Data-Based
Service Engineering (Science, Management)
in Call Centers, Hospitals, . . .

Avishai Mandelbaum

Technion, Haifa, Israel

http://ie.technion.ac.il/serveng

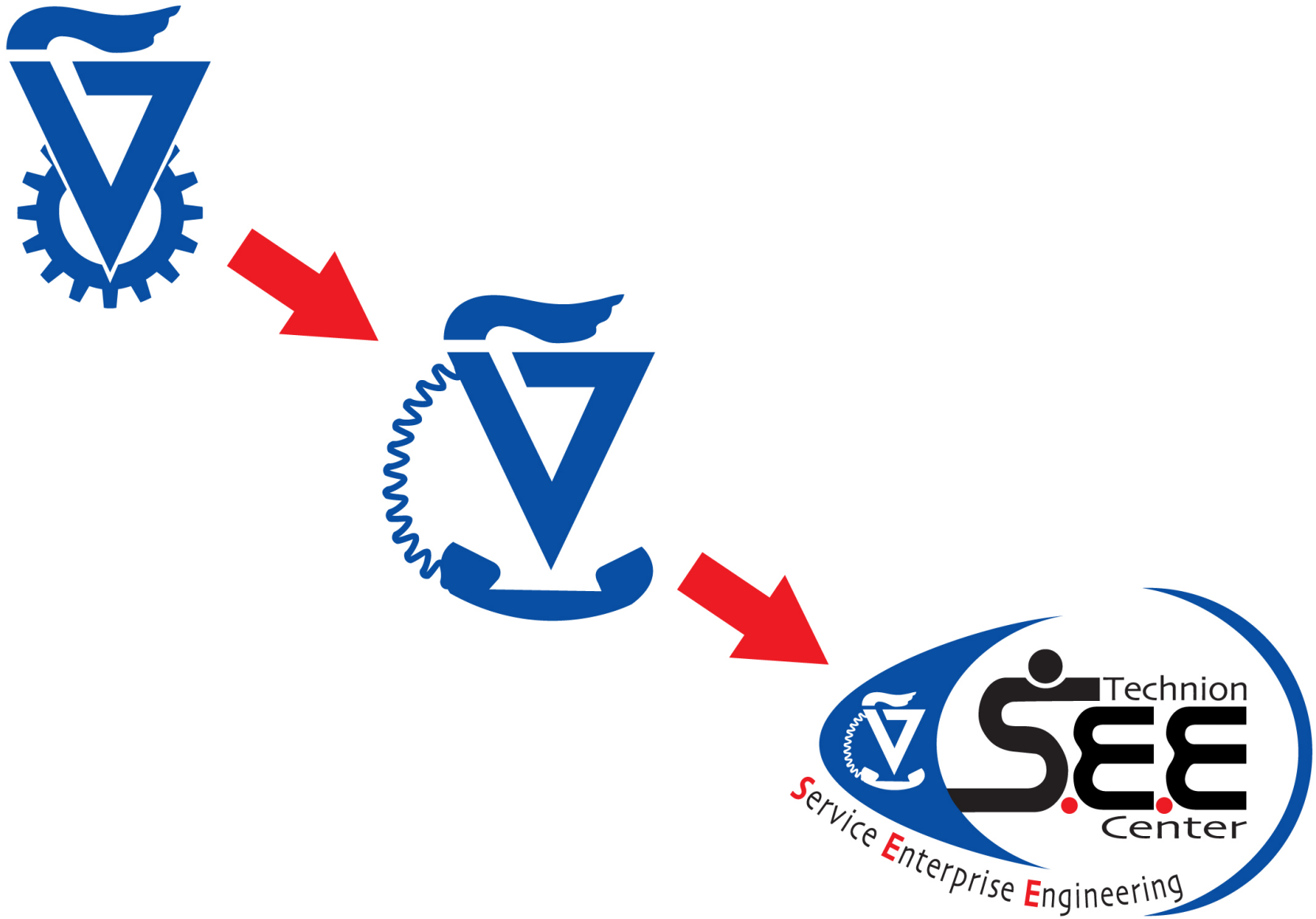
Penn & Technion, MSOM, June 2010

Research Partners

- **Students**:
  Aldor*, Baron*, Carmeli, Feldman, Garnett*, Gurvich*, Khudiakov*, Maman*, Marmor, Reich, Rosenshmidt*, Shaikhet*, Senderovic, Tseytlin*, Yom-Tov, Zaied, Zeltyn*, Zohar*, Zviran, . . .
- **Empirical/Statistical Analysis**:
  Brown, Gans, Zhao; Shen; Ritov, Goldberg; Allon, Bassamboo, Gurvich; Armony, . . .
- **Theory**:
  Armony, Atar, Feigin, Gurvich, Jelenkovic, Kaspi, Massey, Momcilovic, Reiman, Shimkin, Stolyar, Wasserkrug, Whitt, Zeltyn, . . .
- **Industry**:
  IBM Research (OCR: Carmeli, Vortman, Wasserkrug, Zeltyn), Rambam Hospital, Hapoalim Bank, Mizrahi Bank, Pelephone Cellular, . . .
- **Technion SEE Center / Labaratory**:
  Feigin; Trofimov, Nadjharov, Gavako, Kutsyy; Liberman, Koren, Rom; Research Assistants, . . .

The Technion SEE Center / Laboratory

Data-Based Research & Teaching



History, Resources (Downloadable)

- Math. + C.S. + Stat. + O.R. + Mgt. $\Rightarrow$ **IE&M**
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  http://ie.technion.ac.il/Labs/Serveng
- **OCR** Project ($\geq$ 2008):
  IBM Research + Rambam Hospital + Technion IE&M
  http://ie.technion.ac.il/Labs/Serveng/closed/OCR_Documents.php

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- **Technion IE&M** = Outsourcing Knowledge (Research, Practice)

Technion Research Impact: An Example

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Scholar Articles and patents anytime include citations

Results **1** - **10** of about **2,510,000**. (**0.06** sec)

[PDF] Telephone **call centers**: Tutorial, review, and research prospects — **psu.edu [PDF]**
N Gans, G Koole, A Mandelbaum - Manufacturing and service operations …, 2003 - Citeseer
∗ The Wharton School, University of Pennsylvania,Philadelphia, PA 19104, USA gans@wharton.upenn.edu **...** † Vrije Universiteit, De Boelelaan 1081a, 1081 HV Amsterdam, The Netherlands koole@few.vu.nl **...** ‡ Industrial Engineering and **...**
Cited by 455 - Related articles - View as HTML - All 32 versions

[PDF] Designing a **call center** with impatient customers — **technion.ac.il [PDF]**
O Garnet, A Mandelbaum, M … - Manufacturing & Service …, 2002 - iew3.technion.ac.il
ABSTRACT. The most common model to support workforce management of telephone **call centers** is the M/M/N/B model, in particular its special cases M/M/N (Erlang C, which models out busy-signals) and M/M/N/N (Erlang B, disallowing waiting). All of these models lack a **...**
Cited by 245 - Related articles - View as HTML - All 18 versions

Statistical Analysis of a Telephone **Call Center** — **psu.edu [PDF]**
L Brown, N Gans, A Mandelbaum, A Sakov, H … - Journal of the American …, 2005 - ASA
A **call center** is a service network in which agents provide telephone-based services. Customers who seek these services are delayed in tele-queues. This article summarizes an analysis of a unique record of **call center** operations. The data comprise a complete operational history **...**
Cited by 205 - Related articles - All 41 versions

Dimensioning large **call centers** — **bell-labs.com [PDF]**
S Borst, A Mandelbaum, MI Reiman - Operations research, 2004 - JSTOR
CWI, P. O. Box 94079, 1090 GB Amsterdam, The Netherlands, and Bell Labs, Lucent Technologies, Murray Hill, New Jersey 07974-0636, sem.borst@cwi.nl Avi Mandelbaum Faculty of Industrial Engineering and Management, Technion, Haifa 32000, Israel, avim@tx. **...**
Cited by 156 - Related articles - BL Direct - All 19 versions

Queueing models of **call centers**: An introduction — **psu.edu [PDF]**
G Koole, A Mandelbaum - Annals of Operations Research, 2002 - Springer
... the modern **call center** is a complex socio-technical system. It thus enjoys central features that

The Technion SEE Center / Laboratory

Technion SEE = Service Enterprise Engineering

SEELab: **Hub for data-based research and teaching**

- **History**: I.E. Dean, **B. Golany**, recruited **Hal and Inge Marcus**.
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SEEServer: **Free for academic use**

Register, then access (presently) U.S. Bank and Small Israeli Bank.

MCE with RFID Support: Rambam Hospital, May 2010

Drill: Chemical **Mass Casualty Event** (**MCE**), Rambam Hospital

Focus on the **red** casualties - severely wounded (50+ in the drill)

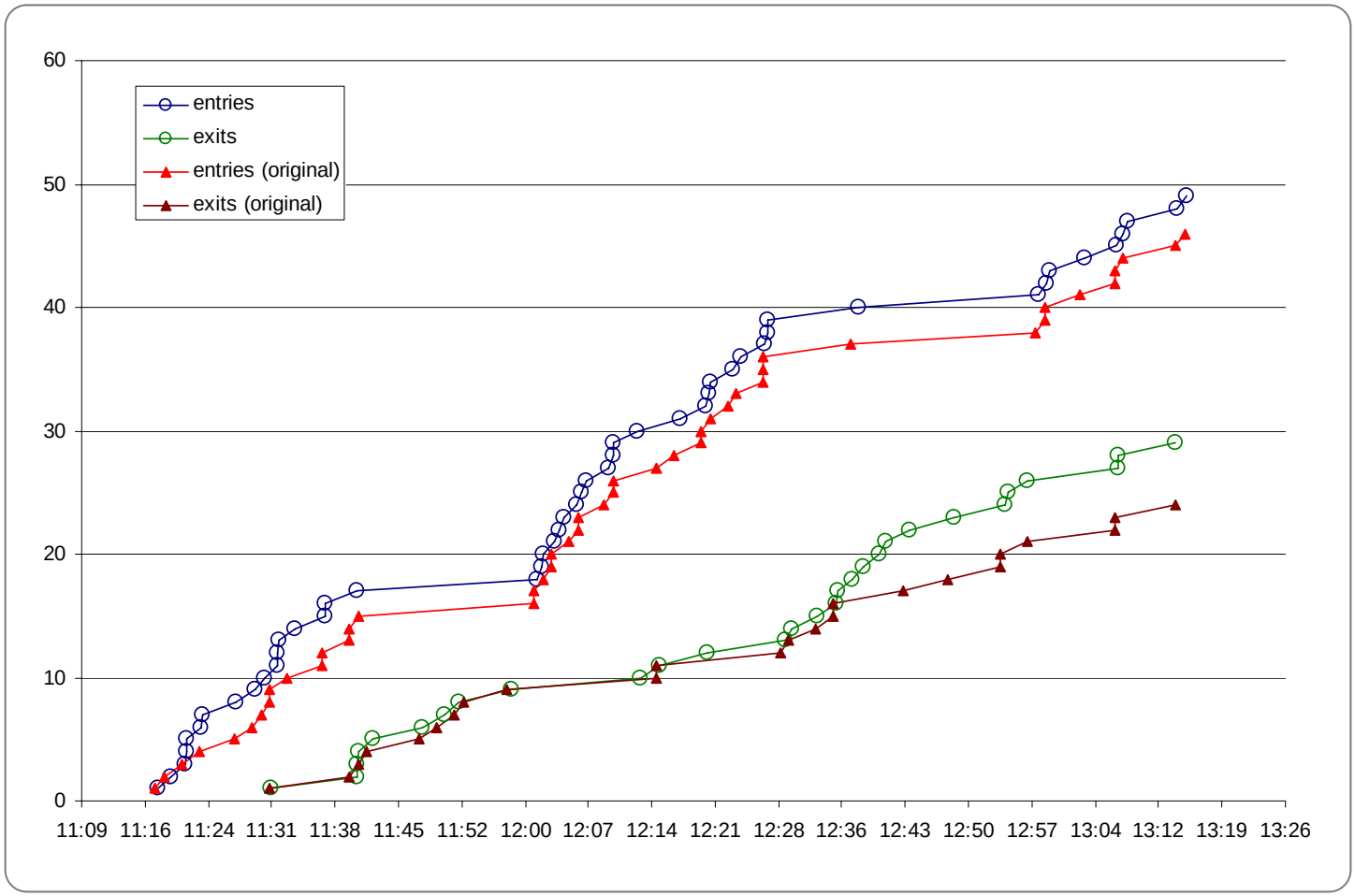
Note: 20 observers taking real-time measurements (validation)

MCE with RFID Support: Data Cleaning

Data-base				Company report		comment
Asset id	order	**Entry** date	**Exit** date	Entry date	Exit date	
4	1	1:14:07 PM		1:14:00 PM		
6	1	12:02:02 PM	12:33:10 PM	12:02:00 PM	12:33:00 PM	
8	1	11:37:15 AM	12:40:17 PM	11:37:00 AM		**exit is missing**
10	1	12:23:32 PM	12:38:23 PM	12:23:00 PM		
12	1	12:12:47 PM	12:35:33 PM		12:35:00 PM	**entry is missing**
15	1	1:07:15 PM		1:07:00 PM		
16	1	11:18:19 AM	11:31:04 AM	11:18:00 AM	11:31:00 AM	
17	1	1:03:31 PM		1:03:00 PM		
18	1	1:07:54 PM		1:07:00 PM		
19	1	12:01:58 PM		12:01:00 PM		
20	1	11:37:21 AM	12:57:02 PM	11:37:00 AM	12:57:00 PM	
21	1	12:01:16 PM	12:37:16 PM	12:01:00 PM		
22	1	12:04:31 PM	12:20:40 PM			first customer is missing
22	2	12:27:37 PM		12:27:00 PM		
25	1	12:27:35 PM	1:07:28 PM	12:27:00 PM	1:07:00 PM	
27	1	12:06:53 PM		12:06:00 PM		
28	1	11:21:34 AM	11:41:06 AM	11:41:00 AM	11:53:00 AM	**exit time instead of entry time**
29	1	12:21:06 PM	12:54:29 PM	12:21:00 PM	12:54:00 PM	
31	1	11:40:54 AM	12:30:16 PM	11:40:00 AM	12:30:00 PM	
31	2	12:37:57 PM	12:54:51 PM	12:37:00 PM	12:54:00 PM	
32	1	11:27:11 AM	12:15:17 PM	11:27:00 AM	12:15:00 PM	
33	1	12:05:50 PM	12:13:12 PM	12:05:00 PM	12:15:00 PM	wrong exit time
35	1	11:31:48 AM	11:40:50 AM	11:31:00 AM	11:40:00 AM	
36	1	12:06:23 PM	12:29:30 PM	12:06:00 PM	12:29:00 PM	
37	1	11:31:50 AM	11:48:18 AM	11:31:00 AM	11:48:00 AM	
37	2	12:59:21 PM		12:59:00 PM		

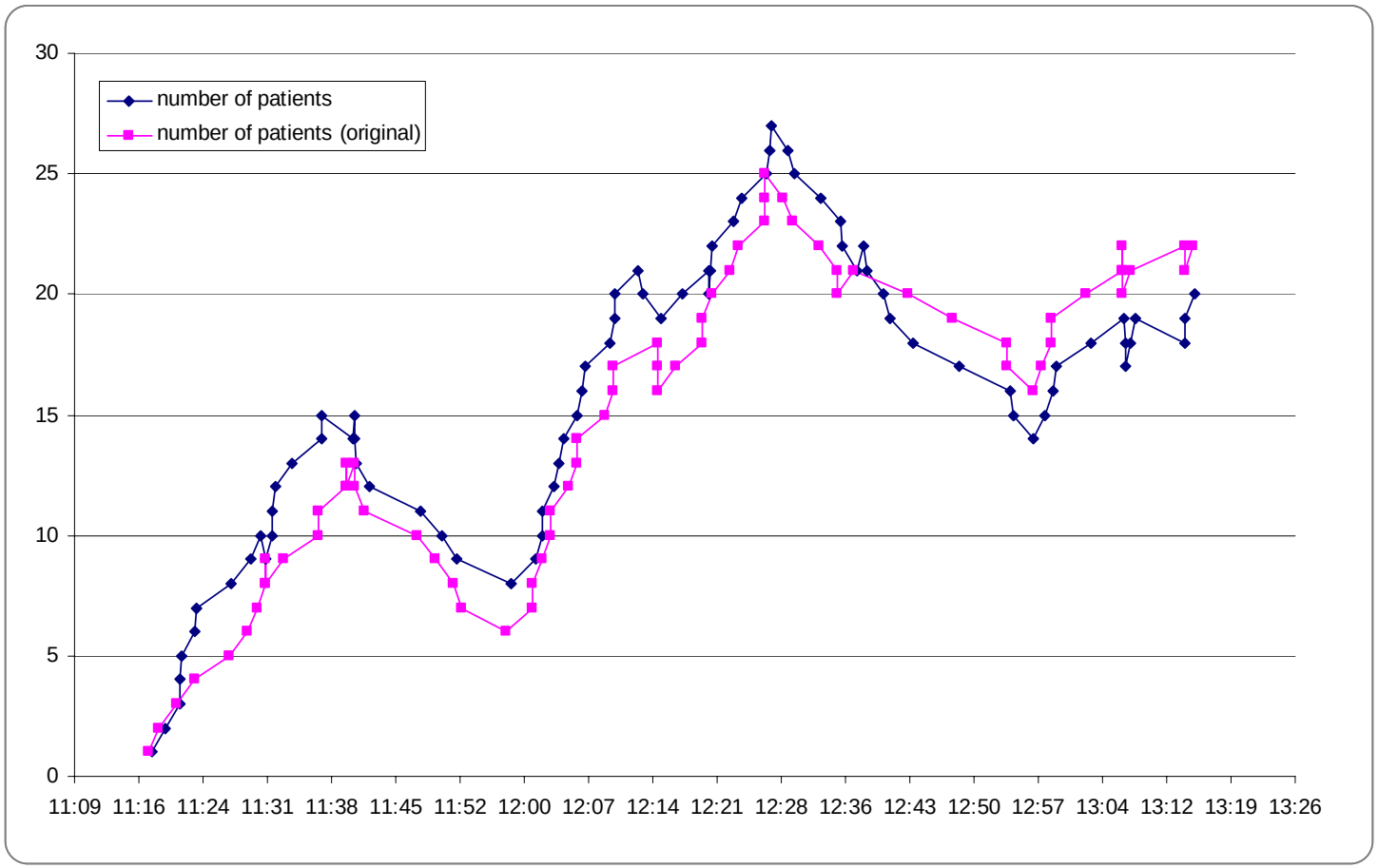
Think **"Cleaning" 60,000+ customers/day** (call centers)?

MCE with RFID Support: Arrivals, Departures



Operational Question: Predict **completion time** (rolling horizon)

MCE with RFID Support: # Severely Wounded Patients



- Paths of doctors, nurses, patients (100+, **1 sec.** resolution) ?
- What if **150+ casualties** severely wounded (feasible) ?

The Case for Service Science / Engineering

- **Service Science / Engineering** (vs. Management) are emerging **Academic Disciplines**. For example, universities (world-wide), IBM (SSME, a là Computer-Science), USA NSF (SEE), Germany IAO (ServEng), ...

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- Simple models that explain fundamental phenomena, which are **common** across applications:
  - Call Centers
  - Hospitals
  - Justice
  - Transportation
  - ...

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- **What Can Be Done** vs. **How To**

Stop for a Commercial

Tomorrow: 2 **Service Engineering Sessions**, Sponsored by **SEE**.

1. **8:30 - 10:00**, Tuesday, June 29, 2010, Session TA, Room B-151
   - On the Accuracy of Delay-History-Based Delay Announcements in Large **Call Centers**; Armony, Bassamboo, Ibrahim, AM.
   - **Emergency Departments**: The Case for Service Engineering; Marmor, Armony, AM, Tseytlin, Yom-Tov.
   - **Uncertainty** in the Demand for Service: The Case of Emergency Departments and Call Centers; Maman, Mandelbaum, Zeltyn.
2. **14:30 - 16:00**, Tuesday, June 29, 2010, Session TC, Rom B-151
   - **Skill Based Routing** (Part II): Data-Based Review and Research Prospects, with a Focus on Staffing and Routing; Gurvich, Liberman, AM.
   - Queueing Systems with Heterogeneous Servers: On **Fair Routing** from Emergency Departments to Internal Wards; Tseytlin, Momcilovic, AM.
   - Design and Inference of a Call Center with an **Answering Machine (IVR)**; Khudyakov, Feigin, Gorfine, AM.

Expanding the Scientific Paradigm

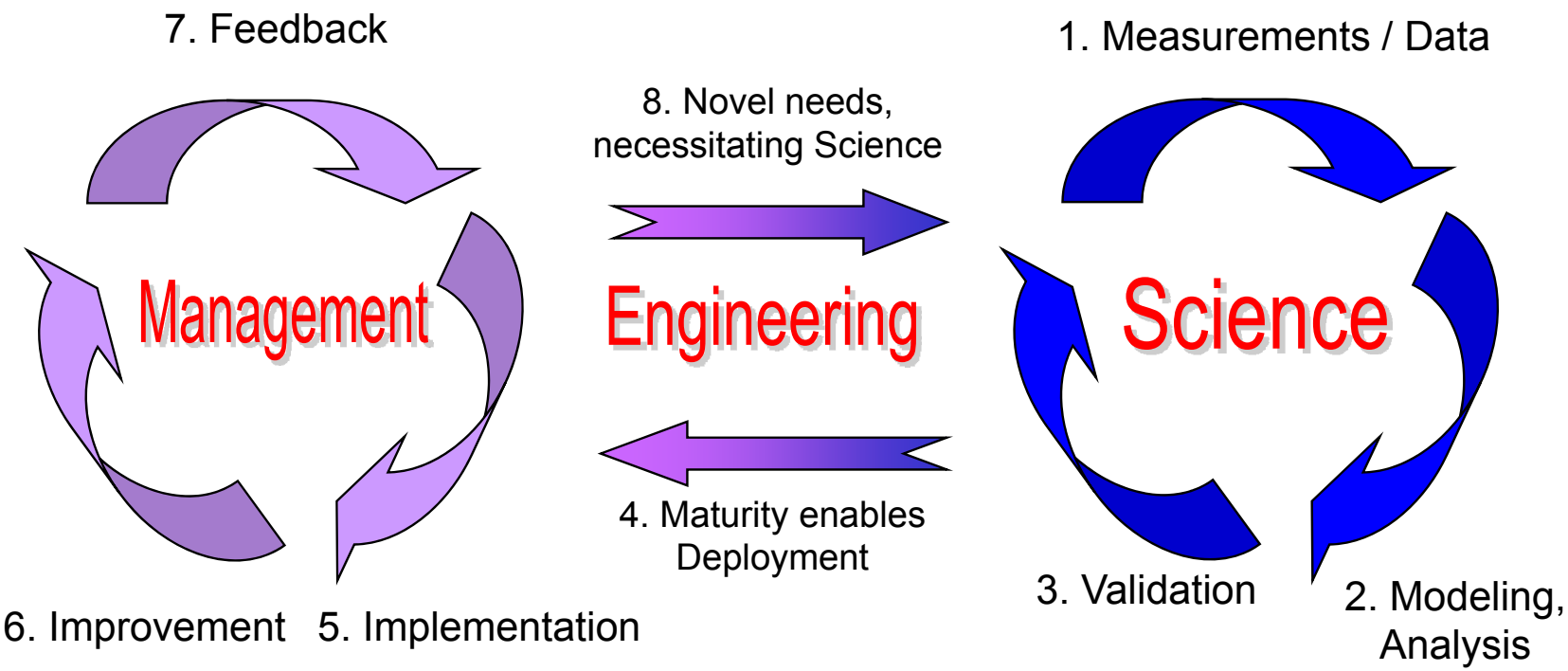
Service Engineering vs. **Industrial** Engineering

Human Complexity

Expanding the Scientific Paradigm

Service Engineering vs. **Industrial** Engineering

Human Complexity $\Rightarrow$ **Scientific Paradigm** (Physics ... Economics) and beyond (with IBM Research):



Started with Call Centers, Expanded to Hospitals

Call Centers - U.S. (Israel) Stat.

- $200 – $300 billion annual expenditures (0.5)
- 100,000 – 200,000 call centers (500)
- “Window" into the company, for better or worse
- Over 3 million agents = **2% – 4% workforce** (11K)

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Healthcare - similar and unique challenges:

- Cost-figures far more staggering
- Risks much higher
- ED (initial focus) = hospital-window
- Over 3 million nurses

Call-Center Environment: Service Network

Call-Centers: “Sweat-Shops of the 21st Century"

ER / ED Environment: Service Network

Acute (Internal, Trauma)

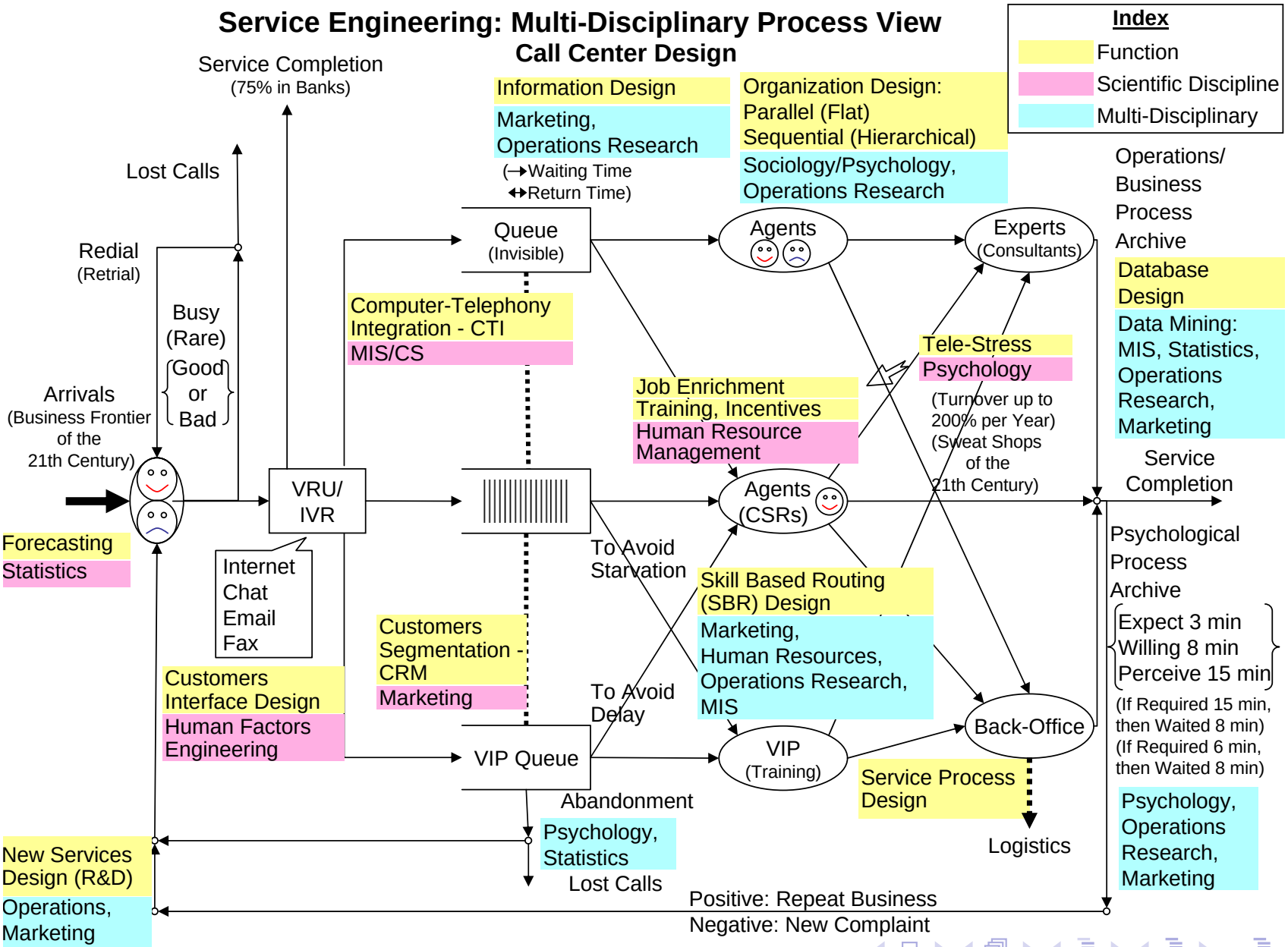
Walking

Multi-Trauma

ED-Environment in Israel

ED-Queue in a “Good" Beijing Hospital

Call-Center: Multi-Disciplinary ServEng View



Skills-Based Routing in Call Centers

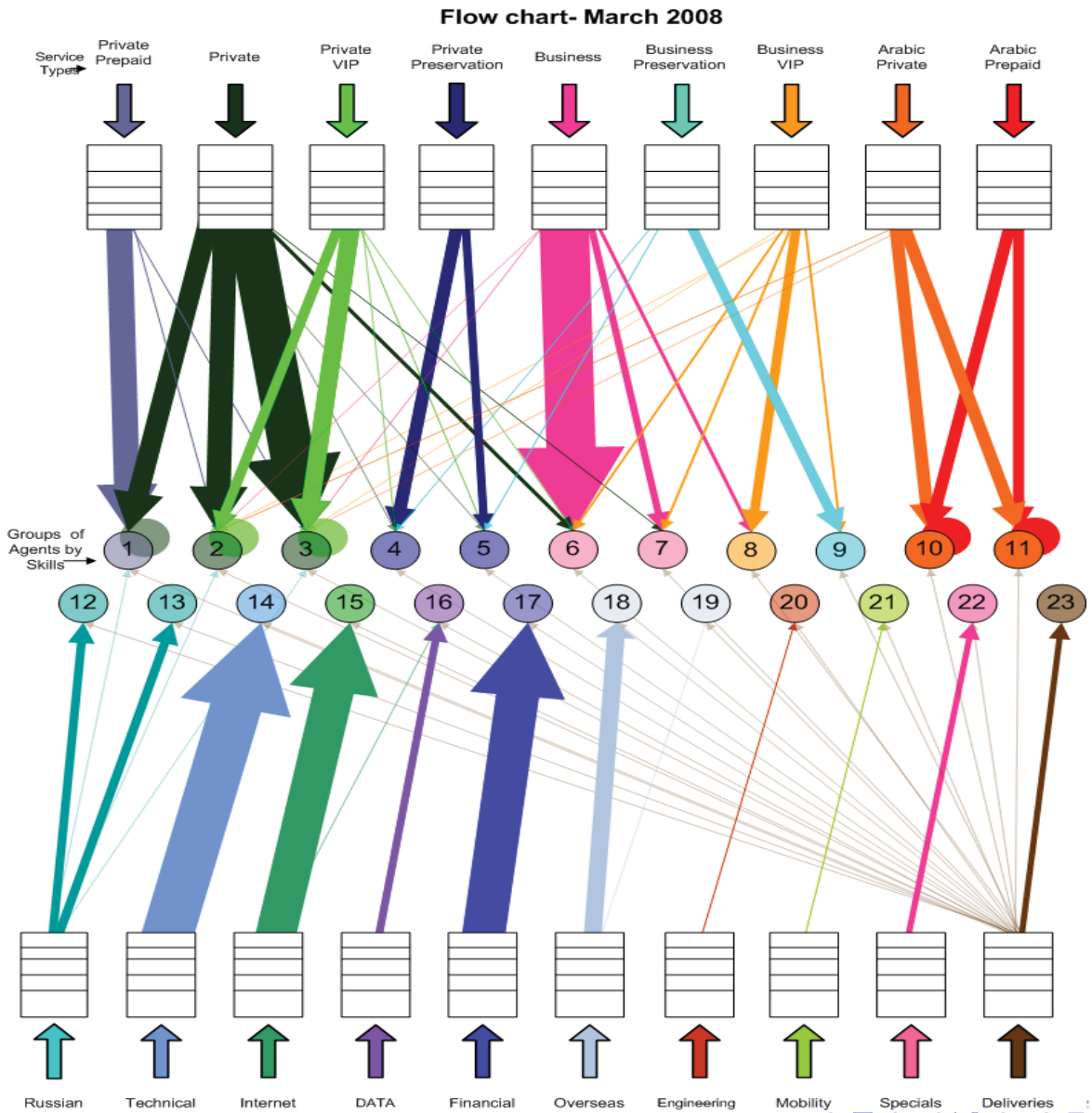
EDA and OR, with I. Gurvich and P. Lieberman

Mktg. ⇒

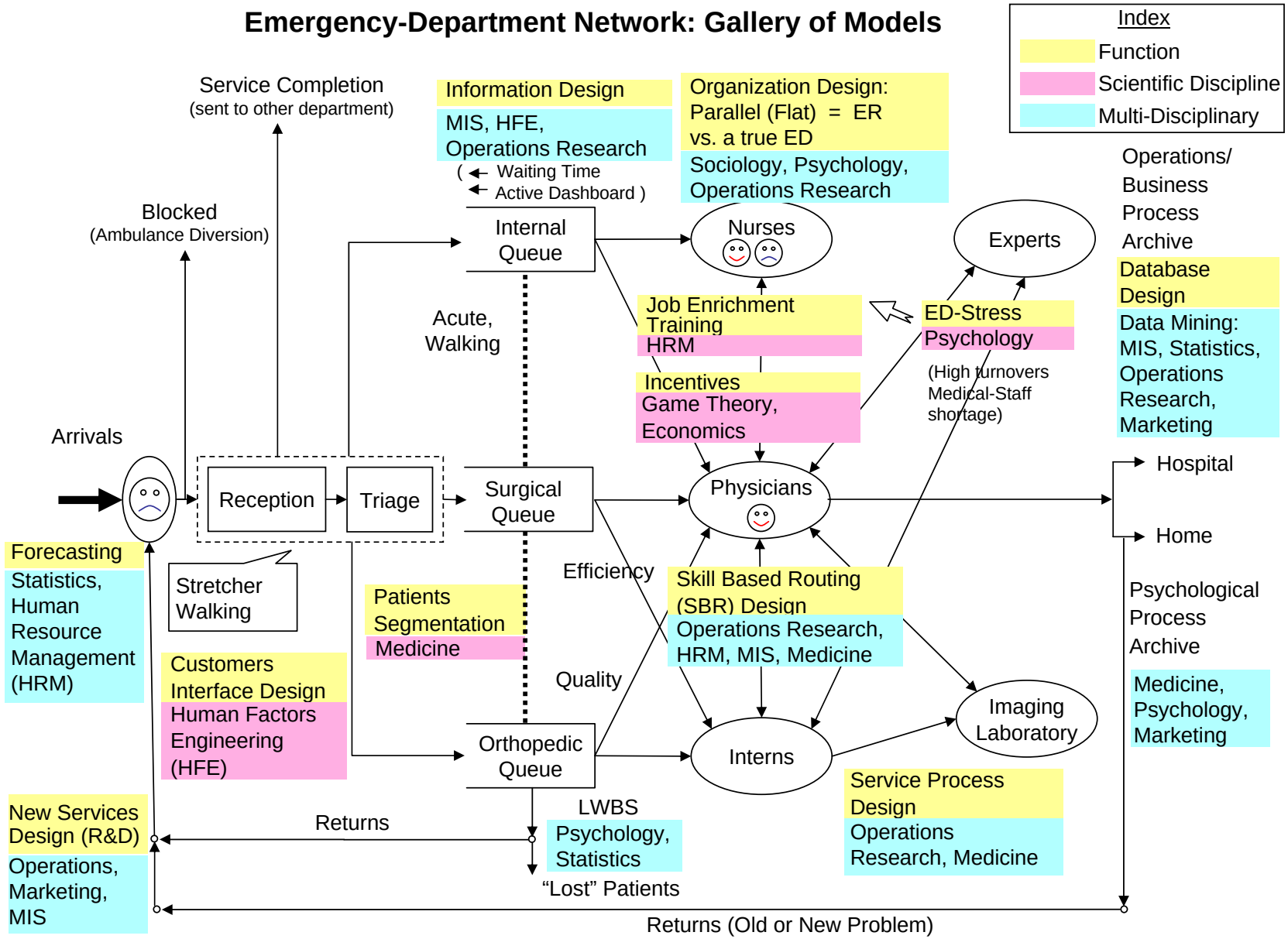
OR ⇒

HRM ⇒

MIS ⇒



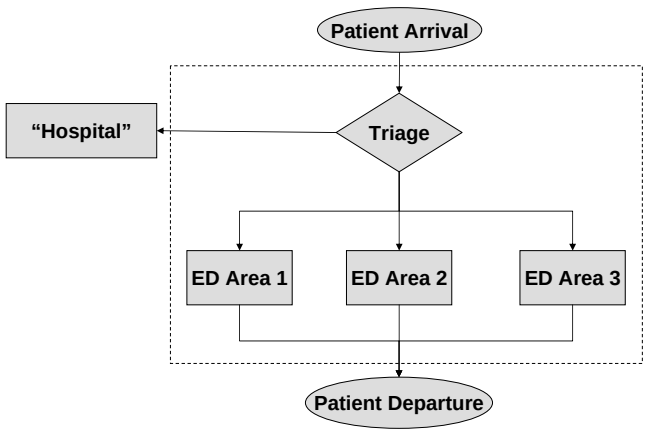
Emergency-Dept.: Multi-Disciplinary ServEng View



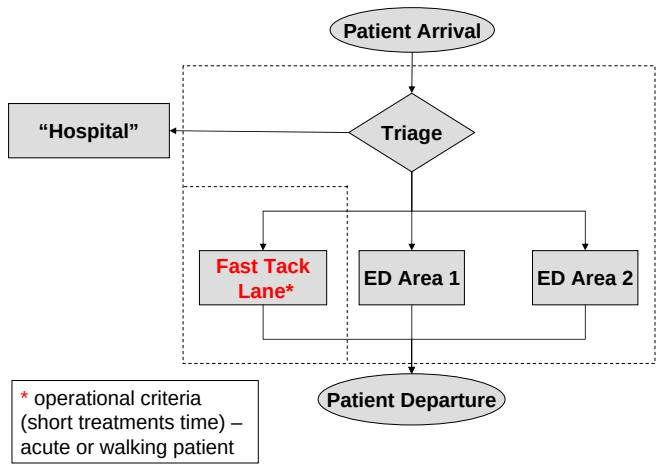
ED Design, with B. Golany and Y. Marmor (PhD)

Routing: Triage (Clinical), Fast-Track (Operational), . . . (via DEA)

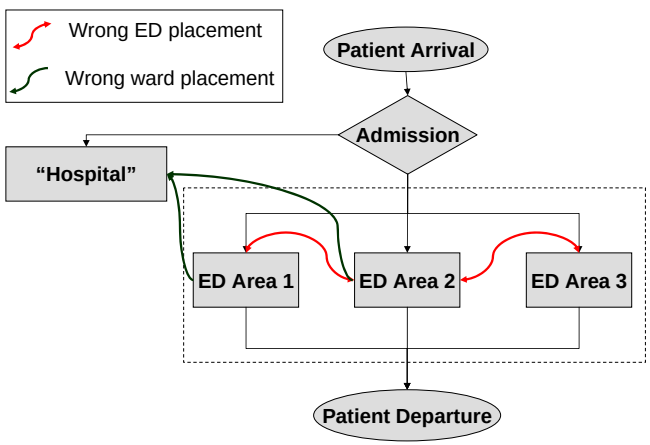
e.g. Fast Track most suitable when elderly dominate



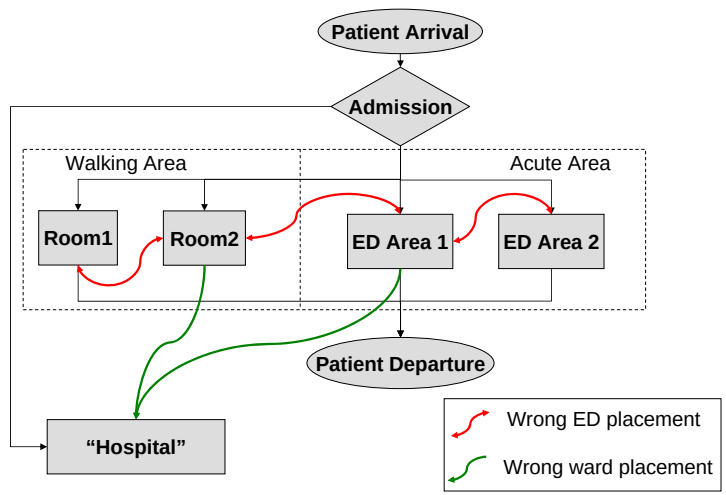
(a) Triage Model



(b) Fast-Track Model



(c) Illness-based Model



(d) Walking-Acute Model

Prerequisite I: Data

Averages Prevalent (and could be useful / interesting).

But I need data at the level of the **Individual Transaction**:
For each service transaction (during a phone-service in a call center, or a patient's visit in a hospital, or browsing in a website, or . . .), its **operational history** = time-stamps of events .

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Sources: **"Service-floor"** (vs. Industry-level, Surveys, . . .)

- Administrative (Court, via "paper analysis")
- Face-to-Face (Bank, via bar-code readers)
- **Telephone** (Call Centers, via ACD / CTI, IVR/VRU)
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- **Hospitals** (Emergency Departments, . . .)
- Expanding:
  - Hospitals, via **RFID**, with **B. Carmeli, S. Israelit, Y. Marmor**
  - Operational + Financial + Contents (Marketing, Clinical)
  - Internet, chat (multi-media)

Prerequisite II: Models (The Fluid View)

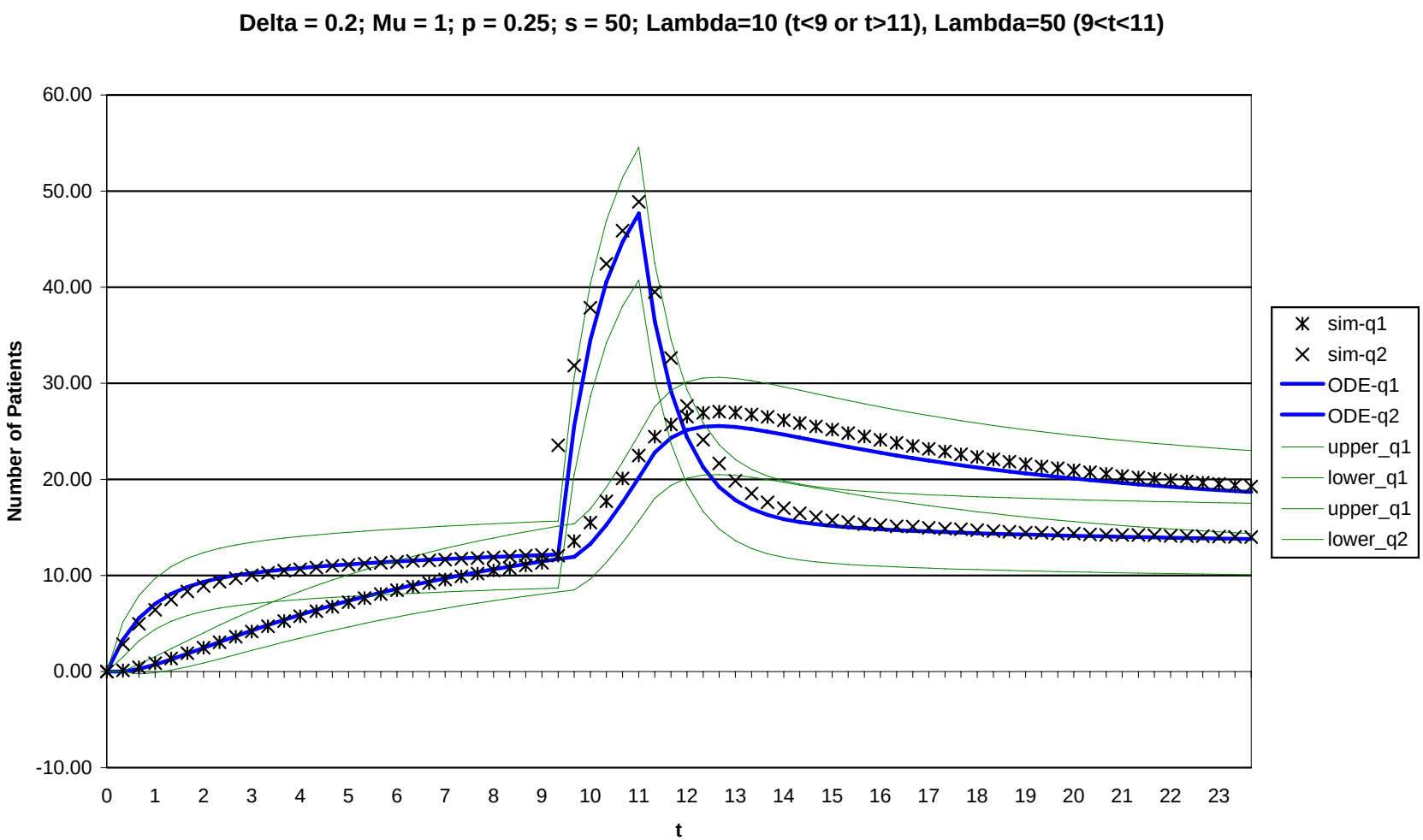
Stochastic Individualism **Averaged** out by the **LLNs** (Scale)

Labor-day Queueing at Niagara Falls

Fluid Models: Preparing for Mass-Casualty Events

e.g. Erlang-R = **R**eEntrant Patients, with **G. Yom-Tov** (PhD).

5-fold Rise in Inflow-Rate, between 9am -11am:



Prerequisite II: Models (Stochastic)

Traditional Queueing Theory predicts that **Service-Quality** and **Servers' Efficiency** **must** be traded off against each other.

e.g. **Single-server** queue (M/M/1) in **Heavy-Traffic**:
91% server's utilization goes with

$$\textbf{Congestion Index} = \frac{E[Wait]}{E[Service]} = \textbf{10},$$

and only 9% of the customers are served immediately upon arrival.

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Yet, heavily-loaded queueing systems with **Congestion Index = 0.1** (Waiting one order of magnitude less than Service) are prevalent:

- **Call Centers**: Wait **"seconds"** for **minutes** service;
- **Transportation**: Search **"minutes"** for **hours** parking;
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and, moreover, a significant fraction are not delayed in queue. (For example, in well-run call-centers, **50%** served "immediately", along with over **90%** agents' utilization, is not uncommon) **?** **QED**

Operational Regimes: Conceptual Framework

R: **Offered Load** not too small.

def. ***R*** = Arrival-rate $\times$ Average-Service-Time

e.g. ***R*** = 25 calls/min. $\times$ 4 min./call = **100**

N = #Agents **?**

Operational Regimes: Rules-of-Thumb, with S. Zeltyn

Constraint	P{Ab}		E[W]		P{$W > T$}	
Offered Load	Tight 1-10%	Loose $\geq 10\%$	Tight $\leq 10\%\mathrm{E}[\tau]$	Loose $\geq 10\%\mathrm{E}[\tau]$	Tight $0 \leq T \leq 10\%\mathrm{E}[\tau]$ $5\% \leq \alpha \leq 50\%$	Loose $T \geq 10\%\mathrm{E}[\tau]$ $5\% \leq \alpha \leq 50\%$
Small (10's)	QED	QED	QED	QED	QED	QED
Moderate-to-Large (100's-1000's)	QED	ED, QED	QED	ED, QED if $\tau \stackrel{d}{=} \exp$	QED	ED+QED

ED: $N \approx R - \gamma R \quad (0.1 \leq \gamma \leq 0.25\,)$.

QD: $N \approx R + \delta R \quad (0.1 \leq \delta \leq 0.25\,)$.

QED: $N \approx R + \beta\sqrt{R} \quad (-1 \leq \beta \leq 1\,)$.

ED+QED: $N \approx (1-\gamma)R + \beta\sqrt{R} \quad (\gamma, \beta$ as above).

Operational Regimes: Rules-of-Thumb, with **S. Zeltyn**

Constraint	P{Ab}		E[W]		P{$W > T$}	
Offered Load	Tight 1-10%	Loose $\geq 10\%$	Tight $\leq 10\%\mathrm{E}[\tau]$	Loose $\geq 10\%\mathrm{E}[\tau]$	Tight $0 \leq T \leq 10\%\mathrm{E}[\tau]$ $5\% \leq \alpha \leq 50\%$	Loose $T \geq 10\%\mathrm{E}[\tau]$ $5\% \leq \alpha \leq 50\%$
Small (10's)	QED	QED	QED	QED	QED	QED
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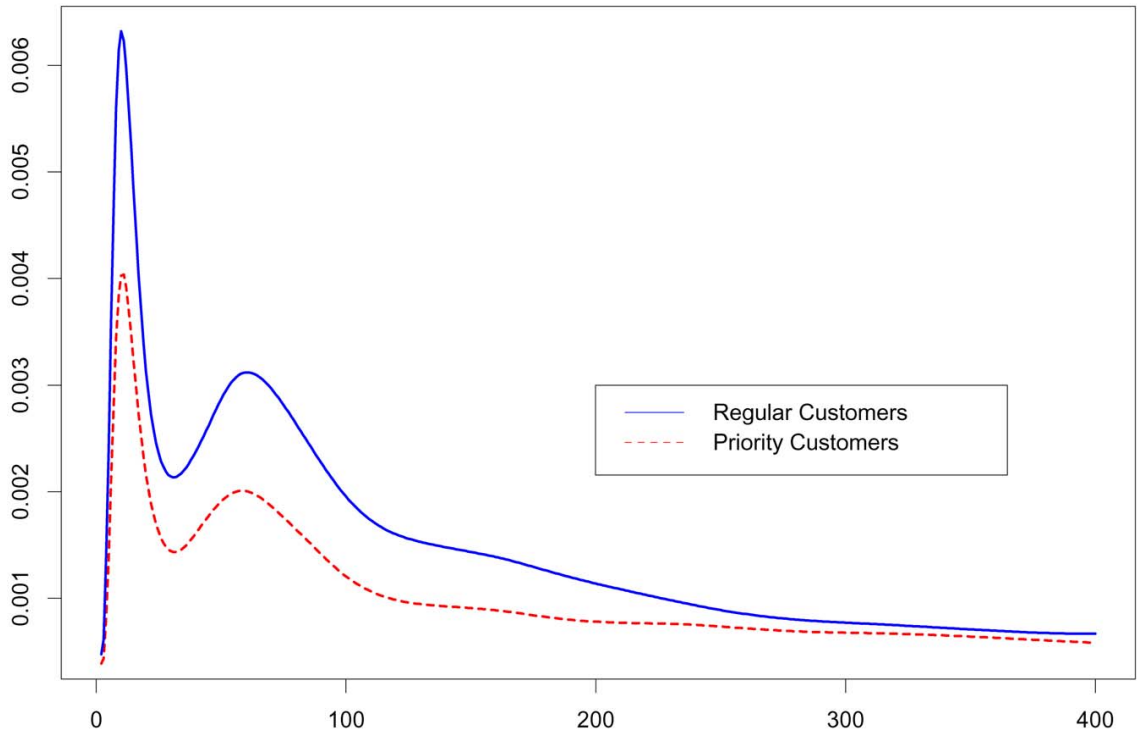
WFM: How to determine specific staffing level $\boldsymbol{N}$? e.g. β.

(Im)Patience while Waiting (Palm 1943-53)

Irritation $\propto$ Hazard Rate of (Im)Patience Distribution
Regular over VIP Customers – Israeli Bank



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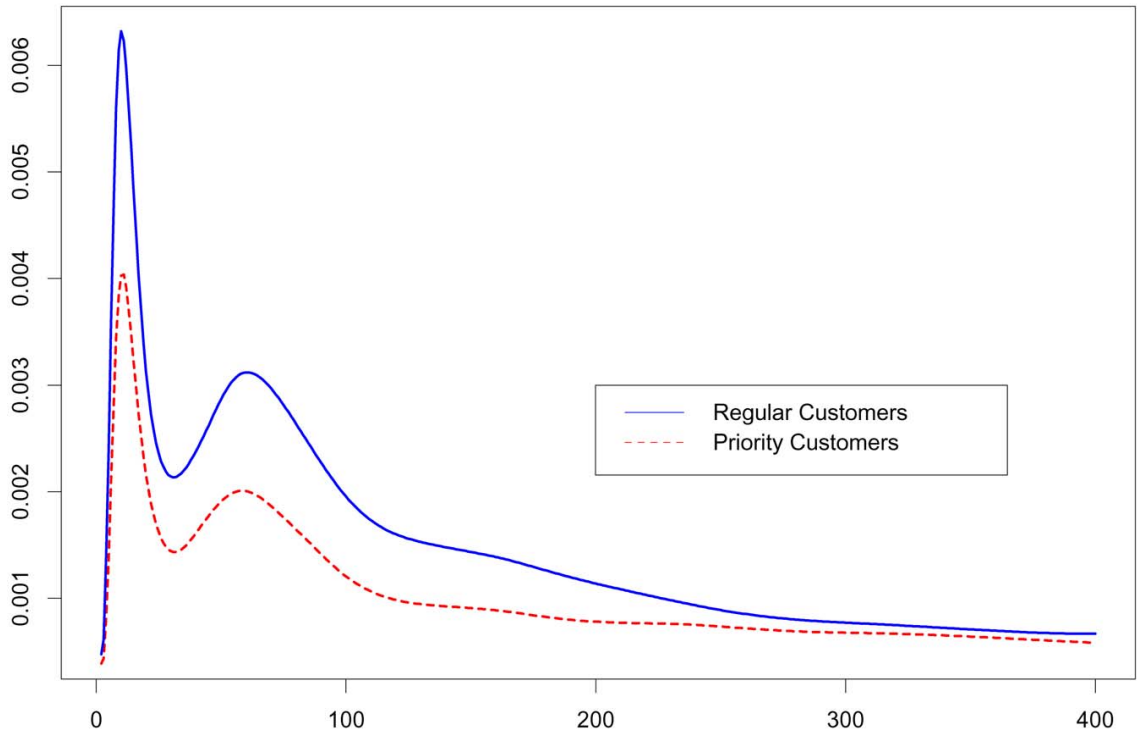

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- **Peaks** of abandonment at times of **Announcements**
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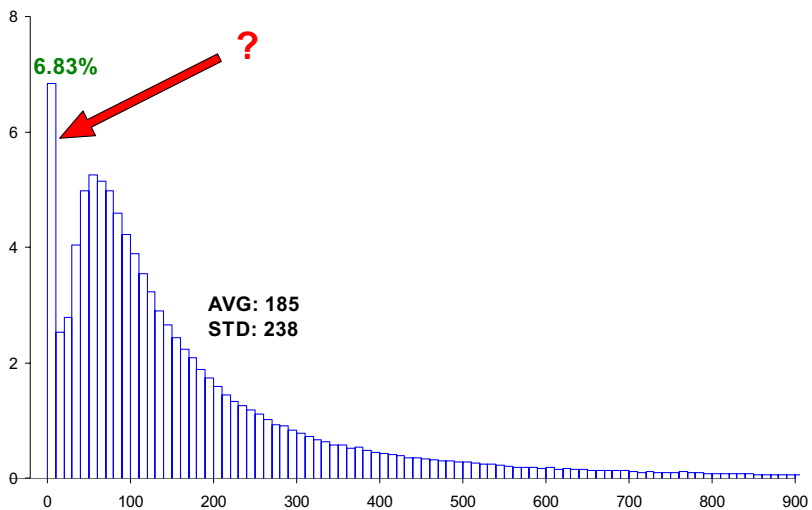
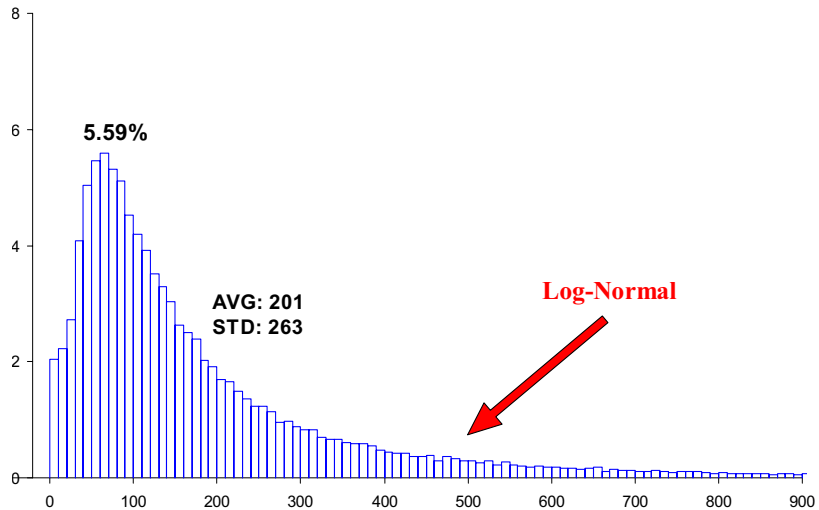
Beyond Averages: The Human Factor

Histogram of Service-Time in a (Small Israeli) Bank

January-October



November-December



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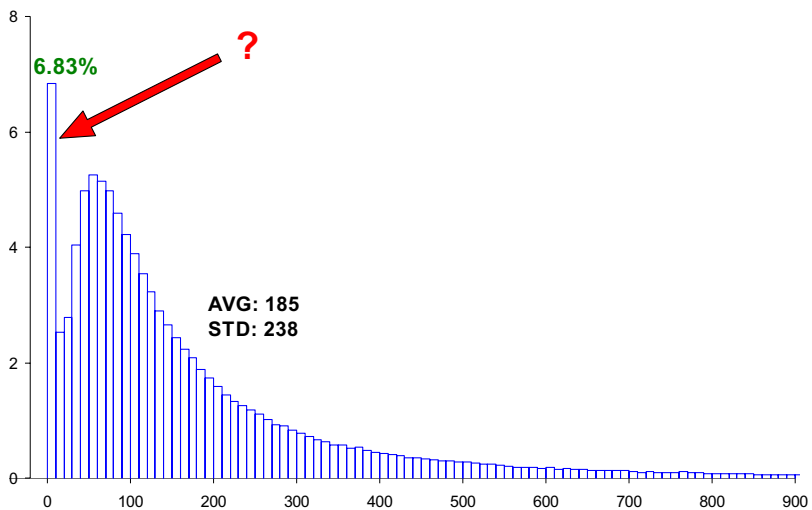

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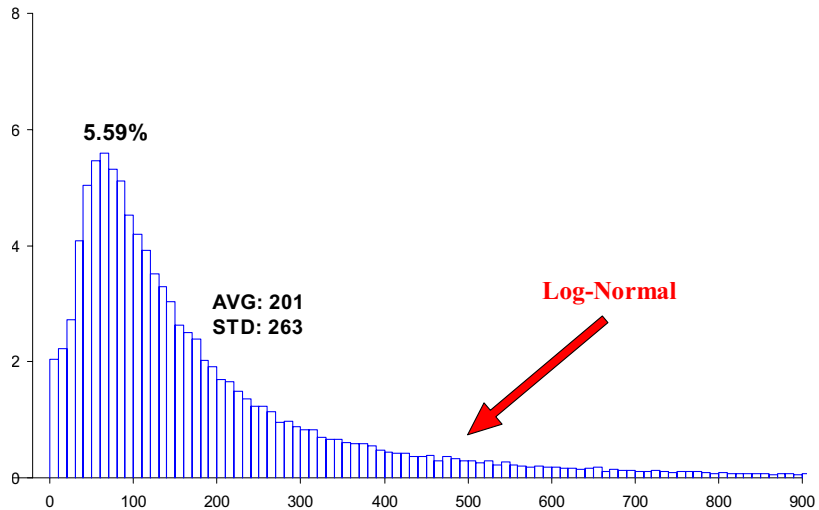
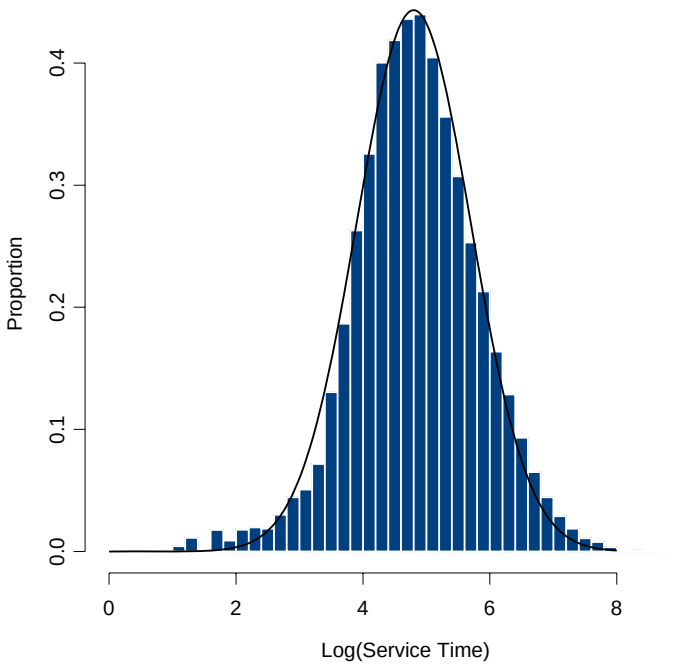


- **6.8% Short-Services:** Agents' "Abandon" (improve bonus, rest), lead by **incentives**
- **Distributions** must be measured (in seconds)
- **LogNormal** service times common in call centers

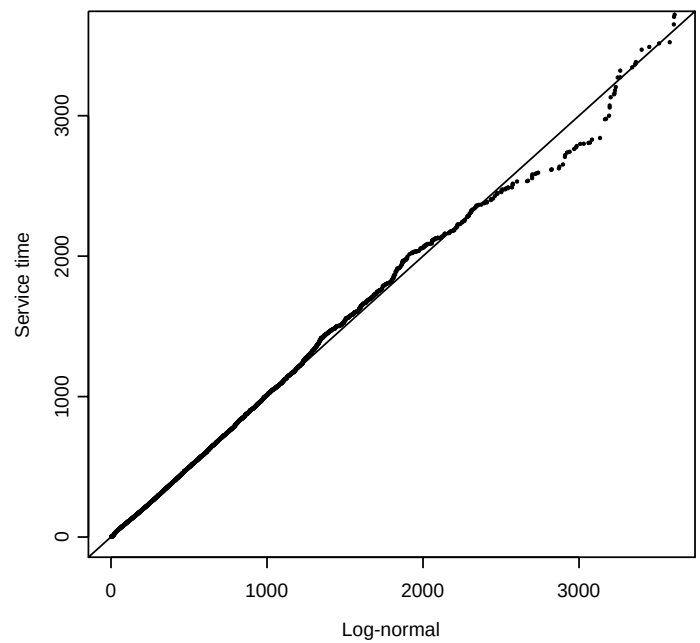
Validating LogNormality of Service-Times

Israeli Call Center, Nov-Dec, 1999

Log(Service Times)



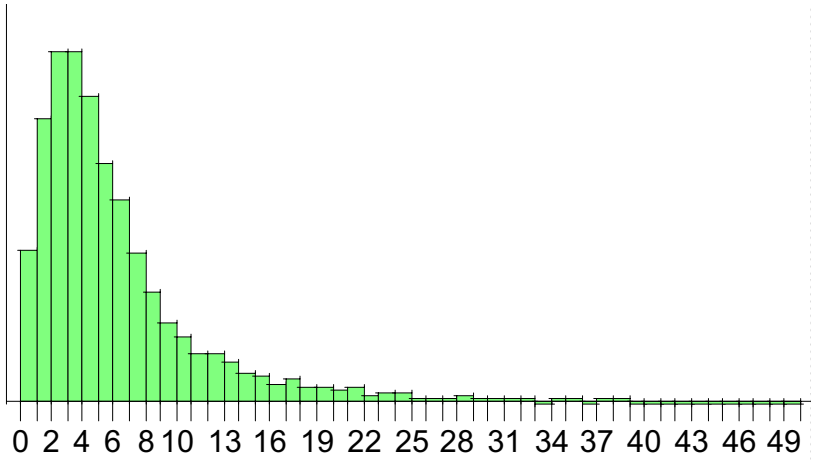
LogNormal QQPlot



- **Practically Important**: (mean, std)(log) capture Service-Times
- **Theoretically Challenging**: Why LogNormal ?
- Simple-model of a complex-reality? The **Service Process:**

Beyond Averages: Length-of-Stay in a Hospital

Israeli Hospital, in Days: LN



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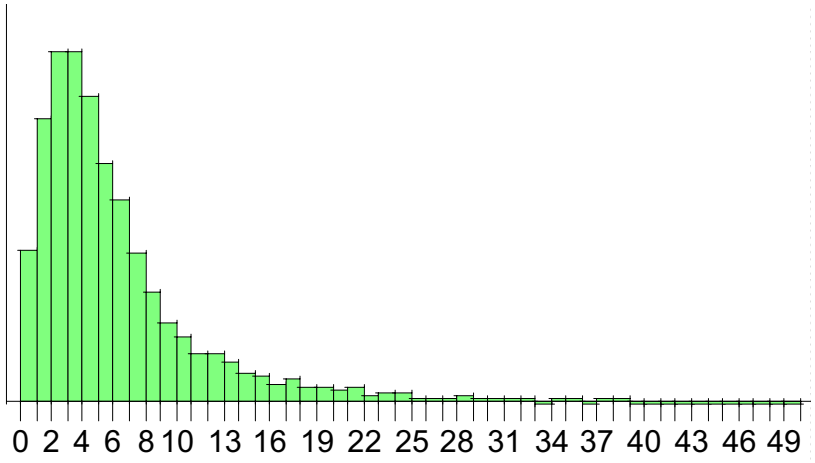
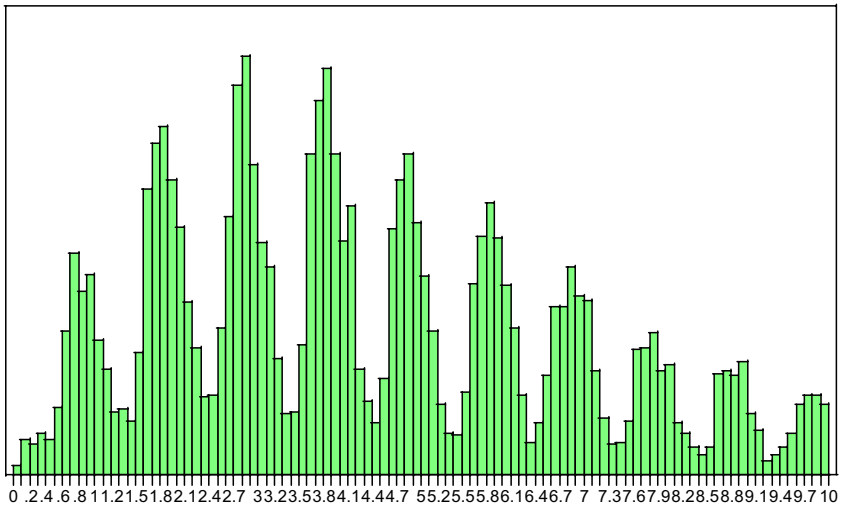
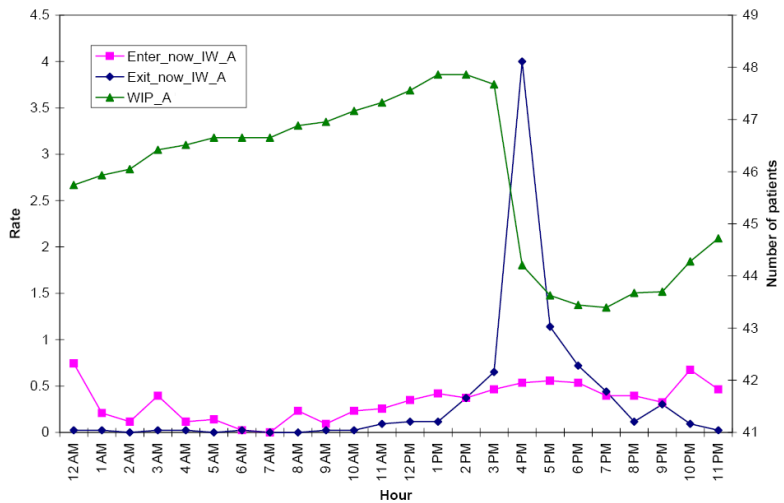


Israeli Hospital, in Hours



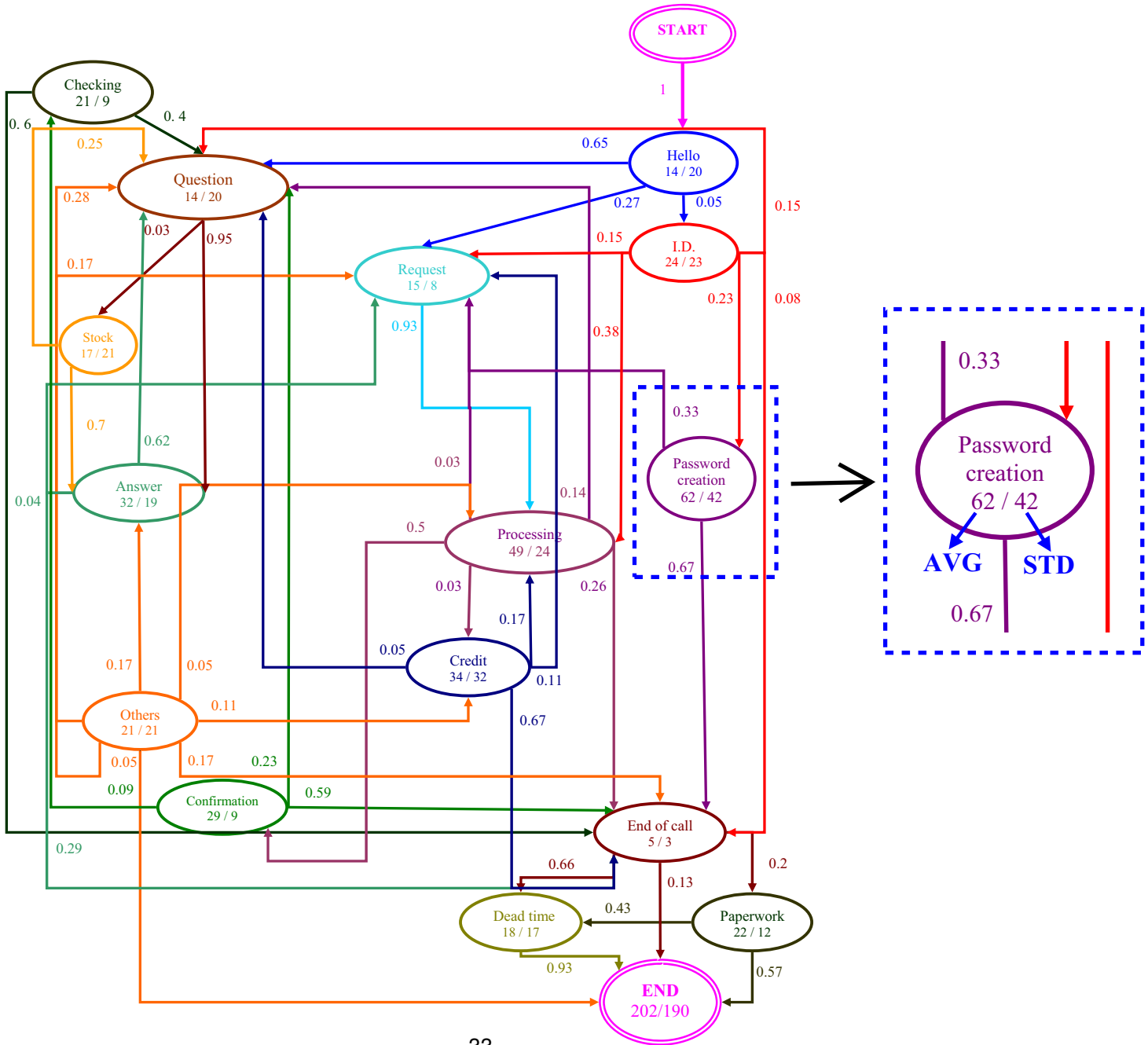
Explanation: Releases around 3pm



The (Telephone) Service Process: Phase-Type Model

Retail Service (Israeli Bank)

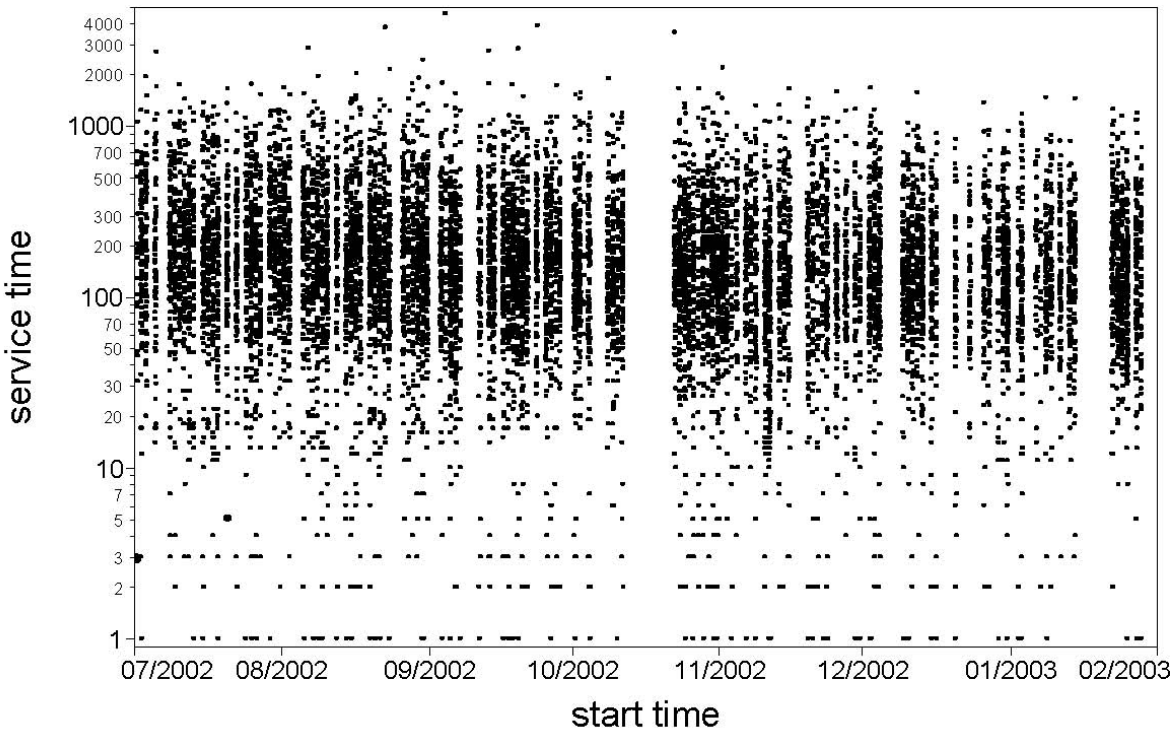
Work Design (Time Study)



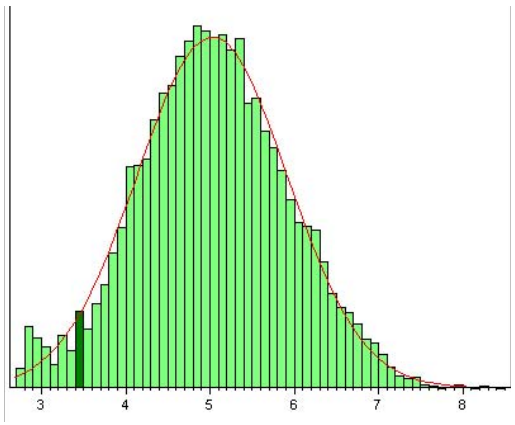
Individual Agents: Service-Time, Variability

Agent 14115

Service-Time Evolution: 6 month



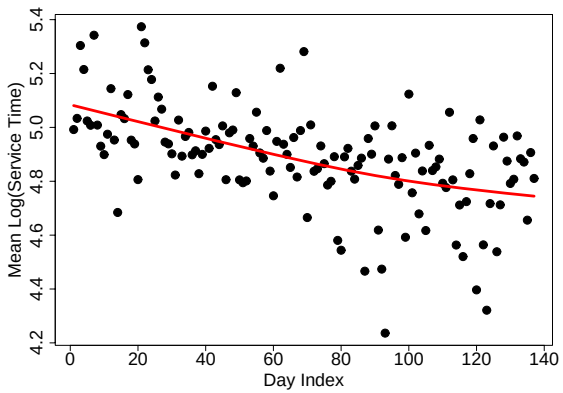
Log(Service-Time)

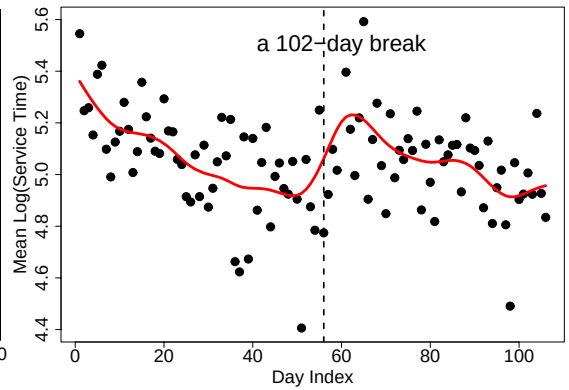


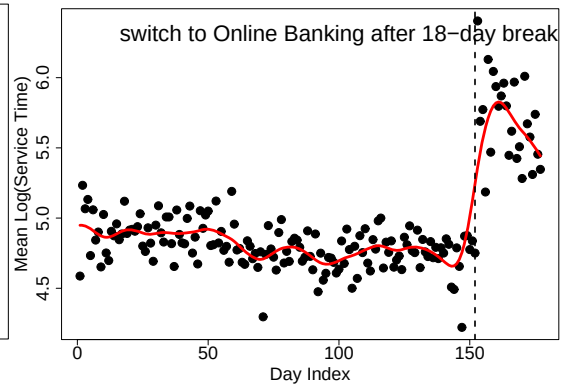
- **Learning**: Noticeable decreasing-trend in service-time
- **LogNormal** Service-Time, individually and collectively

Individual Agents: Learning, Forgetting, Switching

Daily-Average Log(Service-Time), over 6 months
Agents 14115, 14128, 14136







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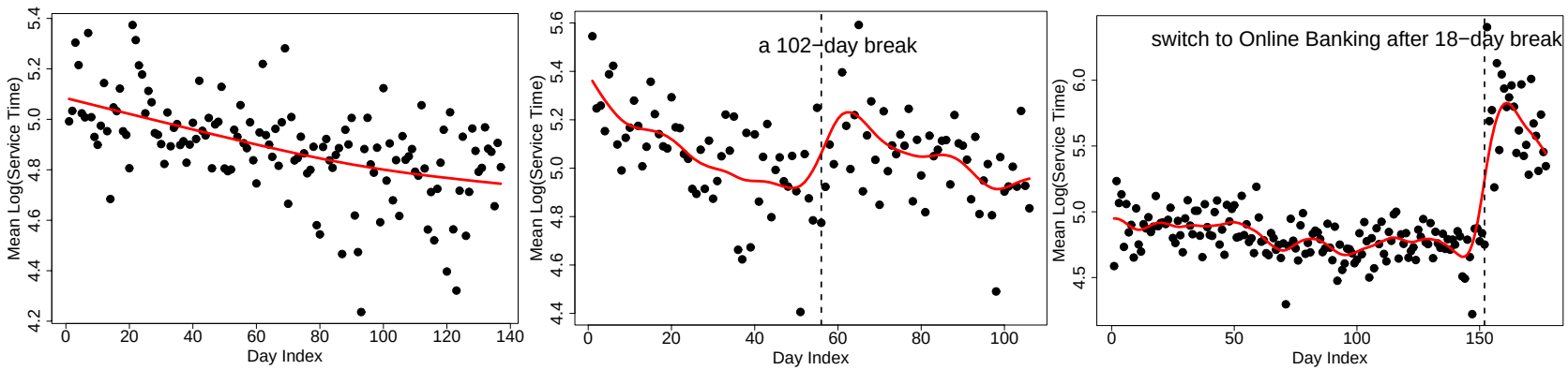
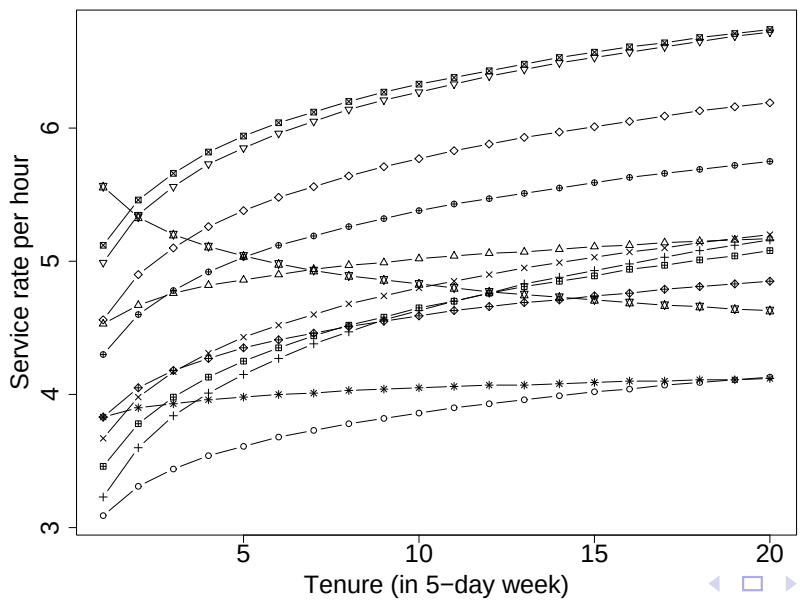


Weakly Learning-Curves for 12 Homogeneous(?) Agents



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- **IVR Process Model**: **75% services**, same method, easier data

The Technion SEE Center / Laboratory

Data-Based Service Engineering