}}$$

$$\boxed{\Delta_r = \frac{1}{24} \sum_{i=0}^{23} \Delta_{ri}}$$

Rescd-Opt Model Notation

Notation:

τ – Minimal time block (a resource shift comprises one or more consecutive time blocks)

H – Upper limit on the amount of available resource hours

A_j – The number of resource units staffed at time j

$\overline{A}$ – Average number of available resource units per time unit

R_j – The number of required resource units at time j

$\overline{R}$ - Average number of required resource units per time unit

$$P_{ij} = \begin{cases} 1 - \text{If a resource that started its shift at time } i \text{ still works at time } j \\ 0 - \text{Otherwise} \end{cases}$$

x_i – Number of resource units that started their shift at time i

Rescd-Opt Model- for WSSA-1 and 2

$$\min\sum_{j=0}^{23}\left|\frac{A_j}{R_j}-\frac{\overline{A}}{\overline{R}}\right|$$

s.t.

$$\sum_{i=0}^{23} x_i \cdot P_{ij} = A_j \qquad \forall j$$

$$A_j \geq 1 \qquad \forall j$$

$$\tau\sum_{i=0}^{23} x_i = H$$

WSSA-1

$$x_i \geq 0 \text{ and } x_i \in \text{integer} \qquad \forall i$$

WSSA-1

1. if more than 24 hours are assigned to resource *r* then $r \in R$. (else – doesn't interesting)
2. Set all resources to their initial schedule and set n=0, $r_0^* = \varnothing$.
3. Run the simulation model of the system and determine the combined average LOS $L(n)$.
4. For all $r \in R$ calculate from the simulation results the delay factors and the requirements for each hour of the day.
5. Arrange all the resources' delay factors $RL(n)$ in a descending order and set p=1, n=n+1.
6. If $p \leq |R|$ continue, otherwise terminate and present the best schedule obtained thus far.

WSSA-1 - continue

7. Choose the resource r_n^* associated to from the $RL(n-1)$ list for which to develop a work shift schedule.
8. If $r_n^* = r_{n-1}^*$ set $p=p+1$ and go to step 6, otherwise continue.
9. Run Sched-Opt for resource r_n^*.
10. If Sched-Opt doesn't not change the current work shift schedule for resource r_n^* then set $p=p+1$ and go to step 6, otherwise continue.
11. Run the simulation model of the system with the new developed schedule and determine the combined average LOS $L(n)$.
12. If LOS $L(n)$ < LOS $L(n-1)$ go to step 4, otherwise set $p=p+1$and go to step 6.

Results – WSSA-1

	WSSA-1 LOS results											
	Internal		Surgical		Ortho'		Fast-Track		Combined Average LOS		Relative Change (-)	
Hospital	0	*n*	0	*n*	0	*n*	0	*n*	0	*n*	LOS	Wait time
1	269	199	224	228	149	115	175	154	216	180	16.8%	34.2%
2	324	277	224	211	151	131			266	232	12.5%	20.4%
3	202	167	103	93	97	73	156	147	141	116	17.5%	44.8%
4	165	141	145	148	135	114	119	102	148	131	11.6%	35.2%
5	173	155	150	140	128	130			157	146	7.2%	27.0%

WSSA-1 Results – continue

	WSSA 1 - Maximal Resource Workload (Number of Hours Workload Exceeds 70%)											
	Int_Dr		Orth_Dr		FT_Dr		Int_Nr		Sur /Orth_Nr		Imaging Tech	
Hospital	0	*n*	0	*n*	0	*n*	0	*n*	0	*n*	0	*n*
1	83% (12)	72% (2)	91% (6)	60% (0)	77% (6)	77% (4)	84% (2)	58% (0)				
2	90% (15)	79% (9)									99% (11)	84% (6)
3	92% (13)	78% (5)	84% (11)	81% (3)					78% (6)	74% (3)		
4	87% (14)	74% (3)							65% (0)	67% (0)	99% (9)	80% (5)
5	83% (6)	64% (0)					61% (0)	42% (0)			93% (10)	91% (9)

Conclusions

- Rescheduling the work shifts of the different ED staff members leads to considerable reductions in the patients' Length of Stay.
- Reducing the gap between the required number of ED staff members and the staff availability leads to a reduction in the maximum staff's workload.
- According to the literature reducing the staff's workload may potentially reduce human errors and improve the quality of service patients experience in the ED.
- WSSA-1 achieved an average reduction of 7% to 17% reduction in the combined average patient LOS (20% to 45% in waiting time).
- For all 15 resources addressed by WSSA-1 the number of hours workload exceeds 70% became lower or remained as is.

Rough Cut Capacity Planning

(On Going Work)

פרו' שטוב, פרו' מנדלבאום,
יריב מרמור, שרון וויסמרק

תוכן

- הגדרה ורקע
- תוצאות ראשוניות לגבי אחות
- דיון ומסקנות
- תוכניות להמשך

RCCP – רקע

RCCP is usually used for checking whether critical resources are available to support the various preliminary master production scheduling.

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

L_s is the loading of workstation s

T_{ks} the processing time per unit for workstation s

Q_k the quantity of product k

T_t the total operating time

Rs is the number of resources in workstation s

תוצאות ראשוניות - אחות

- הבדיקה בוצע על נתוני הדמיה (סימולציה) של המלר"ד בבית חולים רמב"ם בחיפה.
  - 7 סוגי חולים.
  - כ-11 שבועות של נתונים.
- חושב RCCP עבור אחות בכל שעה לכל יום עבור הקבצה (aggregation) של: 1 , 2 , 4 , 6 , 8 , 10 , 12 , 24 ו 48 שעות.
- חושב שעות בפועל (סימולציה).
- בוצעו חישובים של דיוק התחזית (RCCP) לעומת השעות בפועל בערך מוחלט.

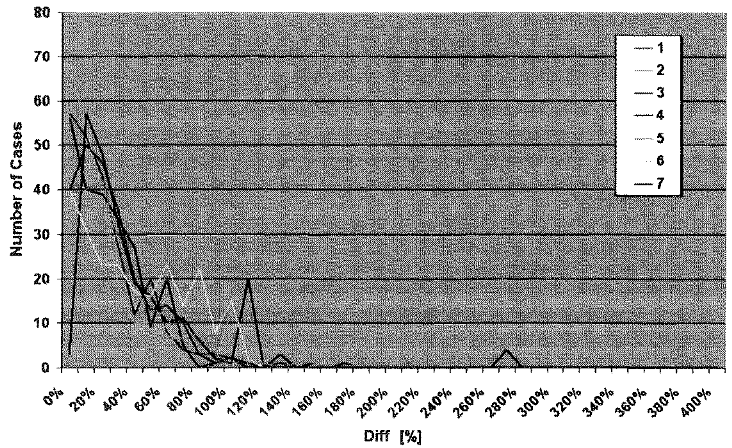
תוצאות ראשוניות - אחות

- רמת הדיוק (בערך מוחלט) הממוצעת לכל סוג חולה ובכלל בכל הקבצה (RCCP כנגד מצב בפועל):

Aggregate	Patient Type							
	1	2	3	4	5	6	7	All
1	90%	62%	74%	70%	89%	85%	78%	36%
2	70%	57%	66%	50%	72%	66%	68%	30%
4	47%	51%	58%	37%	58%	53%	53%	27%
6	34%	41%	43%	31%	46%	46%	34%	23%
8	28%	40%	46%	30%	41%	45%	31%	24%
10	22%	34%	30%	24%	42%	37%	23%	18%
12	21%	30%	25%	18%	29%	27%	21%	11%
24	15%	15%	13%	12%	18%	17%	13%	7%
48	8%	10%	8%	7%	11%	13%	8%	5%

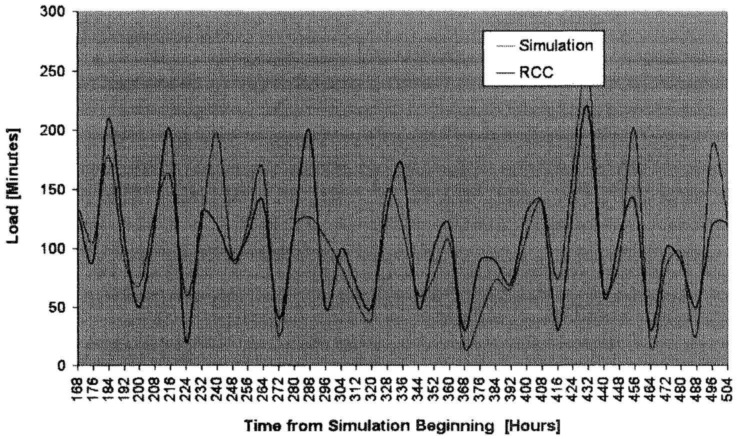
תוצאות ראשוניות - אחות

- התפלגות רמת הדיוק (בערך מוחלט) הממוצעת לכל סוג חולה עבור הקבצה של 8 שעות:



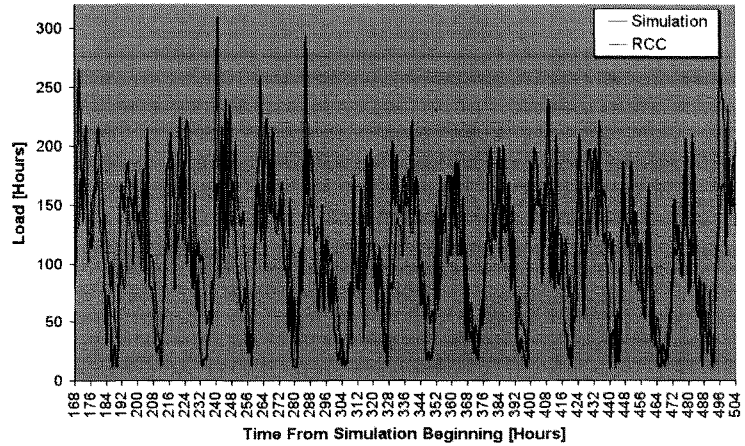
תוצאות ראשוניות - אחות

- דוגמא להערכת RCCP לעומת המצב הקיים בשבוע השני עד רביעי של הנתונים עבור חולה מסוג 1 (הקבצה של 8 שעות):



תוצאות ראשוניות - אחות

- דוגמא להערכת RCCP לעומת המצב הקיים בשבוע השני עד רביעי של הנתונים עבור כל האחיות ביחד (הקבצה של 1 שעה):



דיון, מסקנות ראשוניות והצעות להמשך

- הדיוק של RCCP עבור עומס אחיות במלר"ד במתכונת הנוכחית לא מתאים עבור דיוק של עד 20% במתכונת של קיבוץ תוך יומי כאשר בוחנים את העומס בכל סוג חולה בנפרד.
- הסיבות לחוסר היכולת להגיע לדיוק גבוה:
  - שונות רבה בזמנים בתהליך (מכונות לעומת בני אדם).
  - שונות רבה בתהליך שעובר כל חולה ("תא הרכבה מסובך").
- הצעות להמשך:
  - לנסות למצוא שיטה "שמעדנת" את ה-RCCP כך שיגביר את הדיוק (מהספרות או פיתוח מקומי).
  - לבחון RCCP עבור משאבים נוספים (למשל רופא / X-Ray).
  - לבחון שימוש ב- RCCP לזיהוי צווארי בקבוק (?).

Offered Load

(On Going Work)

פרו' מנדלבאום, יריב מרמור

תוכן

- הגדרה ורקע
- תוצאות ראשוניות לגבי אחות

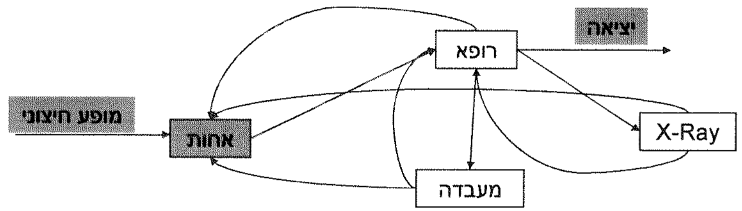
Offered Load – רקע

Offered-Load מוגדר להיות כמות שעות העבודה לשעה.

$$R(t) = \int_{-\infty}^{t} \lambda(u) P(W > t-u) du$$

הבעיה:

המופע למשאב תלוי במצב המערכת:



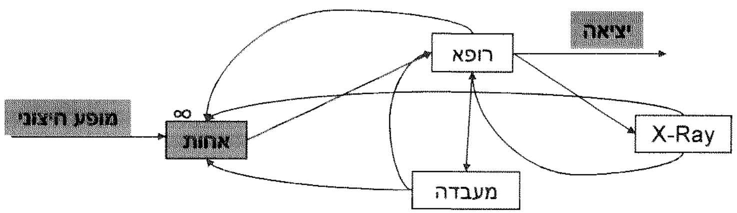
Offered Load – רקע

Offered-Load מוגדר להיות כמות שעות העבודה לשעה.

$$R(t) = \int_{-\infty}^{t} \lambda(u) P(W > t-u) du$$

פתרון:

קביעת המופע, $\lambda(t)$, באמצעות הרצת סימולציה עם אינסוף שרתים על המשאב עליו מחפשים את R(t):



תוצאות ראשוניות - אחות

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- חושב R(t) עבור אחות בכל שעה לכל יום עבור הקבצה (aggregation) של: 1 , 2 , 4 , 6 , 8 , 10 , 12 , 24 ו 48 שעות.
- חושב שעות בפועל (סימולציה).
- בוצע השוואה בין תכנון בפועל של כמות משאבי אחות לעומת תכנון לפי Offered Load ו- RCCP.

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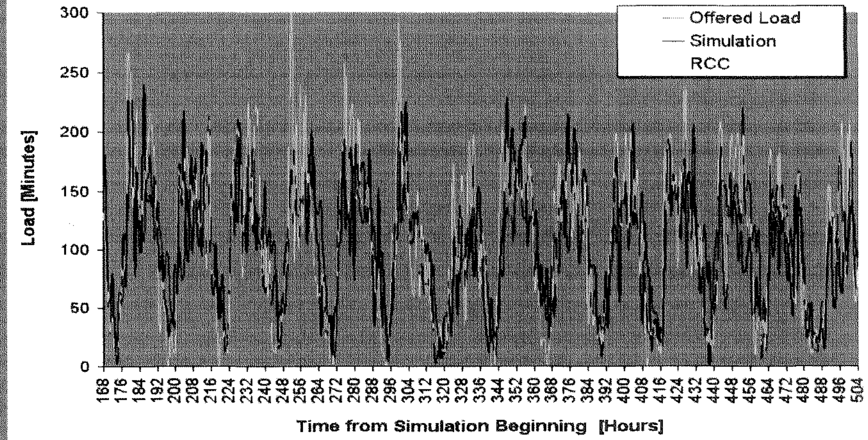
תוצאות ראשוניות - אחות

- רמת הדיוק (בערך מוחלט) הממוצעת לכל סוג חולה ובכלל בכל הקבצה:

Aggregate	Patient Type 1	2	3	4	5	6	7	All
1	148%	80%	102%	122%	101%	117%	132%	43%
2	119%	111%	115%	88%	129%	79%	137%	29%
4	97%	123%	106%	67%	131%	50%	98%	20%
6	76%	107%	122%	44%	88%	36%	67%	17%
8	60%	117%	84%	42%	106%	29%	58%	16%
12	45%	76%	51%	30%	56%	18%	37%	11%
24	25%	51%	33%	19%	30%	14%	23%	8%
48	17%	25%	25%	13%	20%	11%	16%	6%

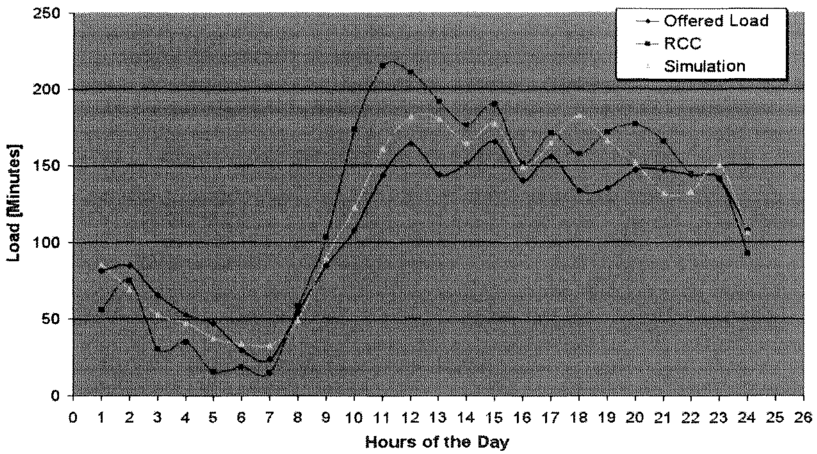
תוצאות ראשוניות - אחות

דוגמא להשוואת RCCP לעומת Offered Load והמצב הקיים בשבוע השני עד רביעי של הנתונים עבור כל האחיות ביחד (הקבצה של 1 שעה):



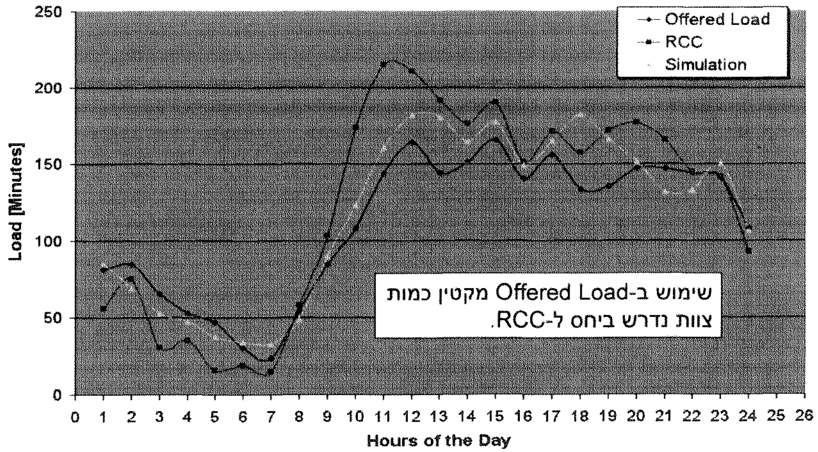
תוצאות ראשוניות - אחות

דוגמא להשוואת RCCP לעומת Offered Load והמצב הקיים על פני כל ימי א' (הקבצה של 1 שעה):



תוצאות ראשוניות - אחות

דוגמא להשוואת RCCP לעומת Offered Load והמצב הקיים על פני כל ימי א' (הקבצה של 1 שעה):



בחינת היבטים תפעוליים של המעבר למלר"ד הזמני בבית החולים רמב"ם

מנחים אקדמיים: פרופ' אבישי מנדלבאום, מר יריב מרמור
מנחה תעשייתי: ד"ר משה מייכלסון – מנהל המלר"ד
ד"ר פואד בסיס – סגן מנהל המלר"ד

סטודנטים (תואר I):
כאמל בדראן , ענבל הס,
רשא חולי

תוכן

- רקע אודות המצב הקיים
- מטרת הפרויקט
- השיטה
- הצגת התרחישים
- פתרון: הצגת המצב המוצע
- דיון ומסקנות
- תוכניות להמשך

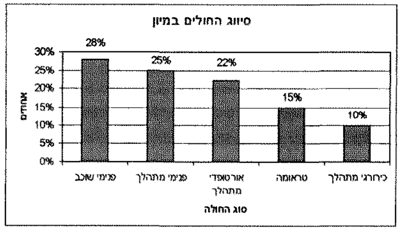
רקע – בית החולים רמב"ם

רמב"ם הינו בית חולים ממשלתי ובו 36 מחלקות אשפוז.

- סה"כ ביה"ח כולל כ- 1,000 מיטות אשפוז.
- ביה"ח מחולק ל-45 יחידות רפואיות, 9 מכונים, 6 מעבדות ו- 30 מחלקות מנהליות ומשקיות.
- מדי שנה מתאשפזים בביה"ח כ- 75,000 איש ועוד כ- 500,000 נמצאים בטיפול ובמעקב במרפאות החוץ והמכונים.
- הנהלת המלר"ד החליטה להעביר את המחלקה לשטח רחב יותר. המעבר יתרחש בשני שלבים:
  - מעבר לקומת המרתף (מלר"ד זמני) בחודש מרץ
  - מעבר למשכן הקבוע (עוד כשנתיים)

רקע – המלר"ד ברמב"ם

- המלר"ד מורכב משתי תת יחידות עיקריות: מיון פנימי ומיון כירורגי/אורתופדי.
- קיימים 5 סיווגים שונים של חולים:



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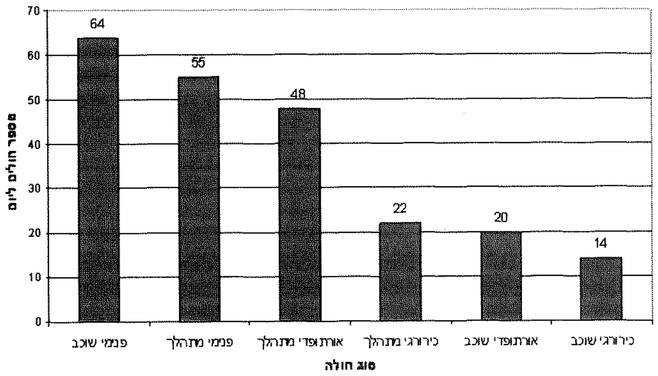
רקע – המלר"ד ברמב"ם

- המלר"ד מורכב משתי תת יחידות עיקריות: מיון פנימי ומיון כירורגי/אורתופדי.
- קיימים 5 סיווגים שונים של חולים.
- סה"כ מטפל המלר"ד בכ-120,000 חולים בשנה.
- קצבי הגעת החולים:



רקע – המלר"ד ברמב"ם

- המלר"ד מורכב משתי תת יחידות עיקריות: מיון פנימי ומיון כירורגי/אורתופדי.
- קיימים 5 סיווגים שונים של חולים.
- סה"כ מטפל המלר"ד בכ-120,000 חולים בשנה.
- קצבי הגעת החולים
- זמני שהייה ממוצעים:

סוג חולה	ממוצע [שעות]	סטיית תקן [שעות]
חולה פנימי	4:38	3:37
חולה אורתופדי	2:14	2:36
חולה כירורג	2:25	2:47

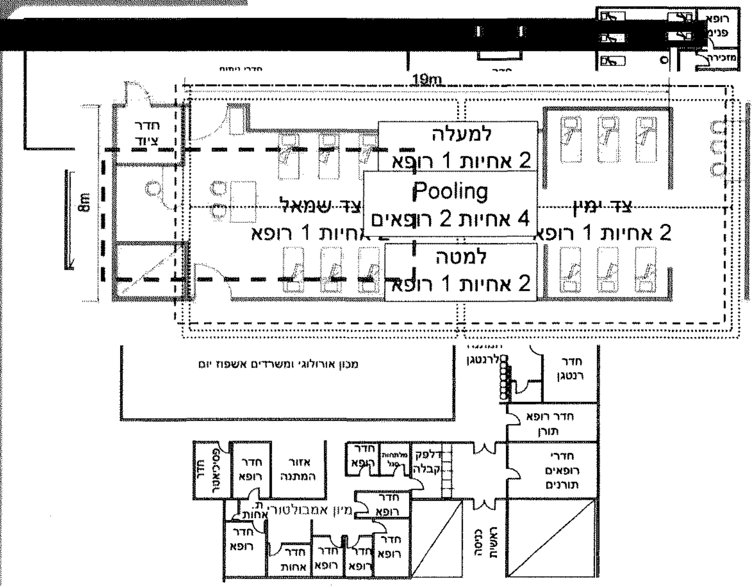
מטרת הפרוייקט

- בדיקת מכלול התוכניות הקשורות למעבר למלר"ד הזמני ובחינת חלופות בנושאים הבאים:
  - הצעת תוכנית עבודה שתאפשר עבודה עם המספר הנוכחי של אנשי הצוות.
  - קביעת מספר מיטות בעזרתן ניתן להקטין את אחוז הזמן שנימצא בחוסר.
  - בחינת חלוקת החדרים (בהתאם לשיטת העבודה: מספר אנשי צוות ומרחקי ההליכה).
  - בחינת חלופות למדיניות הקיימת של שליחת החולים לרנטגן המשותף, לרנטגן במלר"ד, ולשעות פתיחת רנטגן המלר"ד.

שיטת הפתרון המוצעת: הצגת השיטה

- שימוש במודל סימולציה המדמה את פעילות המלר"ד ברמב"ם במצב הקיים ובמצב הזמני המתוכנן, תוך ביצוע ההתאמות הנדרשות.
- בדיקת תפקוד המלר"ד מהיבטים שונים, כולל רגישות שלו לשינויים.
- ניתוח המצב הזמני המתוכנן בהתבסס על מודל ההפעלה הקיים וזיהוי נושאים בעייתיים.
- הצעת פתרונות לנושאים בעייתיים שיתגלו בניתוח המצב הזמני.

המיון הפנימי



תרחישים שנבחנו

- חלוקת הצוות
  - חלוקת המיון הפנימי שוכבים
    - ימין שמאל
    - מעלה מטה
    - Pooling
- חדר הרנטגן
- תצורה פיזית
- מצב מוצע

תרחישים שנבחנו

- חלוקת הצוות
  - חלוקת המיון הפנימי שוכבים
    - ימין שמאל
    - מעלה מטה
    - Pooling
  - העברת אחות למתהלכים
    - מאחיות טראומה
    - מאחיות פנימיים שוכבים
- חדר הרנטגן
- תצורה פיזית
- מצב מוצע

המיון הפנימי

זמן משוקלל

	מצב: Pooling	ימין שמאל	מעלה מטה
זמן שהייה משוקלל [דק']	276.95	315.31	286.3
זמן המתנה משוקלל [דק']	220.38	258.26	229.88

מספר המיטות בשימוש ב

זמן משוקלל =
25% פנימיים מתהלכים +
6% כירורגי שוכבים
10% כירורגי מתהלכים +
9% אורתופדי שוכבים +

	סוג חולה	מצב: pooling	ימין שמאל	מעלה מטה
יום חול	פנימיים שוכבים	43	58	49
	טראומה שוכבים	7	7	7
סוף שבוע	פנימיים שוכבים	28	42	42
	טראומה שוכבים	5	5	5

הנחה: חולים לא "נחסמים"

אחוז הזמן שנימצא במחסור של מיטות

	סוג חולה	מס' מיטות מתוכנן	מצב: pooling	ימין שמאל	מעלה מטה
יום חול	פנימיים שוכבים	20	39%	62%	46%
	טראומה שוכבים	11	0.50%	0.50%	0.40%

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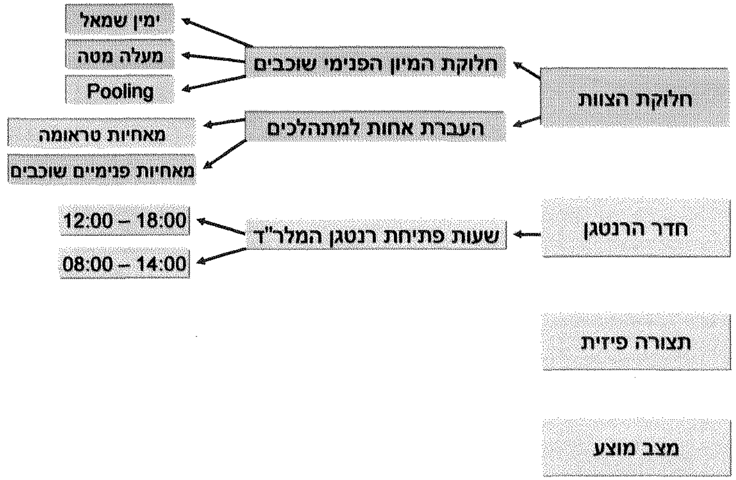
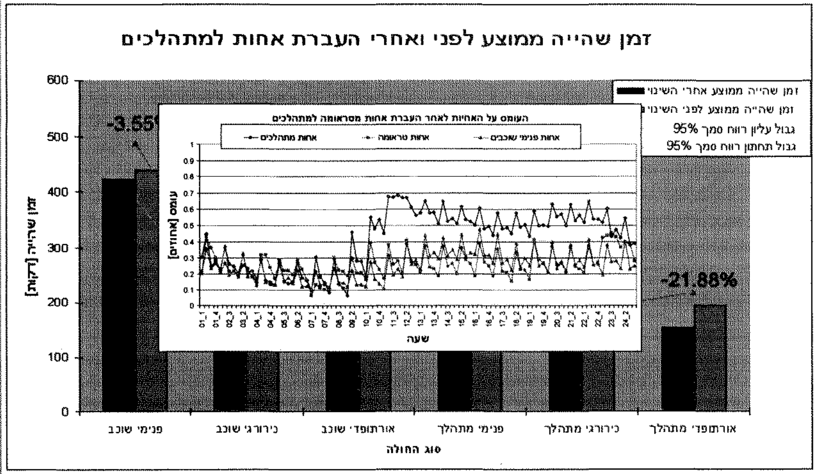
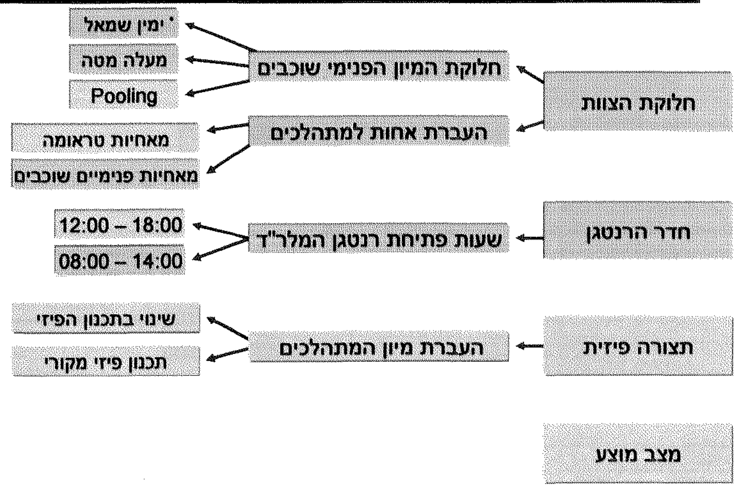
תרחישים שנבחנו



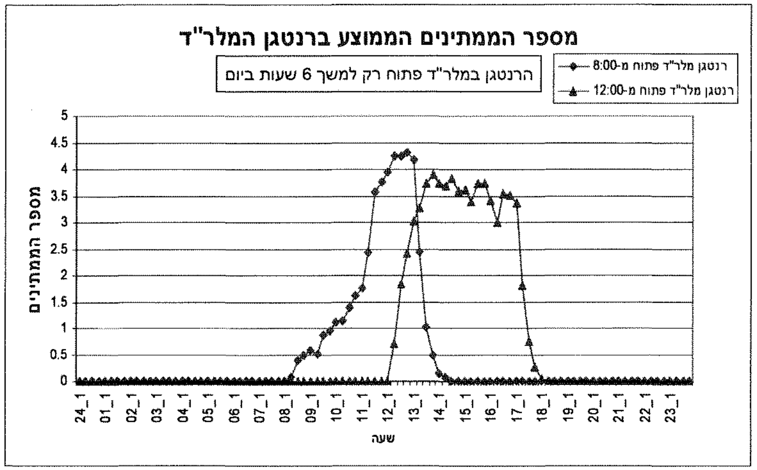
העברת אחות למתהלכים



תרחישים שנבחנו



בחינת שעות פתיחת הרנטגן במלר"ד



תצורה פיזית

איש הצוות	אחוז זמן הליכה - חפאים		
	נוכחי	ללא שינוי פיזי	שינוי פיזי
רופא פנימי שוכבים	(4.6%) 3.5%	(12.6%) 10.1%	(6.8%) 5.2%
חפא כירורג	(3.0%) 1.2%	(6.6%) 2.7%	(1.5%) 0.6%
חפא אורתופד	(2.9%) 1.2%	(6.0%) 2.6%	(3.6%) 1.5%
רופא פנימי מתהלכים	(3.7%) 2.6%	(3.7%) 1.2%	(1.7%) 1.2%

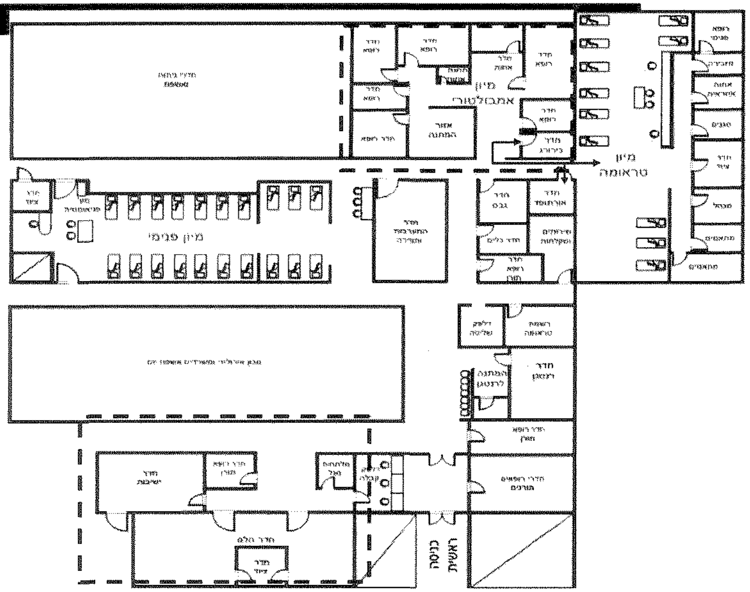
איש הצוות	אחוז זמן הליכה - אחיות		
	נוכחי	ללא שינוי פיזי	שינוי פיזי
אחיות פנימיים שוכבים	(3.2%) 1.0%	(6.1%) 1.5%	(3.9%) 0.9%
אחיות טראומה	(16.5%) 5.4%	[illegible] 1.6%	(3.7%) 0.6%
אחיות מתהלכים*	(2.1%) [illegible]%	(4.[illegible]) 2.4%	(4.1%) 2.4%

* אחיות פנימיים מתהלכים

X% - אחוז זמן הליכה מתוך סה"כ המשמרת
(Y%) - אחוז זמן הליכה מתוך סה"כ הזמן הפעיל

ההליכות המצוינות נובעות רק מתוך המעבר בין המיון האמבולטורי לטראומה.

תצורה פיזית

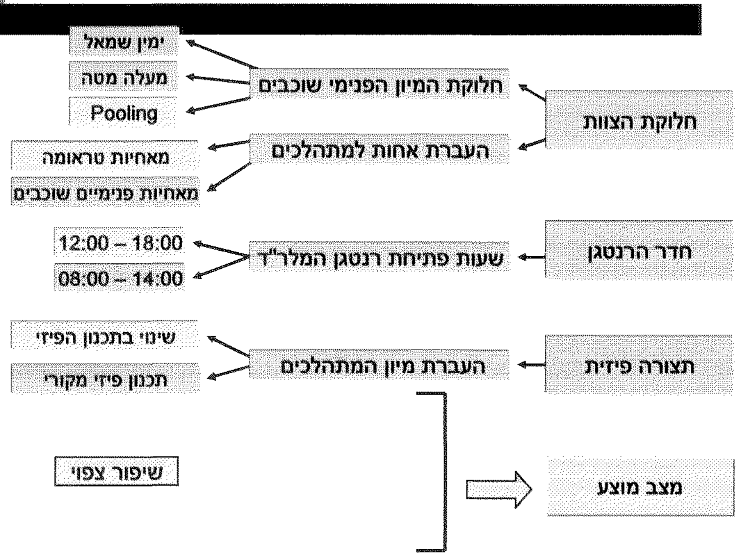


שיפור בזמני השהייה במצב המוצע

סוג חולה	ממוצע בדקות	אחוז השינוי יחסית לתצורה ללא שינוי פיזי (pooling)	השינוי בדקות יחסית לתצורה ללא שינוי פיזי (pooling)
פנימי שוכב	389.64	-11.10%	-48.67
כירורגי שוכב	157.01	-5.15%	-8.53
אורתופדי מתהלך	167.00	-3.48%	-6.03
פנימי מתהלך	212.10	-22.24%	-60.65
כירורגי מתהלך	123.50	-30.21%	-53.47
אורתופדי מתהלך	144.11	-25.99%	-50.61

	ללא שינוי פיזי (pooling)	נוכחי	מוצע
זמן שהייה משוקלל [דק']	276.95	238.91	230.62
זמן המתנה משוקלל [דק']	220.38	184.06	175.56

תרחישים שנבחנו



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הקטנת מספר הכיסאות הנחוצים

מספר הכיסאות בשימוש ע"י כל החולים המתהלכים ב-95% מהזמן.

	מצב	
	ללא שינוי פיזי (pooling)	מוצע
מס' כיסאות	30	19

מספר הכיסאות המתוכנן הוא 27

הקטנת מספר המיטות הנחוצות

מספר המיטות בשימוש ב-95% מהזמן

		מצב	
	סוג חולה	ללא שינוי פיזי (pooling)	מוצע
יום חול	פנימיים שוכבים	43	36
	טראומה שוכבים	7	6
סוף שבוע	פנימיים שוכבים	28	26
	טראומה שוכבים	5	5

המספר המקסימאלי של מיטות שניתן לצופף בעת הצורך הוא 40!

אחוז הזמן שנימצא במחסור של מיטות בימי חול

			מצב	
	סוג חולה	מס' מיטות מתוכנן	ללא שינוי פיזי (pooling)	מוצע
יום חול	פנימיים שוכבים	20	39%	33%
	טראומה שוכבים	11	0.50%	0.20%

דיון ומסקנות

- ניתן לשפר את תפקוד המלר"ד באופן שיועיל הן לחולים והן לצוות הרפואי:
  - קיצור זמני שהייה והמתנות (לדוגמא לרנטגן)
  - הקטנת העומס על הצוות הרפואי
  - הקטנת מספר המיטות הדרושות
- ניתן לשפר במידה מסוימת את תפקוד המלר"ד ללא עלות כספית (ללא יישום השינוי הפיזי המוצע).
- בעזרת השקעת משאבים בשינוי תצורתו הפיזית של המלר"ד ניתן לשפר את תפקוד המלר"ד באופן משמעותי.