# Pause for a Commercial:

# The Technion SEE Center / Laboratory

Technion
S.E.E
Center

Service Enterprise Engineering

# Technion Research Impact: An Example

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[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 **...**
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[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 **...**
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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

# Technion SEE = Service Enterprise Engineering

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

- **History**: I.E. Dean, **B. Golany**, recruited **Hal and Inge Marcus**.
  - **Technion**: In 2007, w/ **P. Feigin, V. Trofimov**.
  - **Wharton**: L. Brown, N. Gans, H. Shen (UNC).
  - **industry**

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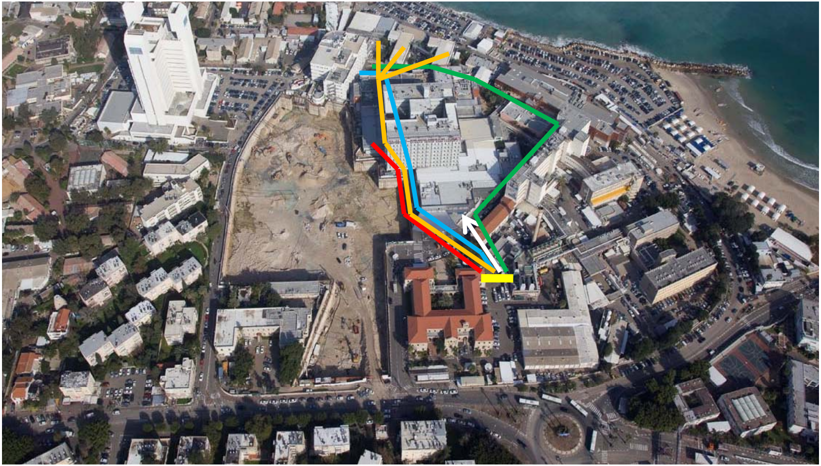
  - **Wharton**: L. Brown, N. Gans, H. Shen (UNC).
  - **industry** (partial list):
    - U.S. Bank: **2.5 years, 220M calls, 40M by 1000 agents**.
    - Israeli Cellular: **2.5 years, 110M calls, 25M calls by 750 agents**.
    - Israeli Bank: **from January 2010, daily-deposit at a SEESafe**.
    - Israeli Hospital: **4 years, 1000 beds; 8 ED's - Sinreich's data**.

## SEEStat: Environment for graphical EDA in real-time

- **Universal Design, Universal Access, Real-Time Response**.

# eg. RFID-Based Data: Mass Casualty Event (MCE)

## Drill: Chemical MCE, Rambam Hospital, May 2010



Focus on **severely wounded** casualties ($\approx$ 40 in drill)

**Note**: 20 observers support real-time control (helps validation)

# Data Cleaning: MCE with RFID Support

| 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 | | |

Imagine **“Cleaning" 60,000+ customers per day** (call centers) !


Entry
VRU
Retail
Telesales
Premier
Business
Consumer Loans
Platinum
EBO
Subanco
Summit
A
C
Out
Abandoned
Continued
(Branch,
Another ID)
Completed
1 hour

8 AM - 9 AM


SBR Network
Private AT
Private
Business
Business AT
Business Preservation
Private Preservation
Overseas
2049
2208
4592
1143
2626
85
445
47
4658
34
411
480
444
43
847
181
974
1484
873
1433
193
1
18
4
17
2
16
15
10
11
12
13
5
8
20
21
24
25
Agent Pools
2104
30
792
54
1240
43
44
33
1096
823
1390
1253
84
3793
49
735
N-design
Customer classes
Private Prepaid
Russian
Arabic Private
Arabic Prepaid
Arabic Prepaid
Internet surfing
DATA

Private AT
Private
Business
Business AT
Business Preservation
Private Preservation
Financial
Overseas
Deliveries
2049
2208
4592
1143
2626
85
445
47
4658
34
411
480
444
43
847
181
974
1484
873
3791
1433
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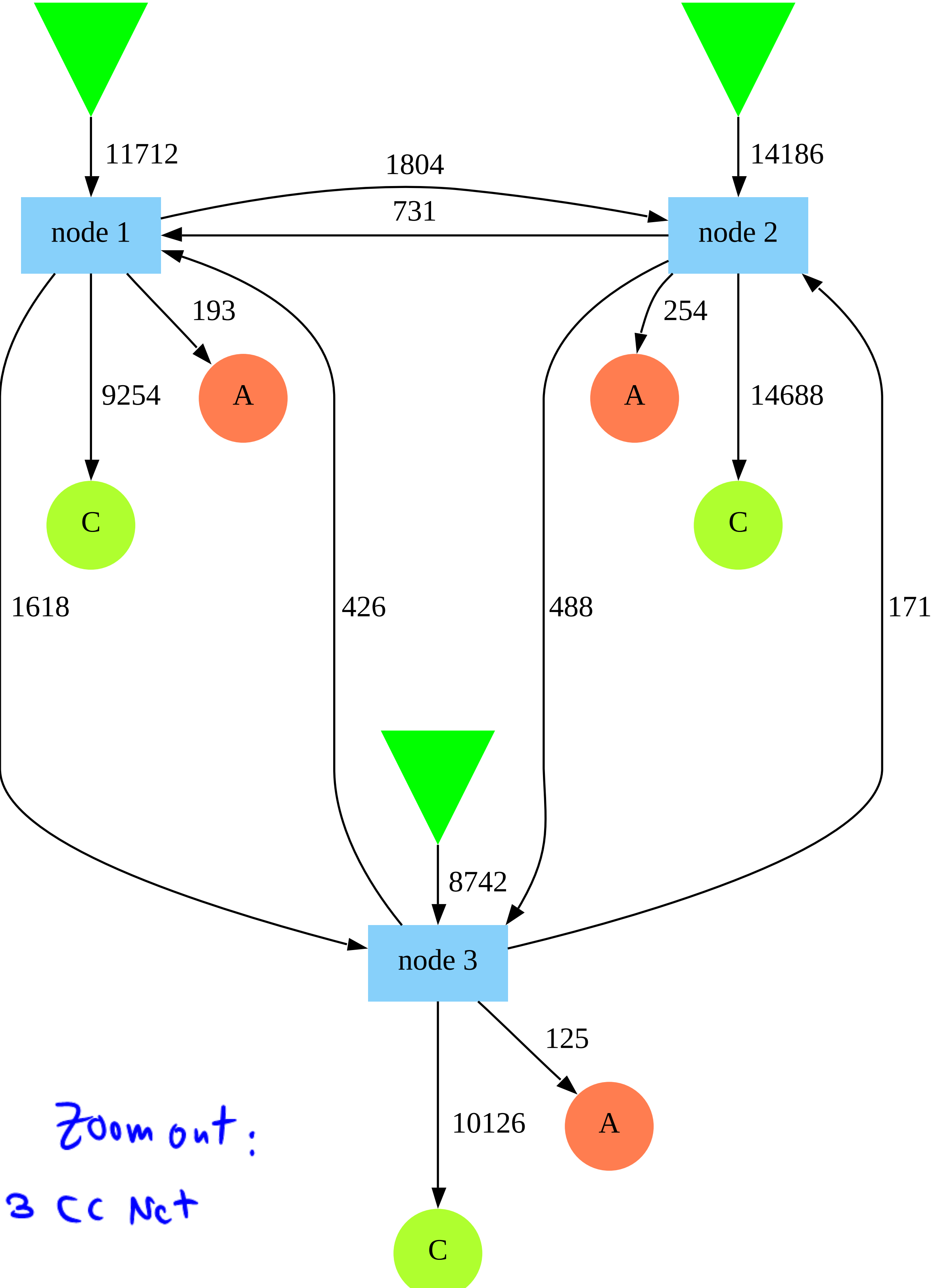
28
30
2104
30
792
54
1240
43
44
33
1096
823
1390
1253
84
5217
3793
49
735
58
125
685
Private Prepaid
Russian
Arabic Private
Arabic Prepaid
Arabic Prepaid Bothersome
Technical
Internet surfing
DATA
Engineering
Mobility
Specials

EBO
Business
Platinum
Subanco
Premier
Consumer Loans
Online Banking
Telesales
Case Quality
Priority Service
AST
CCO
Quick&Reilly
BPS
639
51
555
2372
597
91
195
325
54
1455
257
342
3660
2173
3251
487
32
12
619
2352
3668
4844
447
1_1
7
1_5
3_1
3_5
1_15
2_3
2_6
5_1
6
8
10_1
11
12
13
15
17
10430
2947
18993
40
384
98
157
Retail
≈ 60% calls

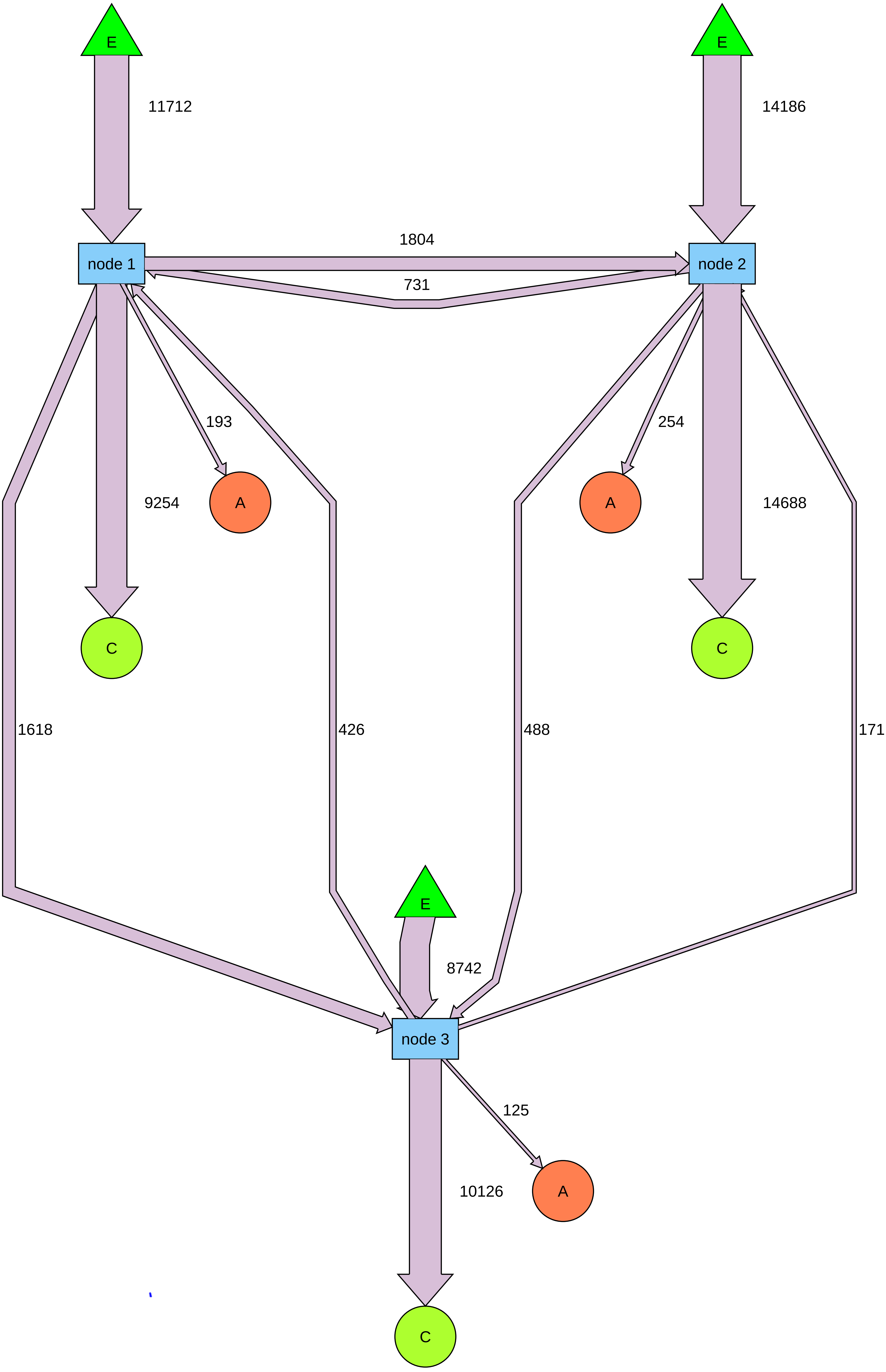

Identification
Query
Change
Check
Fax
Saving Accounts
Credit
Deposit (daily)
Stock Market
Poly
Error
Trans
Agent
43123
4115
35315
768
1352
26091
3900
49
897
1032
107
40
147
6
42
16
14
68
65
234
8
35
830
962
30
28
21
20
21
18
71
133
9
10
29
114
72
5
53
114
165
1063
1039
231
54
7895
12317
273
270
Zoom in:
IVR

3900
49
897
147
6
1032
42
107
16
40
14
234
68
8
65
35
830
962
133
30
28
21
20
9
21
18
71
10
29
72
768
114
43123
4115
1352
5
35315
26091
53
114
165
1063
1039
231
54
7895
12317
273
270
Entry
Entry
Entry
Entry
Identification
Query
Change
Check
Poly
Fax
Saving Accounts
Credit
Deposit (daily)
Stock Market
Error
Trans
Agent




Zoom out:

3 CC Net


E
11712
E
14186
1804
node 1
node 2
731
193
254
9254
A
A
14688
C
C
1618
426
488
171
E
8742
node 3
125
10126
A
C

EBO
Business
Platinum
Subanco
Premier
Consumer Loans
Online Banking
Telesales
Case Quality
Priority Service
AST
CCO
Quick&Reilly
BPS
639
51
555
2372
597
91
195
325
54
1455
257
342
3660
2173
3251
487
32
12
619
2352
3668
4844
447
1_1
7
1_5
3_1
3_5
1_15
2_3
2_6
5_1
6
8
10_1
11
12
13
15
17
10430
2947
18993
40
384
98
157
Retail


What is lacking?

- Durations
- Protocols
- Dynamics (Network-valued Stochastic Processes)

Private VIP
Private
Business
Business VIP
Business Customer Retention
Private Customer Retention
Overseas
2049
2208
4592
1143
2626
85
445
47
4658
34
411
480
444
43
847
181
974
1484
873
1433
193
1
18
4
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13
5
8
20
21
24
25
2104
30
792
54
1240
43
44
33
1096
823
1390
1253
84
3793
49
735
Private Prepaid
Other Language2
Other Language Private
Other Language Prepaid
Other Language Prepaid
Internet Surfing
Internet


What is lacking?

- Durations
- Protocols
- Dynamics


Entry
VRU
Entry
Entry
Entry
Entry
Entry
Entry
Entry
Subanco
Premier
Telesales
Business
Retail
Summit
Consumer Loans
EBO
Platinum
A
C
Out
VRU
Premier
Retail
Business
Consumer Loans
EBO
Telesales
Summit
Platinum
VRU
Retail

8 AM - 9 AM

Entry
VRU
Entry
Entry
Entry
Entry
Entry
Entry
Entry
Subanco
Premier
Telesales
Business
Retail
Summit
Consumer Loans
EBO
Platinum
A
A
A
A
A
A
A
A
A
C
C
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C
C
C
C
C
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VRU
C
Out
Out
Out
Premier
Retail
Out
Business
Consumer Loans
EBO
Telesales
Out
Summit
Out
Out
Out
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Platinum
A
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C
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C
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C
C
C
VRU
C
Out
Retail
Out
Out
Business
C
C


9 AM - 10 AM


Entry
VRU
Entry
Entry
Entry
Entry
Entry
Entry
Entry
Subanco
Premier
Telesales
Business
Retail
Summit
Consumer Loans
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VRU
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Out
Retail
Out
Out
Business
C
C

10 AM - 11 AM


Entry
VRU
Subanco
Premier
Telesales
Business
Retail
Summit
Consumer Loans
EBO
Platinum
A
C
Out

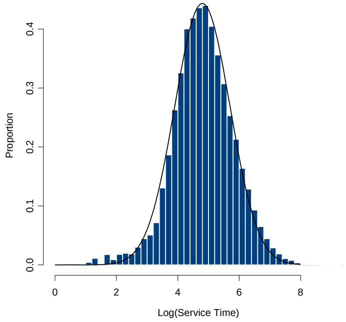
11 AM - 12 PM

# Validating LogNormality of Service-Duration

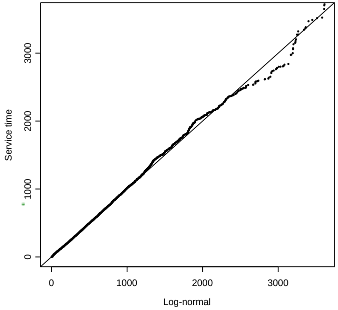
## Israeli Call Center, Nov-Dec, 1999

" distribution fitting

### Log(Service Times)




### LogNormal QQPlot

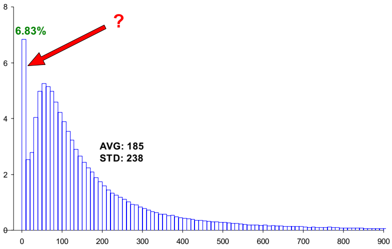



- **Practically Important**: (mean, std)(log) characterization
- **Theoretically Intriguing**: Why LogNormal ? Naturally multiplicative but, in fact, also **Infinitely-Divisible** (Generalized Gamma-Convolutions)

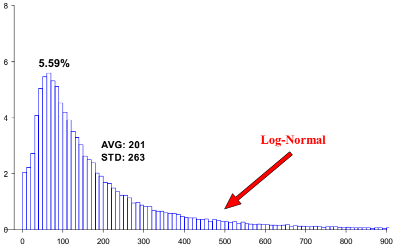
# Beyond Averages: The Human Factor

## Histogram of Service-Time in a (Small Israeli) Bank, 1999

### January-October



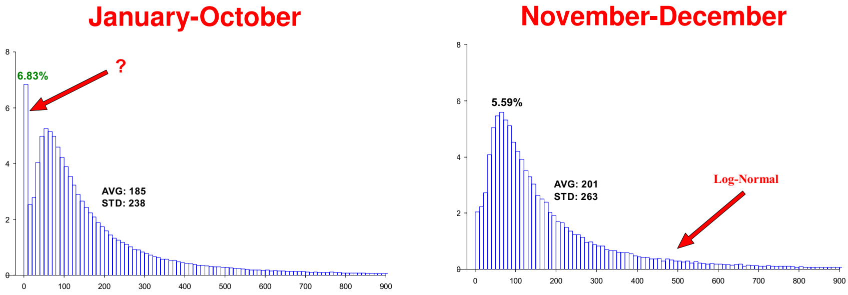

### November-December



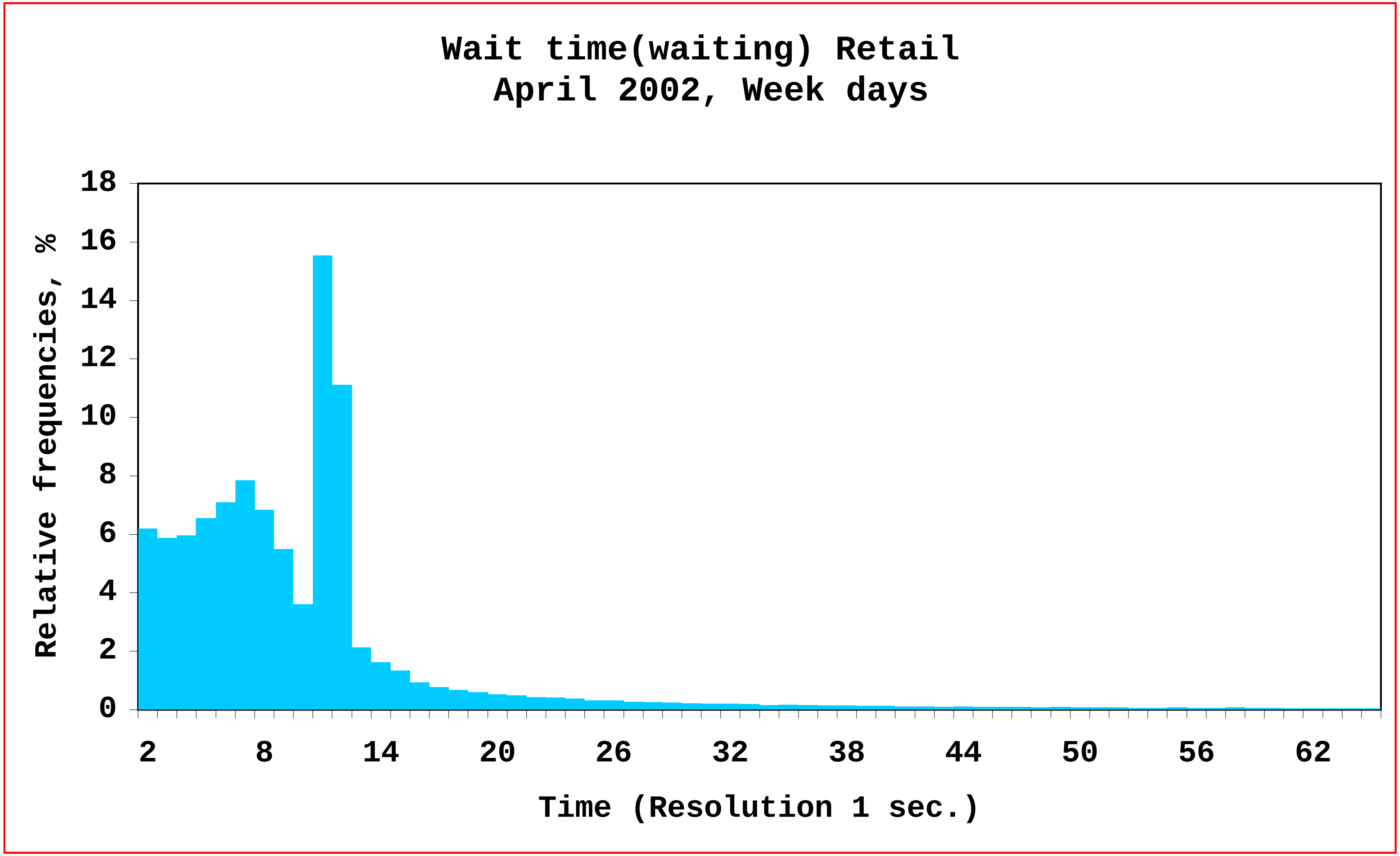

- 6.8% Short-Services:

# Beyond Averages: The Human Factor

## Histogram of Service-Time in a (Small Israeli) Bank, 1999

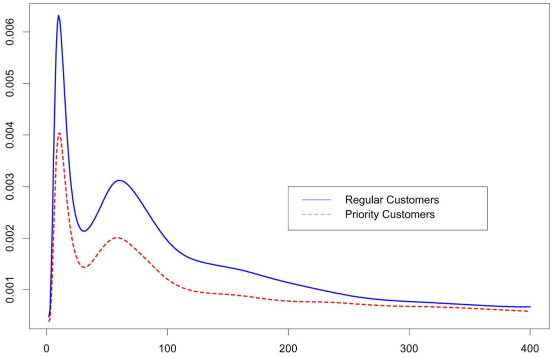



- **6.8% Short-Services:** Agents' "Abandon" (improve bonus, rest), (mis)lead by **incentives**
- **Distributions** must be measured (in **seconds** = **natural scale**)
- **LogNormal** service times common in call centers


Wait time(waiting) Retail
April 2002, Week days
Relative frequencies, %
0
2
4
6
8
10
12
14
16
18
2
8
14
20
26
32
38
44
50
56
62
Time (Resolution 1 sec.)

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

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



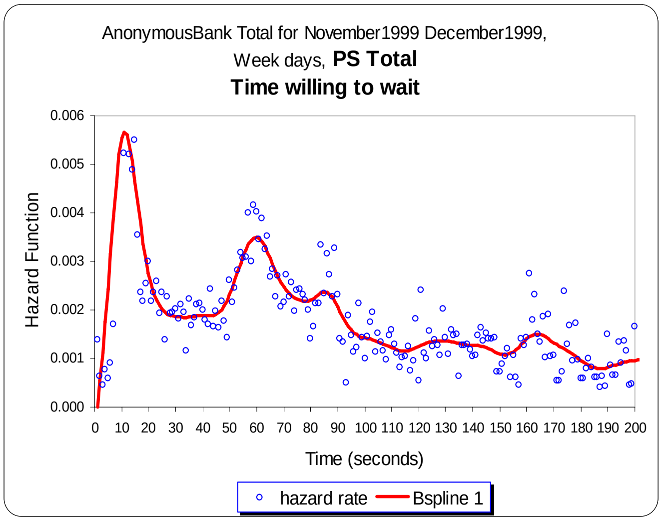

- **Peaks** of abandonment at times of **Announcements**
- **Call-by-Call Data (DataMOCCA)** required (& Un-Censoring).

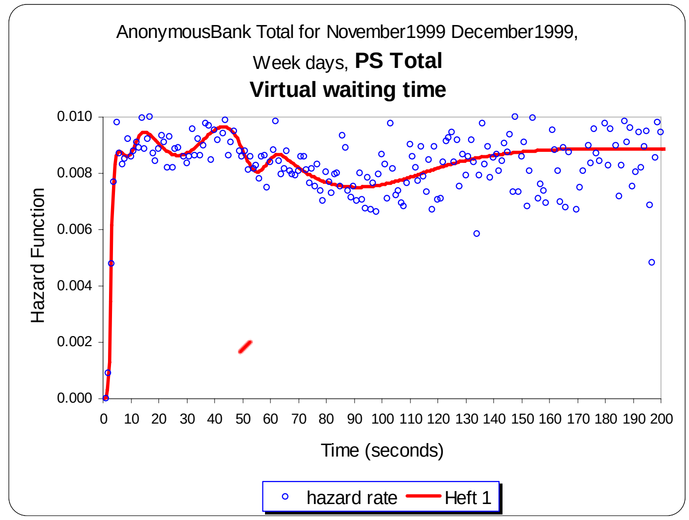
Observation: **VIP** are **more patient** (Needy)

Protocol Inference

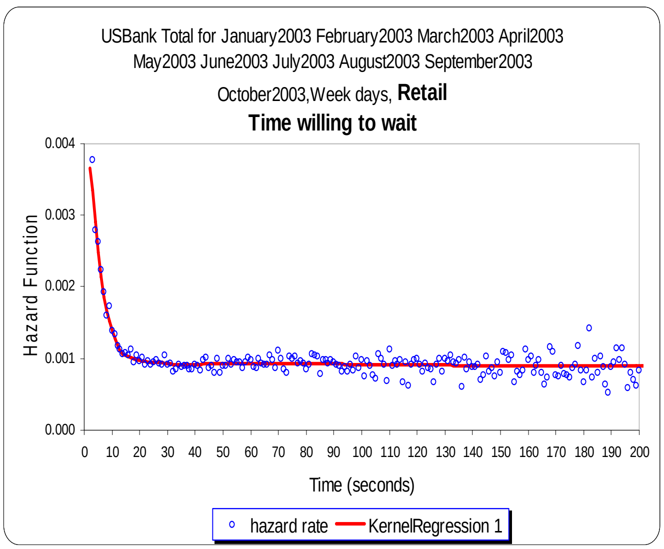
| | Time Willing to Wait ( $\tau$ ) | Time Required to Wait ( $V$ ) |
|---|---|---|

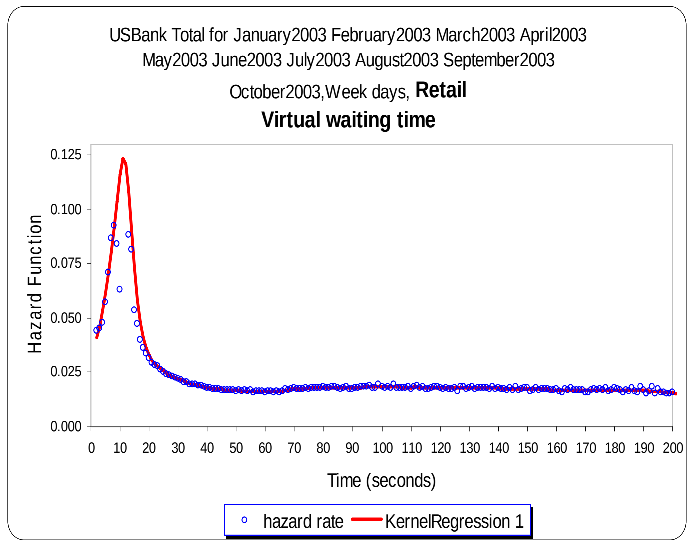
**Israel**



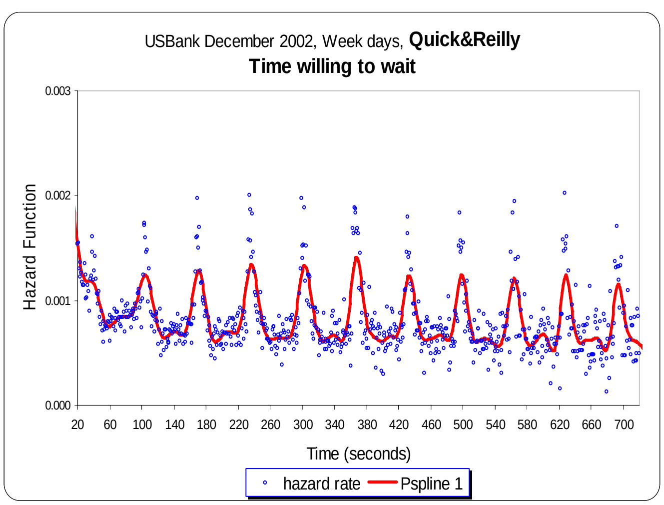



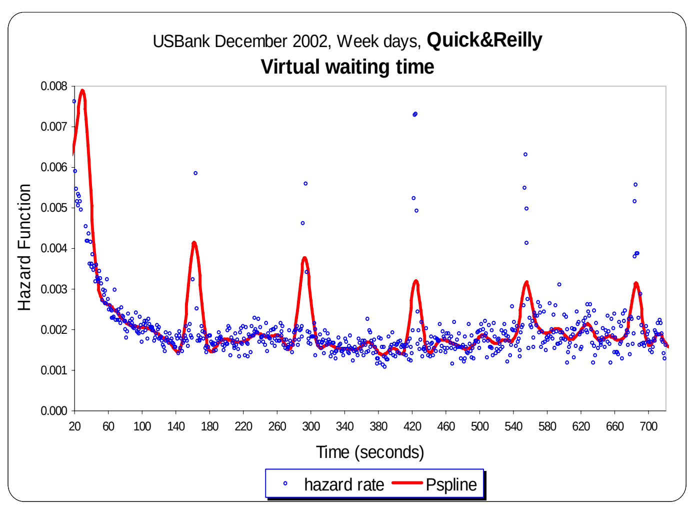

**USA Retail**



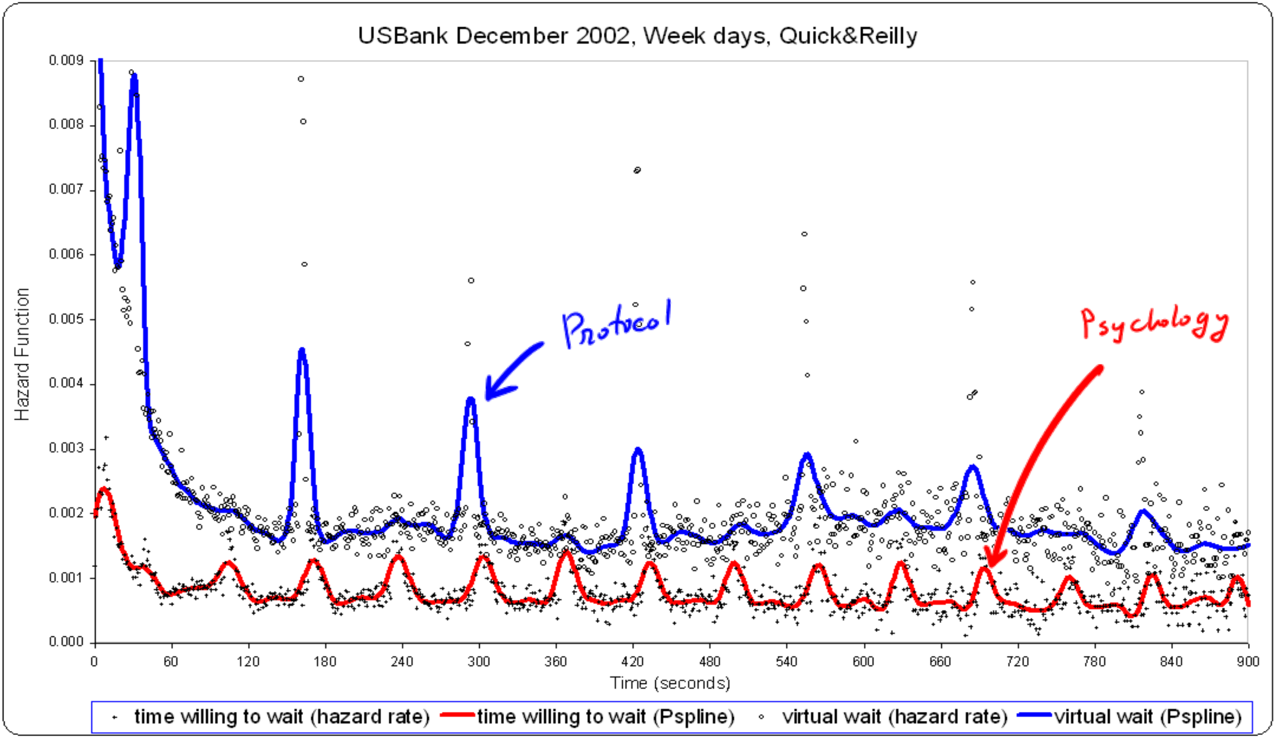

**USA Stocks**



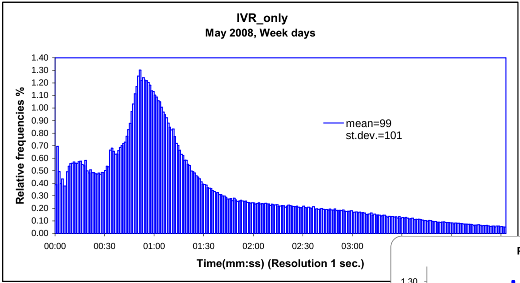

| | **Psychology** | **Protocols** |
|---|---|---|

# even Psychology + Protocols

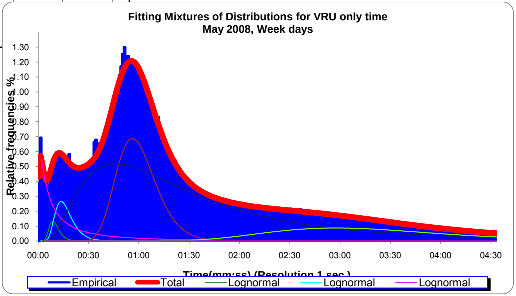


# IVR-Time: Histograms

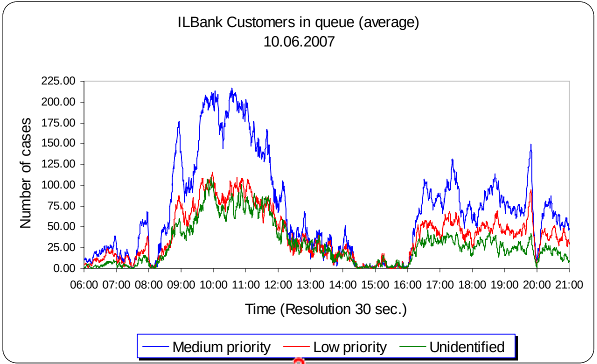
## Israeli Bank: IVR/VRU Only, May 2008



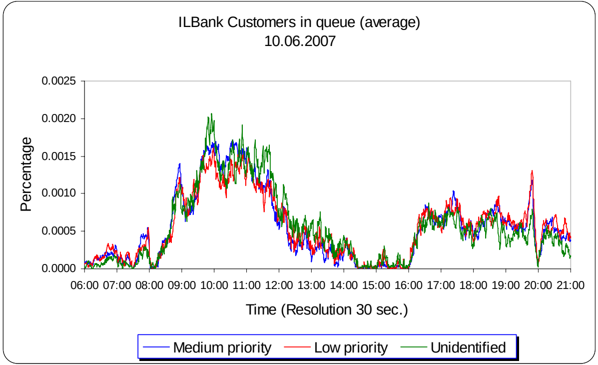

## Mixture: 7 LogNormals



## 3.1 Three Queues in IL Bank

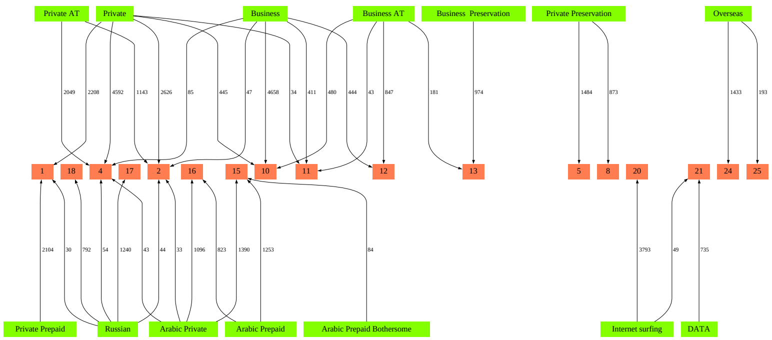


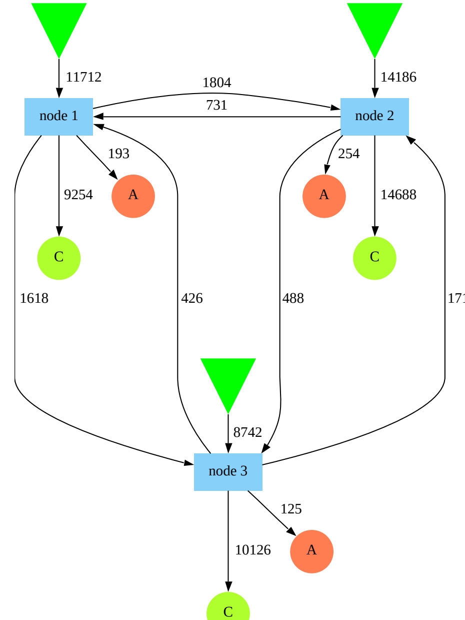

## 3.2 State-Space Collapse (Area normalized to 1)



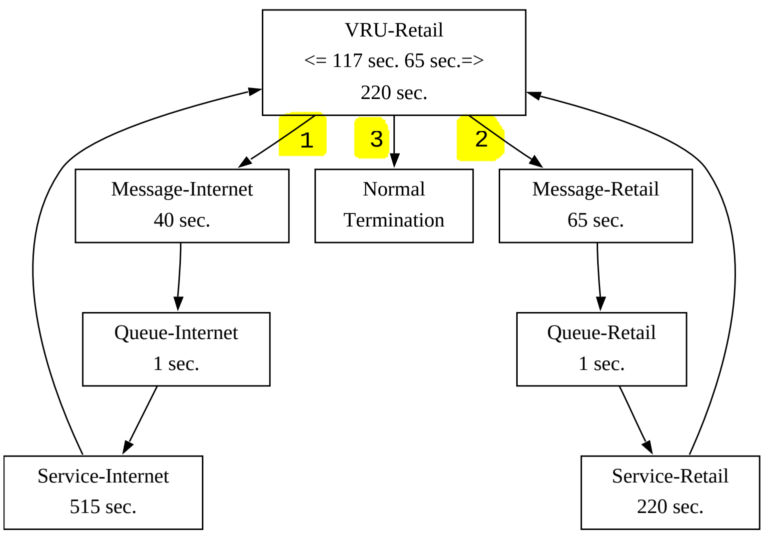

Why be Optimistic? continued

## Skills-Based Routing, IL Telecom

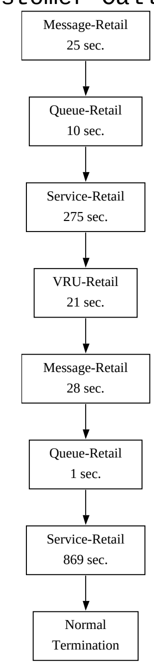



## Individual Customer Call (3 sub calls), US Bank




## Individual Customer Call (2 sub calls), US Bank

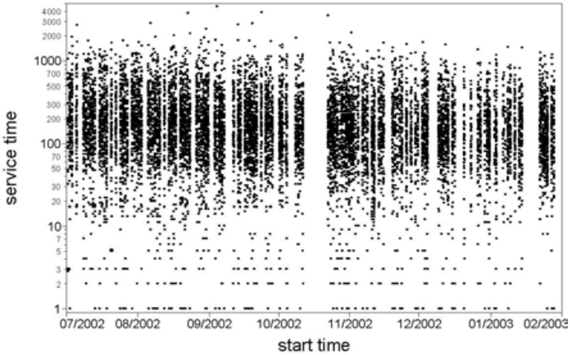


# Individual Agents: Service-Duration, Variability

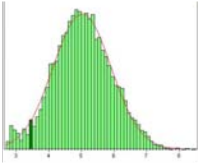
w/ **Gans, Liu, Shen & Ye**

## Agent 14115

**Service-Time Evolution: 6 month**



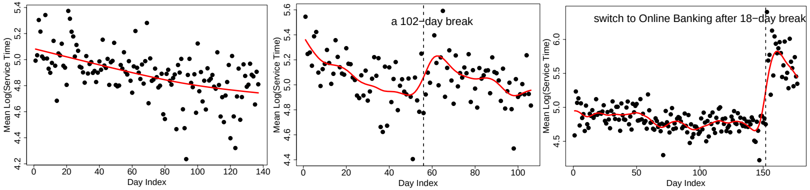

**Log(Service-Time)**



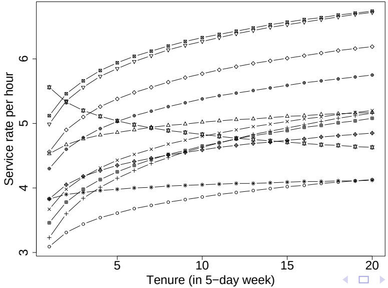
- **Learning**: Noticeable decreasing-trend in service-duration
- **LogNormal** Service-Duration, individually and collectively

# Individual Agents: Learning, Forgetting, Switching

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

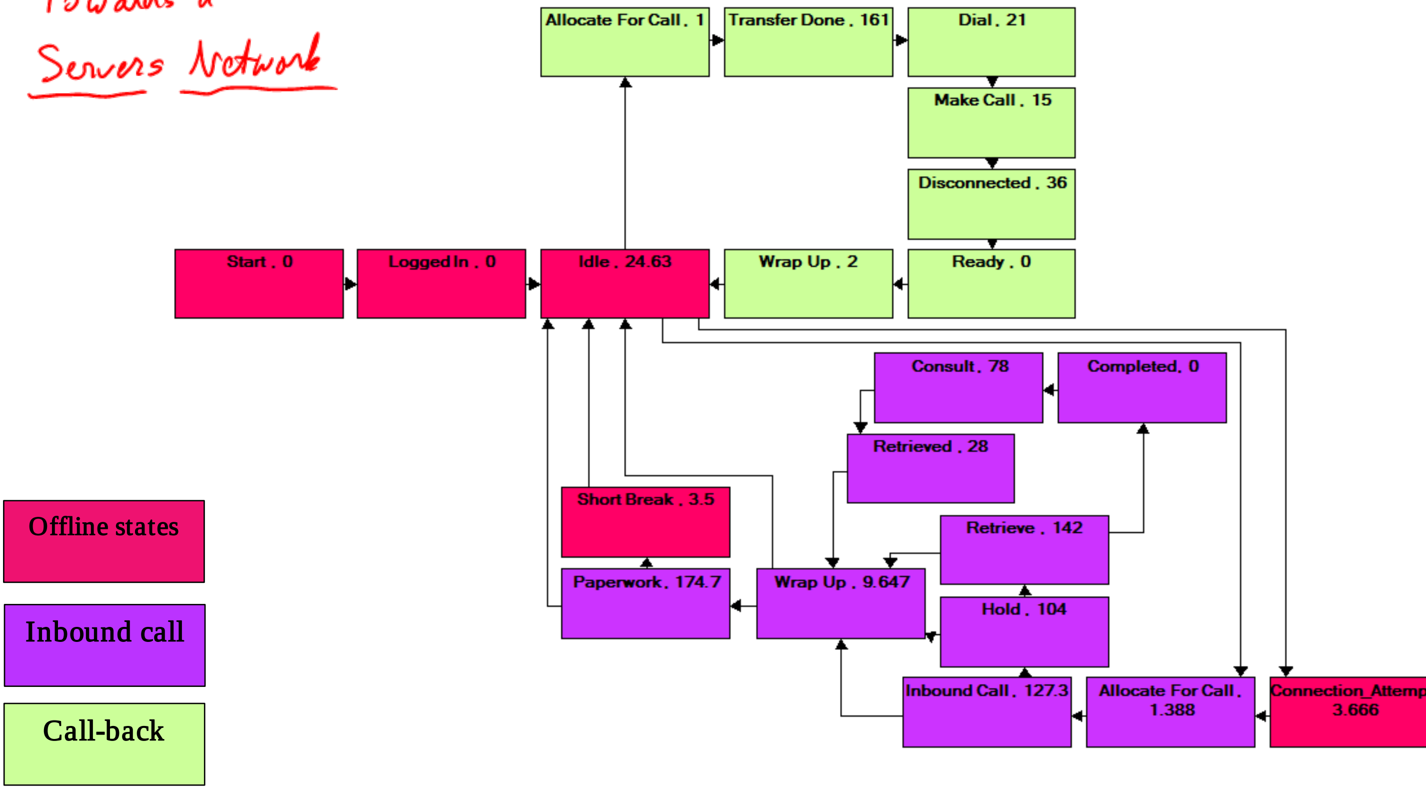



## Weakly Learning-Curves for 12 Homogeneous(?) Agents

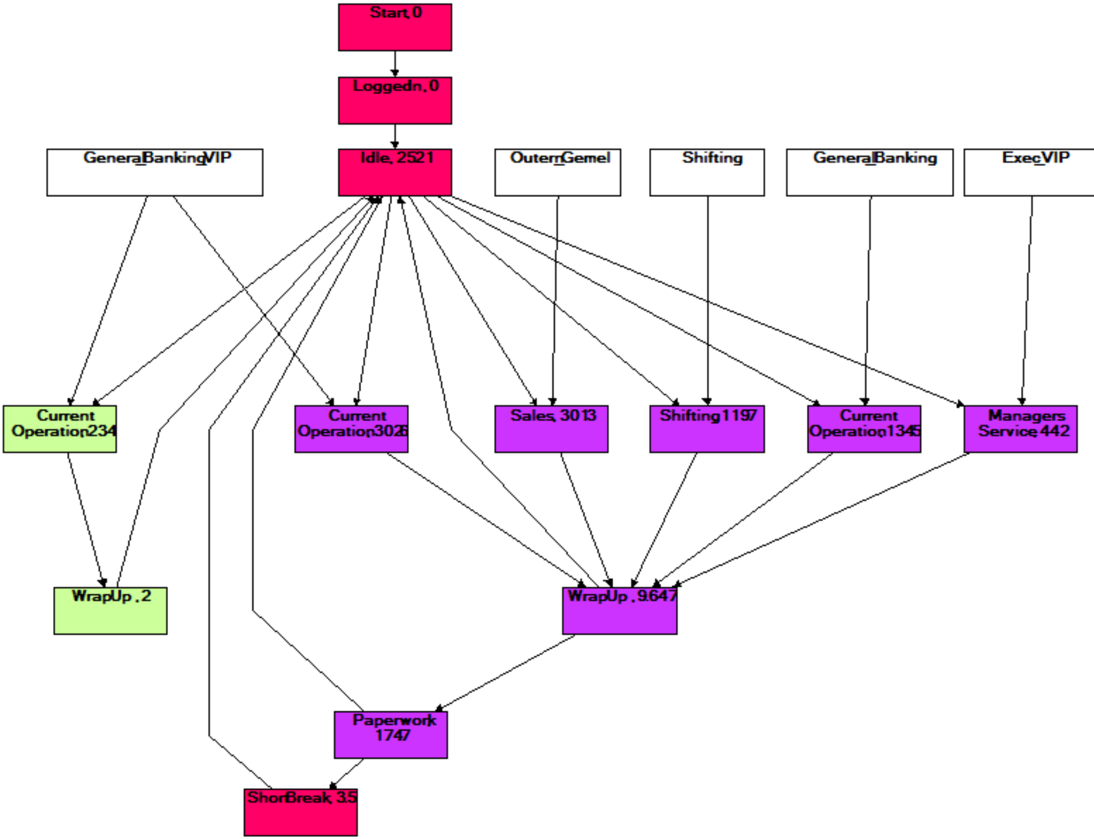


# One Agent (Number 3) – 9:00-11:00 (January 24th)

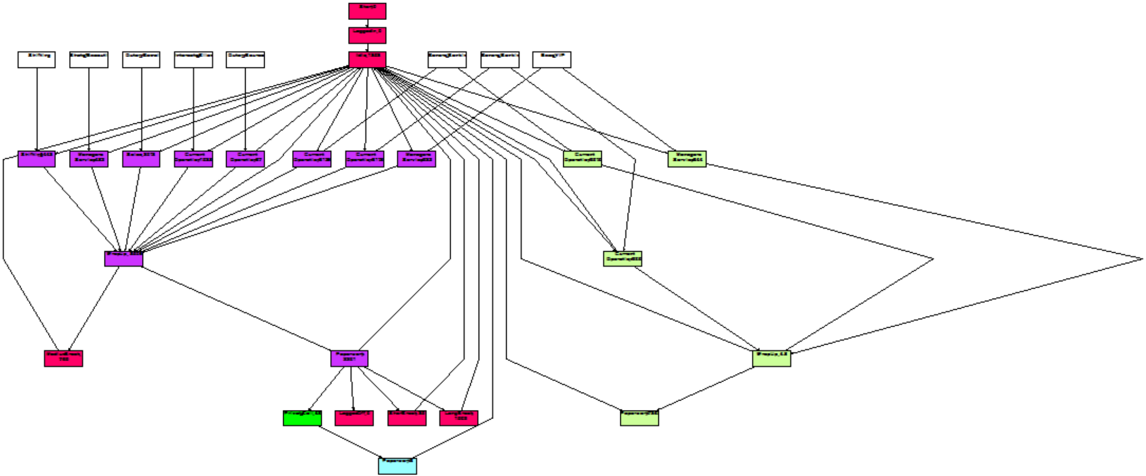
Towards a Servers Network



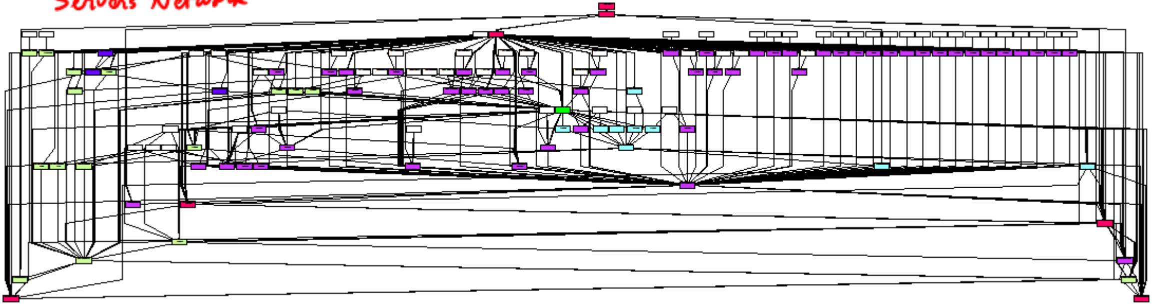
Example 1: One Agent on January 24th – 9-11



Example 2: A whole day (January 24th) of the same agent

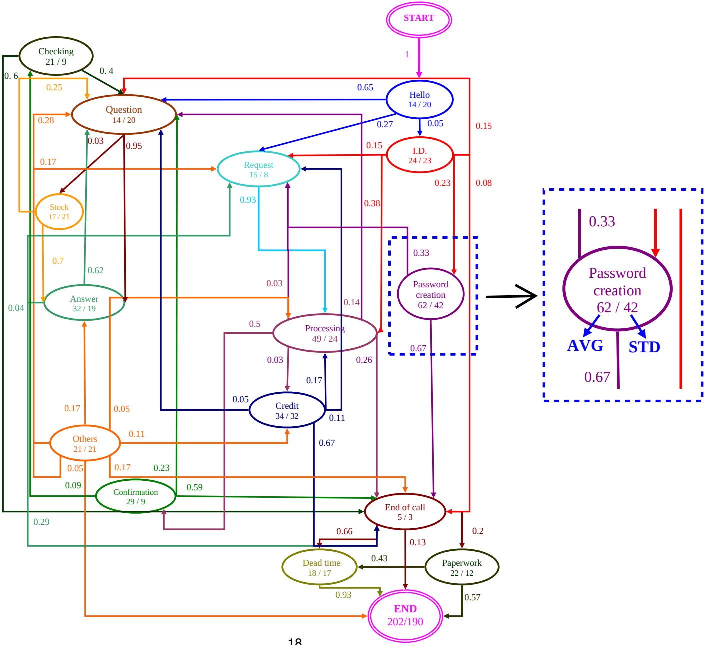


Servers Network



# (Telephone) Service-Process = “Phase-Type" Model

**Retail Service (Israeli Bank)**




**Statistics OR IE**

Table 1: *(Part of the) Asymptotic Landscape of Erlang-A = 9 Operational Regimes*

| Erlang-A | Conventional scaling | | | Many-Server scaling | | | NDS scaling | | |
|---|---|---|---|---|---|---|---|---|---|
| **$\mu$ & $\theta$ fixed**[1] | **Sub** | **Critical** | **Over** | **QD** | **QED** | **ED** | **Sub** | **Critical** | **Over** |
| **Offered load per server** | $\frac{1}{1+\delta}$ | $1-\frac{\beta}{\sqrt{n}}$ | $\frac{1}{1-\gamma}$ | $\frac{1}{1+\delta}$ | $1-\frac{\beta}{\sqrt{n}}$ | $\frac{1}{1-\gamma}$ | $\frac{1}{1+\delta}$ | $1-\frac{\beta}{n}$ | $\frac{1}{1-\gamma}$ |
| **Arrival rate $\lambda$** | $\frac{\mu}{1+\delta}$ | $\mu-\frac{\beta}{\sqrt{n}}\mu$ | $\frac{\mu}{1-\gamma}$ | $\frac{n\mu}{1+\delta}$ | $n\mu-\beta\mu\sqrt{n}$ | $\frac{n\mu}{1-\gamma}$ | $\frac{n\mu}{1+\delta}$ | $n\mu-\beta\mu$ | $\frac{n\mu}{1-\gamma}$ |
| **# servers** | $1$ | | | $n$ | | | $n$ | | |
| **Time-scale** | $n$ | | | $1$ | | | $n$ | | |
| **Impatience rate** | $\theta/n$ | | | $\theta$ | | | $\theta/n$ | | |
| **Staffing level** | $\frac{\lambda}{\mu}(1+\delta)$ | $\frac{\lambda}{\mu}(1+\frac{\beta}{\sqrt{n}})$ | $\frac{\lambda}{\mu}(1-\gamma)$ | $\frac{\lambda}{\mu}(1+\delta)$ | $\frac{\lambda}{\mu}+\beta\sqrt{\frac{\lambda}{\mu}}$ | $\frac{\lambda}{\mu}(1-\gamma)$ | $\frac{\lambda}{\mu}(1+\delta)$ | $\frac{\lambda}{\mu}+\beta$ | $\frac{\lambda}{\mu}(1-\gamma)$ |
| **Utilization** | $\frac{1}{1+\delta}$ | $1-\sqrt{\frac{\theta}{\mu}}\frac{h(\hat{\beta})}{\sqrt{n}}$ [2] | $1$ | $\frac{1}{1+\delta}$ | $1-\sqrt{\frac{\theta}{\mu}}\frac{\hat{h}(\hat{\beta})}{\sqrt{n}}$ [3] | $1$ | $\frac{1}{1+\delta}$ | $1-\sqrt{\frac{\theta}{\mu}}\frac{h(\hat{\beta})}{n}$ | $1$ |
| $\mathbb{E}(Q)$ | $\frac{1}{\delta(1+\delta)}$ | $\sqrt{n}g(\hat{\beta})$ [4] | $\frac{n\mu\gamma}{\theta(1-\gamma)}$ | $\frac{1}{\delta}\varrho_n$ [5] | $\sqrt{n}g(\hat{\beta})\alpha$ [6] | $\frac{n\mu\gamma}{\theta(1-\gamma)}$ | $o(1)$ | $ng(\hat{\beta})$ | $\frac{n^2\mu\gamma}{\theta(1-\gamma)}$ |
| $\mathbb{P}(Ab)$ | $\frac{1}{n}\frac{1}{\delta}\frac{\theta}{\mu}$ | $\frac{\theta}{\sqrt{n}\mu}g(\hat{\beta})$ | $\gamma$ | $\frac{1}{n}\frac{(1+\delta)}{\delta}\frac{\theta}{\mu}\varrho_n$ | $\frac{\theta}{\sqrt{n}\mu}g(\hat{\beta})\alpha$ | $\gamma$ | $o(\frac{1}{n^2})$ | $\frac{\theta}{n\mu}g(\hat{\beta})$ | $\gamma$ |
| $\mathbb{P}(W_q>0)$ | $\frac{1}{1+\delta}$ | $\approx 1$ | | $\varrho_n$ | $\alpha\in(0,1)$ | $\approx 1$ | $\approx 0$ | $\approx 1$ | |
| $\mathbb{P}(W_q>T)$ | $\frac{1}{1+\delta}e^{-\frac{\delta}{1+\delta}\mu T}$ | $1+O(\frac{1}{\sqrt{n}})$ | $1+O(\frac{1}{n})$ | $\approx 0$ | | $f(T)$ [7] | $\approx 0$ | $\frac{\bar{\Phi}(\hat{\beta}+\sqrt{\theta\mu}T)}{\bar{\Phi}(\hat{\beta})}$ | $1+O(\frac{1}{n})$ |
| **Congestion** $\frac{\mathbb{E}W_q}{\mathbb{E}S}$ | $\frac{1}{\delta}$ | $\sqrt{n}g(\hat{\beta})$ | $n\mu\gamma/\theta$ | $\frac{1}{n}\frac{(1+\delta)}{\delta}\varrho_n$ | $\frac{\alpha}{\sqrt{n}}g(\hat{\beta})$ | $\frac{\mu\gamma}{\theta}$ | $o(\frac{1}{n})$ | $g(\hat{\beta})$ | $n\mu\gamma/\theta$ |

[1] $\delta>0, \gamma\in(0,1)$ **and** $\beta\in(-\infty,\infty)$, $\hat{\beta}=\beta\sqrt{\frac{\mu}{\theta}}$

[2] $h(x)=\frac{\phi(x)}{\bar{\Phi}(x)}$ **is the hazard rate function of the standard normal distribution**

[3] $\hat{h}(\hat{\beta})=(1-\alpha)\hat{\beta}+\alpha h(\hat{\beta})$, [4] $g(\hat{\beta})=\sqrt{\frac{\mu}{\theta}}[h(\hat{\beta})-\hat{\beta}]$, [6] $\alpha=[1+\sqrt{\frac{\theta}{\mu}}\frac{h(\hat{\beta})}{h(-\beta)}]^{-1}$

[5] $\varrho_n=\frac{1}{\sqrt{2\pi n}}\frac{1+\delta}{\delta}(\frac{1}{1+\delta}e^{\frac{\delta}{1+\delta}})^n$, [7] $f(T)=e^{-\theta T}\times 1_{\{e^{-\theta T}>1-\gamma\}}$,

+
- ED + QED
- hazard-rate scaling
- time-varying

# The Technion SEE Center / Laboratory

**Data-Based Service Science / Engineering**

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