Empirically-Based Staffing in Call Centers

Simple Models at the Service of Complex Realities

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Joint work with Professor Avi Mandelbaum

Outline

Subject/Flow of the Talk:
Hierarchy of operational decisions in **call centers**, with emphasis on **staffing**.

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Erlang-A Model and the **QED** operational **regime** applied to call center **staffing**.

Main message II:
Empirically-Based Analysis is a Prerequisite for Research, Teaching and Practice of service operations.

Supported by:
DataMOCCA – Data MOdel for Call Center Analysis.

Call Centers Industry

U.S. Statistics

- Over 60% of annual business volume via the telephone
- 70,000 – 200,000 call centers
- 3 – 6.5 million employees (3% – 6% workforce)
- 20% annual growth rate
- $100 – $300 billion annual expenditures
- 1000's agents in a “single" call center.

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- Over 90% U.S. consumers form company image via call center experience.

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Objective:

Having the right number of appropriately skilled agents when needed.

Staffing Problem

Determination of load-dependent **number of agents**.

Prevailing method:
SIPP (Stationary Independent Period-by-Period),
a constant number of agents over each period (15, 30 or 60 min).

Agents and **customers** are assumed **homogeneous**.
In particular, every agent can potentially serve every customer.

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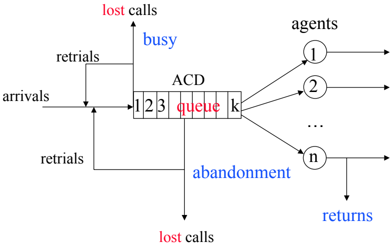
Main Approaches to Staffing

Constraint Satisfaction: find minimal number of agents n^* that satisfies some performance goal(s) (e.g. less than 3% abandonment). Prevalent in practice, Service-Level Agreements (SLA) in outsourcing.

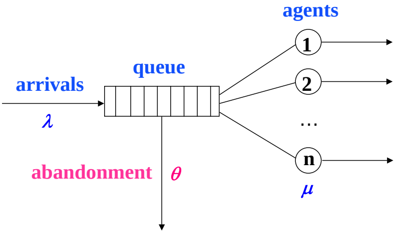
Cost/Revenue Optimization: find n^* that optimizes service revenues and costs of staffing, abandonment and waiting.

M/M/n+M (Erlang-A, Palm): Main Staffing Model

Call Center: Schematic Representation



Erlang-A Queue



Erlang-A Assumptions:

- λ – **Poisson** arrival rate
- μ – **Exponential** service rate
- n – number of service agents
- θ – **Exponential** individual abandonment rate

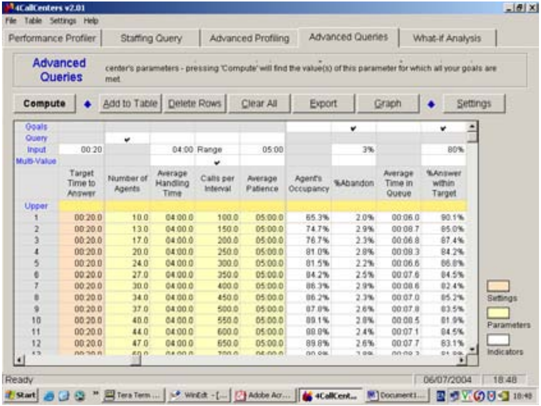
- **No busy** signals
- First Come First Served.

Erlang-A Model: Calculations

Performance measures can be calculated relatively easily.

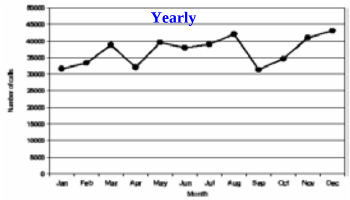
4CallCenters - A Personal Tool for Workforce Management.
Based on the M.Sc. thesis of Ofer Garnett.

http://iew3.technion.ac.il/serveng2006S/4CallCenters/Downloads.htm

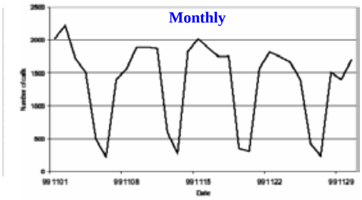


Time Scale: Arrival to a Call Center in 1999

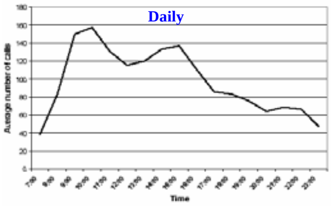
Strategic



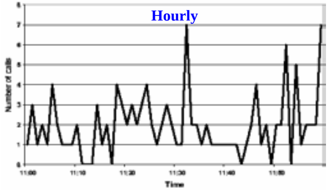
Tactical



Operational



Stochastic



Queueing Science:
Arrival to a Call Center in 1976

(E. S. Buffa, M. J. Cosgrove, and B. J. Luce, "An Integrated Work Shift Scheduling System")

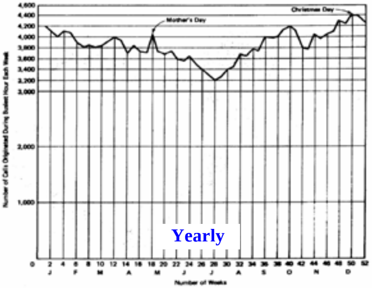


Figure 1 Typical distribution of calls during the busiest hour for each week during a year.

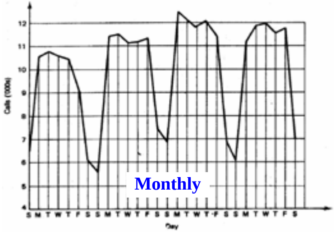


Figure 2 Daily call load for Long Beach, January 1972.

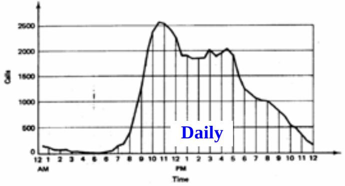


Figure 3 Typical half-hourly call distribution (Bundy D A).

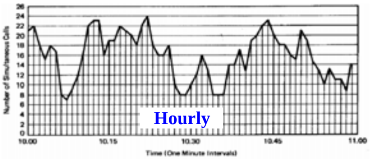
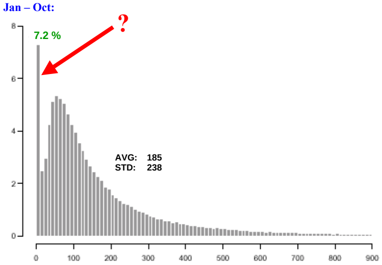


Figure 4 Typical intrahour distribution of calls, 10:00–11:00 A.M.

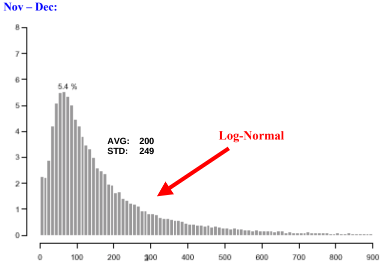
Service Times: Distribution and Psychology

Histogram of Service Times in an Israeli Call Center

January-October



November-December



- **Lognormal** service times prevalent in call centers

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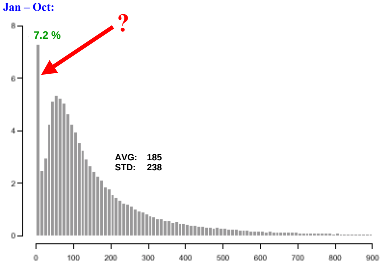

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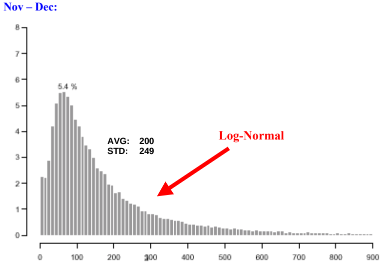

- **Lognormal** service times prevalent in call centers
- **7.2% Short-Services:** Agents' "Abandon" (improve bonus, rest)
- **Distributions**, not only Averages, must be measured.

Erlang-A: Modelling (Im)Patience

- **Patience Time:** $\tau \sim \exp(\theta)$
  Time a customer is **willing to wait** for service.
- **Offered Wait:** V
  Time a customer is **required to wait** for service.
  (= Waiting time of a customer with infinite patience.)
- If $\tau \leq V$ then customer **abandons**, else **served**.
- **Actual Wait** $W_q = \min(\tau, V)$.

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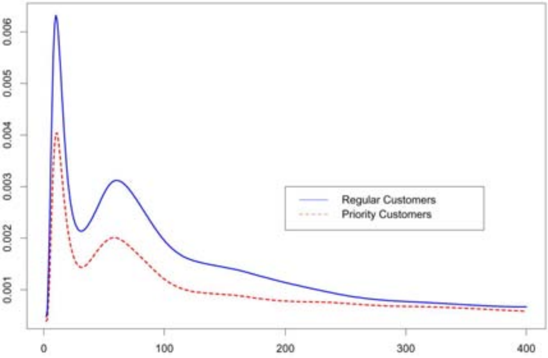
Patience data is **censored**: 2% abandoning implies 98% censored!

Measuring Patience

Hazard Rates of Patience in an Israeli Bank: Regular over VIP Customers



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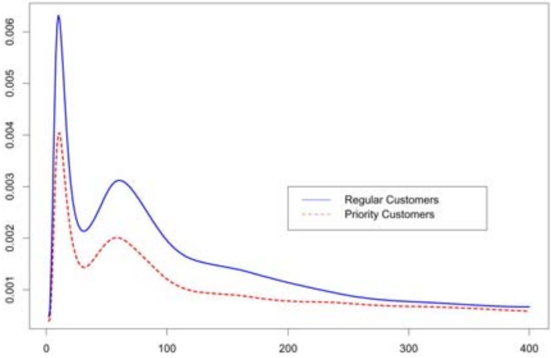
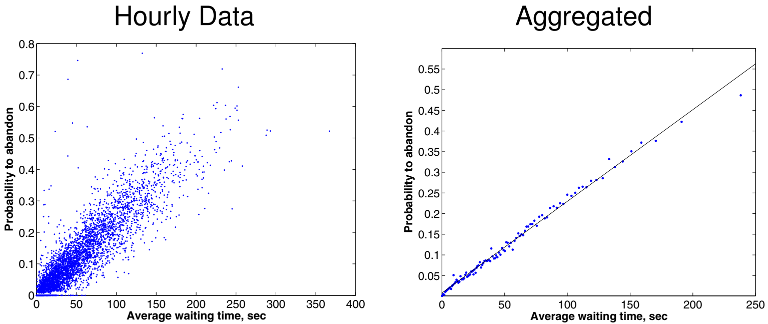


- **VIP** customers are **more patient** (needy).
- Why the peaks in abandonment? **Announcements!**
- **Call-by-call data** required to obtain this graph (+Uncensoring).

Estimating Patience: P{Ab} $\propto$ E[W_q] Relation

In queues with **exp(θ)** patience: $\text{P}\{\text{Ab}\} = \theta \cdot \text{E}[W_q]$.

Israeli Bank: Yearly Data

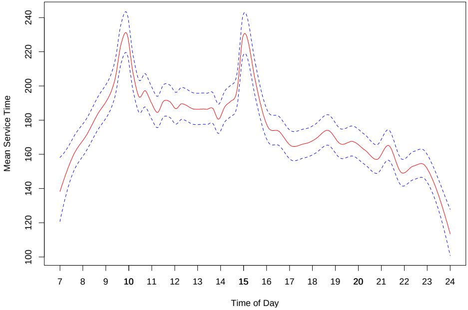


Graphs are based on 4158 hour intervals.

Estimate of mean patience: 250/0.55 $\approx$ **450 seconds**.

Building block: Interrelation

Average Service Time over the Day – Israeli Bank



Prevalent: **Longest services** at **peak-loads** (10:00, 15:00). **Why?**

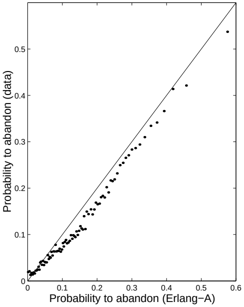
Explanations:

- Prevalent: Service protocol different (longer) at congestion
- Operational: The **needy** abandon less during peak loads; hence the **VIP** remain on line, with their **longer** service times.

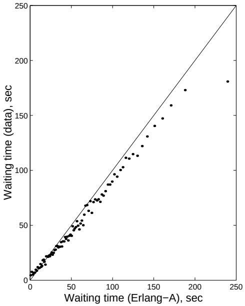
Erlang-A: Fitting a Simple Model to a Complex Reality

- Small Israeli bank (10 agents)
- Patience estimated via P{Ab} / E[W_q]
- Graphs: **hourly performance vs. Erlang-A predictions**, over 1 year, aggregating groups with 40 similar hours.

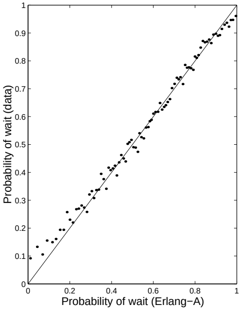
P{Ab}



E[W_q]



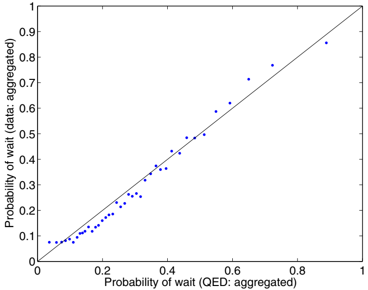
$P\{W_q > 0\}$



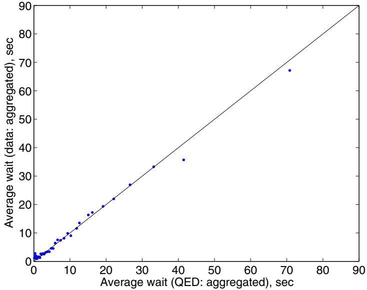
Erlang-A:
Fitting a Simple Model to a Complex Reality II

Large U.S. Bank

Retail. P$\{W_q > 0\}$



Telesales. E$[W_q]$



Partial success, in some cases Erlang-A does not work well (Networking, SBR).

Large Israeli call center – underway.

Erlang-A:
Fitting a Simple Model to a Complex Reality III

We have learned:

- Arrival process can by approximated by **Poisson**
- Service times are **not exponential** (typically close to lognormal)
- Patience times are **not exponential** (various patterns are observed).

Erlang-A: Fitting a Simple Model to a Complex Reality III

We have learned:

- Arrival process can by approximated by **Poisson**
- Service times are **not exponential** (typically close to lognormal)
- Patience times are **not exponential** (various patterns are observed).

Question: why Erlang-A works with non-exponential patience and service times?

Answer: via study of **operational regimes** in call centers.

Operational Regimes: Motivating Example

Health Insurance. ACD Report.

Time	Calls	Answered	Abandoned%	ASA	AHT	Occ%	# of agents
Total	20,577	19,860	**3.5%**	**30**	307	95.1%	
8:00	332	308	7.2%	27	302	87.1%	59.3
8:30	653	615	5.8%	58	293	96.1%	104.1
9:00	866	796	8.1%	63	308	97.1%	140.4
9:30	1,152	1,138	1.2%	28	303	90.8%	211.1
10:00	1,330	1,286	3.3%	22	307	98.4%	223.1
10:30	1,364	1,338	1.9%	33	296	99.0%	222.5
11:00	1,380	1,280	7.2%	34	306	98.2%	222.0
11:30	1,272	1,247	2.0%	44	298	94.6%	218.0
12:00	1,179	1,177	0.2%	1	306	91.6%	218.3
12:30	1,174	1,160	1.2%	10	302	95.5%	203.8
13:00	1,018	999	1.9%	9	314	95.4%	182.9
13:30	**1,061**	**961**	**9.4%**	**67**	**306**	**100.0%**	**163.4**
14:00	1,173	1,082	7.8%	78	313	99.5%	188.9
14:30	**1,212**	**1,179**	**2.7%**	**23**	**304**	**96.6%**	**206.1**
15:00	1,137	1,122	1.3%	15	320	96.9%	205.8
15:30	1,169	1,137	2.7%	17	311	97.1%	202.2
16:00	1,107	1,059	4.3%	46	315	99.2%	187.1
16:30	914	892	2.4%	22	307	95.2%	160.0
17:00	**615**	**615**	**0.0%**	**2**	**328**	**83.0%**	**135.0**
17:30	420	420	0.0%	0	328	73.8%	103.5
18:00	49	49	0.0%	14	180	84.2%	5.8

Efficiency-Driven (ED) Regime

Time	Calls	Answered	Abandoned%	ASA	AHT	Occ%	# of agents
13:30	**1,061**	**961**	**9.4%**	**67**	**306**	**100.0%**	**163.4**

- 100% occupancy
- High P{Ab}
- Considerable waiting time
- $\mathrm{P}\{W_q > 0\} \approx 1$.

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Offered load:

$$R_{ED} \triangleq \frac{\lambda}{\mu} = 1061 : \frac{1800}{306} = 180.37\,.$$

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$$n = R_{ED} \cdot (1 - \gamma)\,, \qquad \gamma > 0.$$

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Service grade

$$\gamma = 1 - \frac{n}{R_{ED}} = 1 - \frac{163.4}{180.37} = 0.094 \approx \mathrm{P}\{\mathrm{Ab}\} \,.$$

ED regime captured by **Fluid-Model**.

Quality-Driven (QD) Regime

Time	Calls	Answered	Abandoned%	ASA	AHT	Occ%	# of agents
17:00	**615**	**615**	**0.0%**	**2**	**328**	**83.0%**	**135.0**

- Occupancy far below 100%
- Negligible P{Ab}
- Very short waiting time
- $\mathbf{P\{W_q > 0\} \approx 0}$.

Offered load:

$$R_{QD} = \frac{\lambda}{\mu} = 615 : \frac{1800}{328} = 112.07\,.$$

Characterization:

$$n = R_{QD} \cdot (1 + \gamma)\,, \qquad \gamma > 0.$$

Service grade

$$\gamma = \frac{n}{R_{QD}} - 1 = \frac{135}{112.07} - 1 = 0.205\,.$$

Quality and Efficiency-Driven (QED) Regime

Time	Calls	Answered	Abandoned%	ASA	AHT	Occ%	# of agents
14:30	**1,212**	**1,179**	**2.7%**	**23**	**304**	**96.6%**	**206.1**

- High occupancy, but not 100%
- Small P{Ab} and waiting
- $\mathbf{P}\{W_q > 0\} \approx \alpha$, $0 < \alpha < 1$.

Offered load: $R_{QED} = \frac{\lambda}{\mu} = 1212 : \frac{1800}{304} = 204.69\,.$

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Service grade

$$\beta = \frac{n - R_{QED}}{\sqrt{R_{QED}}} = \frac{206.1 - 204.69}{\sqrt{204.69}} = 0.10\,.$$

Square-Root Staffing Rule: Described by Erlang in 1924!

Awaited the seminal formulation of **Halfin-Whitt** in 1981.

Operational Regimes: Performance.

Assume that **offered load** R is not small ($\lambda \to \infty$).

ED regime: $n \approx R - \delta R$, $0.1 \leq \delta \leq 0.25$.

- Essentially **all** customers are delayed
- %Abandoned $\approx \delta$ (10-25%)
- Average wait $\approx$ 30 seconds - 2 minutes.

QD regime: $n \approx R + \gamma R$, $0.1 \leq \gamma \leq 0.25$.
Essentially **no** delays.

QED regime: $n \approx R + \beta\sqrt{R}$, $-1 \leq \beta \leq 1$.

- %Delayed between 25% and 75%
- %Abandoned is 1-5%
- Average wait is one-order less than average service time (seconds vs. minutes).

Erlang-A Queue: QED Approximations

Assume that **offered load** R is not small ($\lambda \to \infty$).

Let $\hat{\beta} = \beta\sqrt{\frac{\mu}{\theta}}$, $h(\cdot) = \frac{\phi(\cdot)}{1-\Phi(\cdot)}$ = hazard rate of $\mathcal{N}(0,1)$.

- **Delay probability:**

$$\mathrm{P}\{W_q > 0\} \sim \left[1 + \sqrt{\frac{\theta}{\mu}} \cdot \frac{h(\hat{\beta})}{h(-\beta)}\right]^{-1},$$

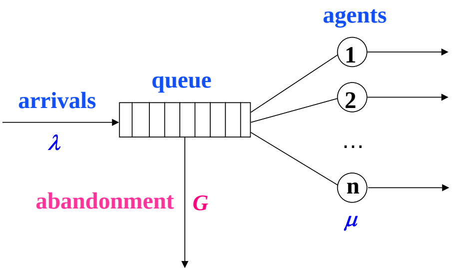
- **Probability to abandon:**

$$\mathrm{P}\{\mathrm{Ab}|W_q > 0\} = \frac{1}{\sqrt{n}} \cdot \sqrt{\frac{\theta}{\mu}} \cdot \left[h(\hat{\beta}) - \hat{\beta}\right] + o\left(\frac{1}{\sqrt{n}}\right).$$

- **Linear relation between P{Ab} and E[W_q]:**

$$\frac{\mathrm{P}\{\mathrm{Ab}\}}{\mathrm{E}[W_q]} = \theta.$$

Generally Distributed Patience: M/M/n+G Model



Back to puzzle of "**Why Erlang-A works?**"
Assume patience times are **generally distributed**.

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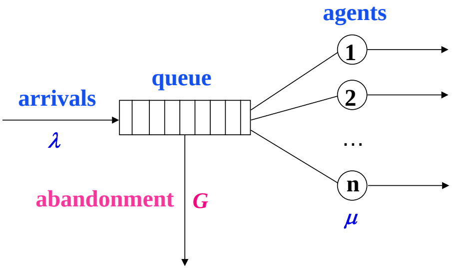

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Assume patience times are **generally distributed**.

Density of patience time: $g = \{g(x), x \geq 0\}$, where $g(0) \triangleq g_0 > 0$.

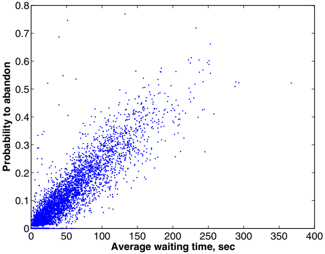
QED regime: $n \approx R + \beta\sqrt{R}$.

QED approximations: use Erlang-A, with g_0 replacing θ.

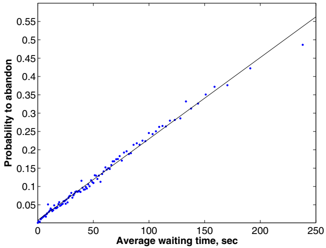
Generally Distributed Patience: Fitting Erlang-A

Israeli Bank: Yearly Data

Hourly Data



Aggregated



Theory

Erlang-A: $P\{Ab\} = \theta \cdot E[W_q]$.

M/M/*n*+G: $P\{Ab\} \approx g_0 \cdot E[W_q]$.

Generally Distributed Patience: Fitting Erlang-A

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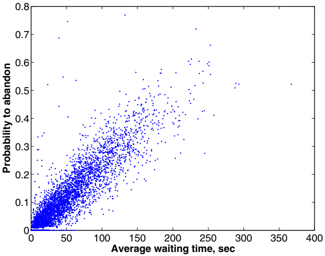

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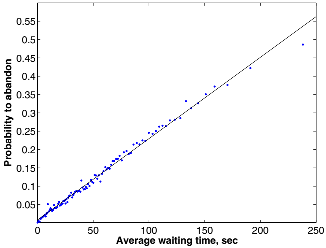

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Recipe:

In both cases, use Erlang-A, with $\hat{\theta} = \widehat{\mathrm{P}\{\mathrm{Ab}\}} / \widehat{\mathrm{E}[W_q]}$ (slope above).

Generally Distributed Service Times

Established: M/M/n+M $\approx$ M/M/n+G ($\theta = g_0$).

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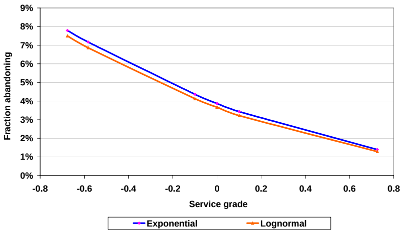
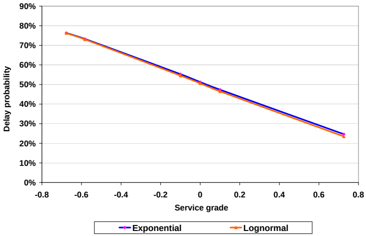
Numerical Experiments: Whitt (2004), Rosenshmidt (2006) demonstrate a **good fit** for typical call-center parameters.

Lognormal (CV=1) vs. Exponential Service Times, QED regime; 100 agents, mean patience = mean service

Fraction Abandoning



Delay Probability



Simple Model for Complex Realities: More on Applications of the QED Regime

- **Simple performance approximations** that are **robust** also in the ED and QD regimes: Mandelbaum, Zeltyn.
- Optimal staffing for **cost/revenue optimization problems** (staffing, abandonment and waiting costs): Borst, Mandelbaum, Reiman, Zeltyn.
- **General service times**: Puhalskii, Reiman; Jelencović, Mandelbaum, Momčilović.
- Generalizations to **time-varying queues**: Jennings, Feldman, Mandelbaum, Massey, Whitt.
- Generalizations to system with non-homogeneous customers and/or servers (**Skills-Based Routing**): Armony, Gurvich, Mandelbaum; Atar, Shaikhet.
- **Load-balancing**: Dai, Tezcan.

The QED Regime and Stochastic-Ignorant Staffing: The Right Answer for the Wrong Reasons

If $\beta = 0$, QED staffing prescribes:

$$n = R \,,$$

R = offered load (minutes of work that arrive per minute).

In word: **Assign number of agents that equals offered load**, which is common practice.

No abandonment: queue “explodes".

With abandonment, $n = 400$, reasonable (im)patience:

- %Delayed $\approx$ 50%
- %Abandoned $\approx$ 2%
- $\mathrm{E}[W_q] \approx 2\% \cdot \mathrm{E}[S]$, few seconds.

Very good service level.

Call Centers: Hierarchical Operational View

Forecasting Customers (Statistics), Agents (HRM)

Staffing: **Queueing Theory** (Erlang-A based)

Service Level, Costs

FTE's (Seats)
per unit of time

Shifts: IP, Combinatorial Optimization; LP

Union constraints, Costs

Shift structure

Rostering: Heuristics, AI (Complex)

Individual constraints

Agents Assignments

Skills-based Routing: Stochastic Control (of Q's)

DataMOCCA = Data MOdel for Call Center Analysis

Project Goal: Designing and Implementing a (universal) data-base/data-repository and interface for storing, retrieving, analyzing and displaying **Call-by-Call-Data**.

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System Components:

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- Friendly yet powerful **Online Interface**: enables convenient fast access to (mostly) operational and (some) administrative data (but no marketing/business data).

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Current Databases:

- Medium-sized U.S. Bank (**2.5 years; 220M calls, 40M via agents; 800 agents at peaks**) – Completed.
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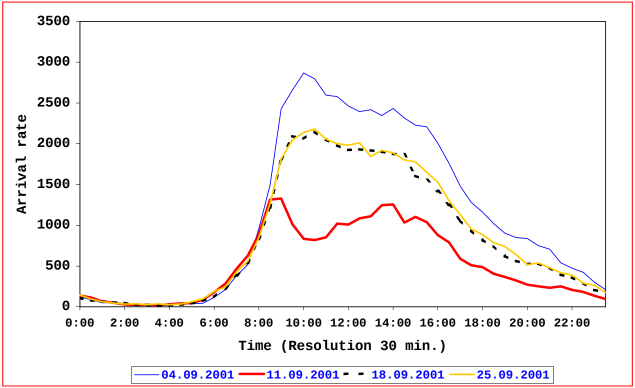
DataMOCCA will now be used to illustrate the hierarchy of operational decisions, from forecasting to SBR.

Arrivals to Service: Predictable vs. Random

Arrival Rates on Tuesdays in a September – U.S. Bank



- **Tuesday**, September 4th: **Heavy**, following Labor Day
- **Tuesdays**, September 18 & 25: **Normal**

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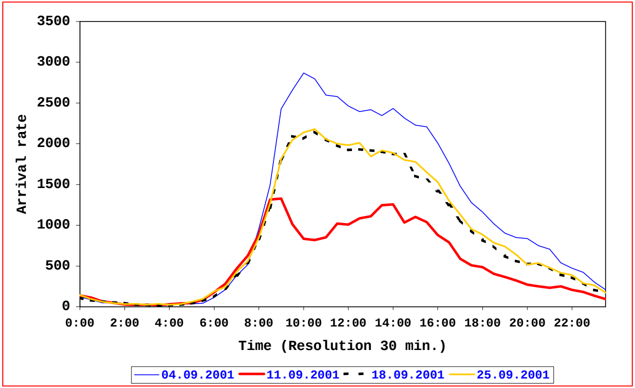

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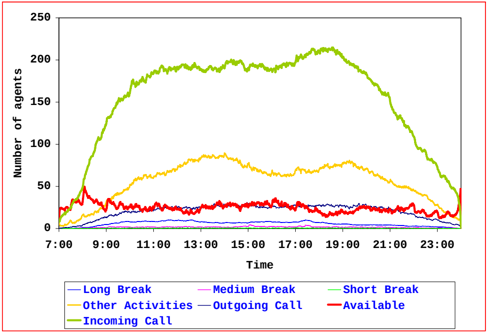
- **Tuesdays**, September 18 & 25: **Normal**
- **Tuesday, September 11th, 2001.**

Agent Status

Erlang-A Model ⇒ optimal **Staffing Level** n.

n = overall number-of-agents that come to work? **No!**

Israeli Bank, Agent Status: Monthly Averages



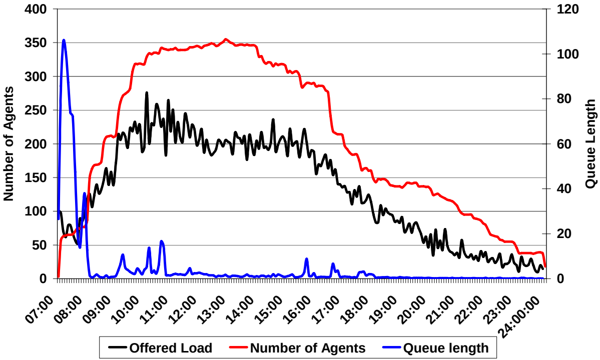
Staffing Level (FTE) = Busy with “Incoming Calls" + “Available" for service.

Shifts Scheduling

Integer Programming given interval-based Staffing Levels.

Example of a shift scheduling problem:
should we bring agents early, given a predictable arrival peak?

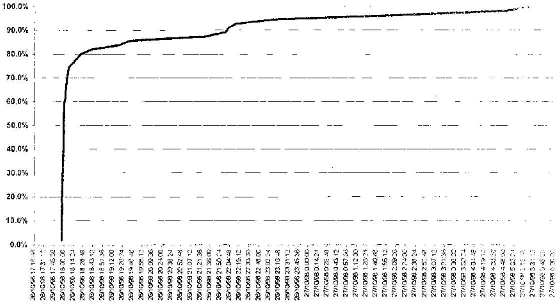
U.S. Bank: Queue-length and Staffing on May 3, 2002



Rostering

Assigning **individual agents** to **schedules**.
Typically, heuristics used to accommodate individual constraints.

Israeli Technical Support Call Center: Online Shift Bidding

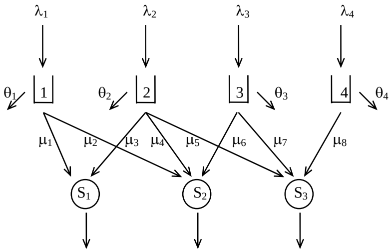


Shift-bidding starts at 18:00.

- 60% of agents are registered till **18:00**
- 80% till 18:24; 90% till 22:00; registration closed at 5:23am.

Introduction to Skills Based Routing

General Setup



Major Control Decisions

- **Customer Routing:** If an agent turns idle and there are queued customers, which customer (if any) should be routed to this agent.
- **Agent Scheduling:** If a customer arrives and there are idle agents, which agent (if any) should serve this customer.
- **Load Balancing:** Routing of customers to distributed call centers (eg. nation-wide).

Customers Relationship/Revenue Management (CRM)

NationsBank CRM relationship groups:

- RG1: high-value customers
- RG2: marginally profitable customers (with potential)
- RG3: unprofitable customer.

NationsBank's Design of the Service Encounter

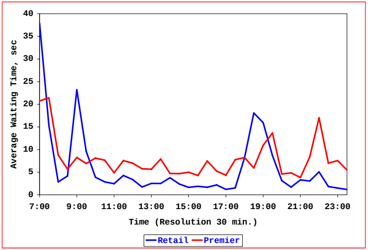
Examples of Specifications: Assignable Grade Of Service

	RG1	RG2	RG3
VRU Target	70% of calls	85% of calls	90% of calls
Abandonment rate	< 1%	< 5%	< 9%
Speed of Answer	100% in 2 rings	80% in 20 seconds	50% in 20 seconds
Average Talk Time	no limit	4 min. average	2 min. average
Rep. Training	universal	product experts	basic product
Rep. Personalization	request rep / callback	FCFS	FCFS
Trans. Confirmation	call / fax	call / mail	mail
Problem Resolution	during call	within 2 business days	within 8 business days

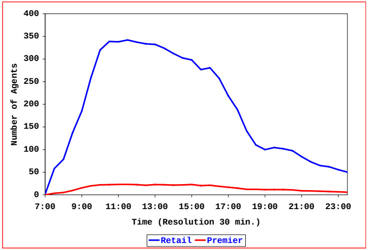
Priorities and Economies-of-Scale

U.S. Bank. Regular vs. VIP Customers. December 2002

Average Wait



Staffing Level



Premier customers do not get a better service level.

Number of agents assigned to Premier is small and they do not get enough help from regular agents.

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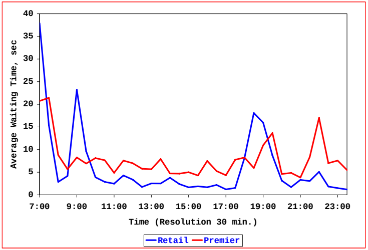
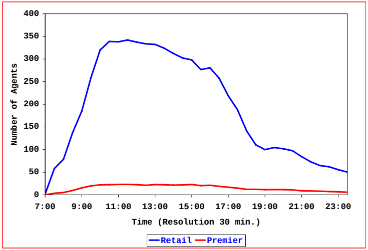


Staffing Level



Premier customers do not get a better service level.

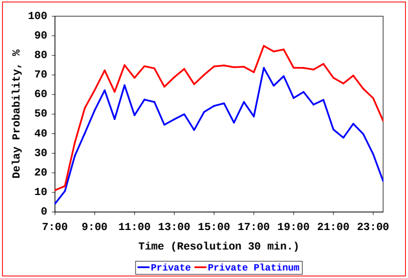
Number of agents assigned to Premier is small and they do not get enough help from regular agents.

Challenge: enable **better service level** for Premier and still serve most of them by a **small dedicated group of agents**.

Priorities and Routing Protocols I

Israeli Bank. Regular vs. VIP Customers. October 2004

Delay Probability



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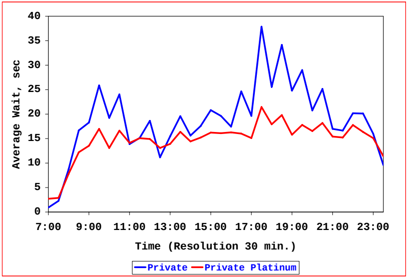
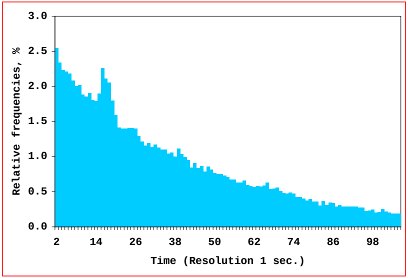


More **Platinum** customers have to wait, **but** their average wait is shorter. **How to explain?**

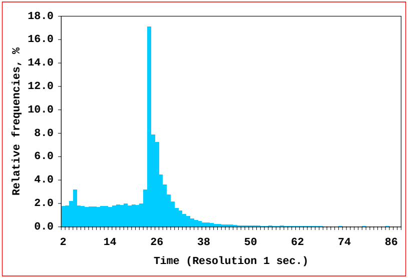
Priorities and Routing Protocols II

Histograms of Waiting Times. October 2004

Private



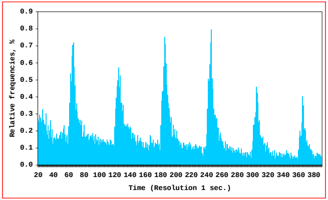
Private Platinum



After **25 seconds** of wait, Platinum are routed to Regular agents getting **high priority**. Hence, almost **no long waiting times** for Platinum.

Dynamic Priority-Upgrade

Large Israeli Bank: Histogram of Waiting Times



Peaks every 60 seconds. Why?

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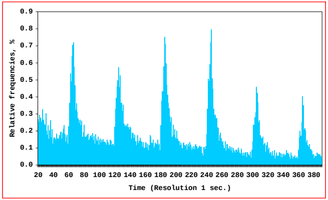

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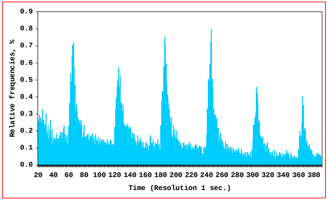

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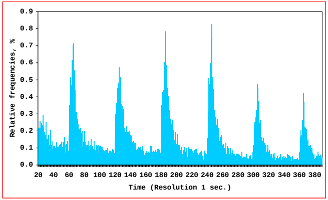
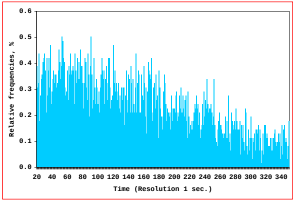
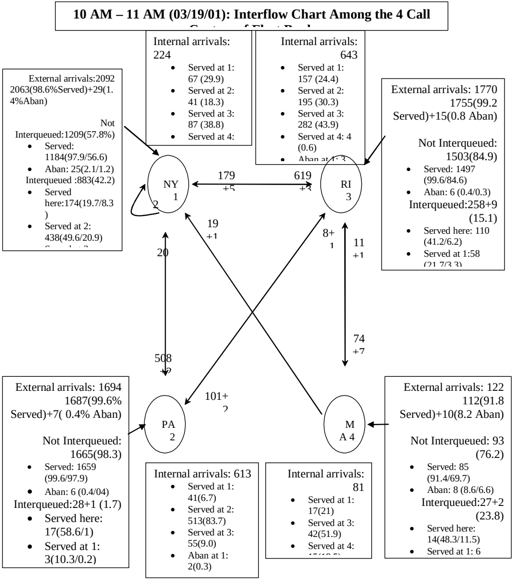
Served Customers



Abandoning Customers



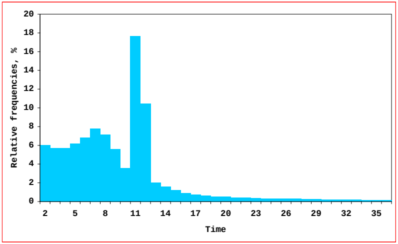
Network Balancing via Interqueue in a U.S. Bank



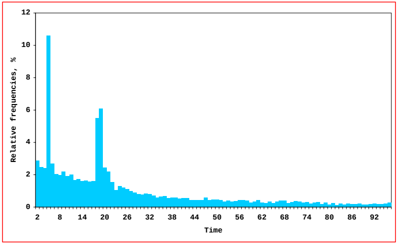
Network Balancing Protocols and Performance Level

U.S. Bank: Histograms of Waiting Times

Retail



Business



Why do we observe a peak for **Retail** service (**10 seconds**)?
After 10 seconds of wait **Retail** customers were sent into the **interqueue**.

Business customers – peak at **5 seconds**, for the same reason.
Second peak – unclear, maybe priority-upgrade.

Main Research and Practical Challenges

- **Skills-Based Routing:** Convergence of Practice and Theory
- **Uncertainty:** in Reality, Model Parameters, Forecasting
- **Time-Varying Queues:** Time-Stable Performance
- **General Service-Times:** Theory
- **Economic Models:** Operations (Dimensioning), Marketing
- **Human Dimensions:**
  Measure, Model, Experiment, Validate, Refine, etc.

All of the above in a **Network** of distributed call centers.

See our **Service Engineering** site for downloads:
http://iew3.technion.ac.il/serveng