Service Engineering & Science:
Data-Based Research, Teaching, Practice

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Wharton Empirical OM, September 2006

Main Messages

1. Simple Models at the Service of **Complex Realities**.

Supported by a Panorama of Empirical and Theoretical Models.

2. Data-Based Analysis is a Must & Fun (after tenure?).

Supported by **DataMOCCA** = Data **MO**dels for **C**all **C**enter **A**nalysis, initiated at **Wharton**, currently developed at **Technion** and available for adoption.

3. Back to the Basic-Research Paradigm (Physics, Biology, . . .): **Measure, Model, Experiment, Validate, Refine, etc.**

4. Ancestors & **Practitioners** **often** knew/apply the **"right answer"**: simply did/do not have our tools/desire/need to prove it so.

Supported by Erlang (1915), Palm (1945),..., seasoned & thoughtful managers.

Background Material (Downloadable)

- Technion's "**Service-Engineering" Course** ($\geq$ 1995): http://ie.technion.ac.il/serveng
- Gans (U.S.A.), Koole (Europe), and M. (Israel): "Telephone Call Centers: Tutorial, Review and Research Prospects." MSOM, 2003.
- Brown, Gans, M., Sakov, Shen, Zeltyn, Zhao: "Statistical Analysis of a Telephone Call Center: A Queueing-Science Perspective." JASA, 2005.
- Trofimov, Feigin, M., Ishay, Nadjharov: "DataMOCCA: Models for Call/Contact Center Analysis." Technion Report, 2004-2006.
- M. "Call Centers: Research Bibliography with Abstracts." Version 7, December 2006.

Present Focus: Call Centers, but Expanding

Call Centers: Business-Frontiers & Sweat-Shops of 21^{st} Century

U.S. Statistics (Relevant Elsewhere)

- 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.

Expanding, eg. **Healthcare**:

- **Similar** Challenges: Scarce transactional data, natural queueing-network view, human-operations interface (**7% LWBS**), nurse-staffing (several millions), ...
- **Unique** Challenges: More risk, less scale-economies, more synchronization gaps, ...

The First Prerequisite: Data & Measurements

Empirical “Axiom": The data one needs is never there for one to use – always problems with historical data.

Data at the level of **Individual-Transactions**: Time-Stamps of Events

Current Databases: Operations (vs. Marketing, Surveys, . . .)

- Face-to-Face data (bank - bar-code readers): **Recitations**
- Telephone data (small cc - 350K calls/year): **Homework**
- DataMOCCA (large cc’s - 350K call/week): **Research**

Future Research: - experience anyone?

- Healthcare (via RFID)
- Multimedia: Telephone + email + Internet (log-files)
- Field-Support
- Operation + Marketing (ACD + CRM)

Measurements: Face-to-Face Services

23 Bar-Code Readers at a Bank Branch

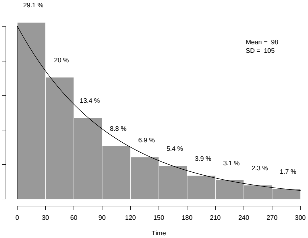
Bank – 2nd Floor Measurements

Measurements: Telephone Call-by-Call Data (Log-File)

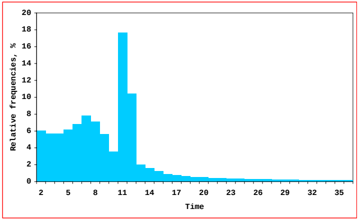
vru+line	call_id	customer_id	priority	type	date	vru_entry	vru_exit	vru_time	q_start	q_exit	q_time	outcome	ser_start	ser_exit	ser_time	server
AA0101	44749	27644400	2	PS	990901	11:45:33	11:45:39	6	11:45:39	11:46:58	79	AGENT	11:46:57	11:51:00	243	DORIT
AA0101	44750	12887816	1	PS	990905	14:49:00	14:49:06	6	14:49:06	14:53:00	234	AGENT	14:52:59	14:54:29	90	ROTH
AA0101	44967	58660291	2	PS	990905	14:58:42	14:58:48	6	14:58:48	15:02:31	223	AGENT	15:02:31	15:04:10	99	ROTH
AA0101	44968	0	0	NW	990905	15:10:17	15:10:26	9	15:10:26	15:13:19	173	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44969	63193346	2	PS	990905	15:22:07	15:22:13	6	15:22:13	15:23:21	68	AGENT	15:23:20	15:25:25	125	STEREN
AA0101	44970	0	0	NW	990905	15:31:33	15:31:47	14	00:00:00	00:00:00	0	AGENT	15:31:45	15:34:16	151	STEREN
AA0101	44971	41630443	2	PS	990905	15:37:29	15:37:34	5	15:37:34	15:38:20	46	AGENT	15:38:18	15:40:56	158	TOVA
AA0101	44972	64185333	2	PS	990905	15:44:32	15:44:37	5	15:44:37	15:47:57	200	AGENT	15:47:56	15:49:02	66	TOVA
AA0101	44973	3.06E+08	1	PS	990905	15:53:05	15:53:11	6	15:53:11	15:56:39	208	AGENT	15:56:38	15:56:47	9	MORIAH
AA0101	44974	74780917	2	NE	990905	15:59:34	15:59:40	6	15:59:40	16:02:33	173	AGENT	16:02:33	16:26:04	1411	ELI
AA0101	44975	55920755	2	PS	990905	16:07:46	16:07:51	5	16:07:51	16:08:01	10	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44976	0	0	NW	990905	16:11:38	16:11:48	10	16:11:48	16:11:50	2	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44977	33689787	2	PS	990905	16:14:27	16:14:33	6	16:14:33	16:14:54	21	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44978	23817067	2	PS	990905	16:19:11	16:19:17	6	16:19:17	16:19:39	22	AGENT	16:19:38	16:21:57	139	TOVA
AA0101	44764	0	0	PS	990901	15:03:26	15:03:36	10	00:00:00	00:00:00	0	AGENT	15:03:35	15:06:36	181	ZOHARI
AA0101	44765	25219700	2	PS	990901	15:14:46	15:14:51	5	15:14:51	15:15:10	19	AGENT	15:15:09	15:17:00	111	SHARON
AA0101	44766	0	0	PS	990901	15:25:48	15:26:00	12	00:00:00	00:00:00	0	AGENT	15:25:59	15:28:15	136	ANAT
AA0101	44767	58859752	2	PS	990901	15:34:57	15:35:03	6	15:35:03	15:35:14	11	AGENT	15:35:13	15:35:15	2	MORIAH
AA0101	44768	0	0	PS	990901	15:46:30	15:46:39	9	00:00:00	00:00:00	0	AGENT	15:46:38	15:51:51	313	ANAT
AA0101	44769	78191137	2	PS	990901	15:56:03	15:56:09	6	15:56:09	15:56:28	19	AGENT	15:56:28	15:59:02	154	MORIAH
AA0101	44770	0	0	PS	990901	16:14:31	16:14:46	15	00:00:00	00:00:00	0	AGENT	16:14:44	16:16:02	78	BENSION
AA0101	44771	0	0	PS	990901	16:38:59	16:39:12	13	00:00:00	00:00:00	0	AGENT	16:39:11	16:43:35	264	VICKY
AA0101	44772	0	0	PS	990901	16:51:40	16:51:50	10	00:00:00	00:00:00	0	AGENT	16:51:49	16:53:52	123	ANAT
AA0101	44773	0	0	PS	990901	17:02:19	17:02:28	9	00:00:00	00:00:00	0	AGENT	17:02:28	17:07:42	314	VICKY
AA0101	44774	32387482	1	PS	990901	17:18:18	17:18:24	6	17:18:24	17:19:01	37	AGENT	17:19:00	17:19:35	35	VICKY
AA0101	44775	0	0	PS	990901	17:38:53	17:39:05	12	00:00:00	00:00:00	0	AGENT	17:39:04	17:40:43	99	TOVA
AA0101	44776	0	0	PS	990901	17:52:59	17:53:09	10	00:00:00	00:00:00	0	AGENT	17:53:08	17:53:09	1	NO_SERVER
AA0101	44777	37635950	2	PS	990901	18:15:47	18:15:52	5	18:15:52	18:16:57	65	AGENT	18:16:56	18:18:48	112	ANAT
AA0101	44778	0	0	NE	990901	18:30:43	18:30:52	9	00:00:00	00:00:00	0	AGENT	18:30:51	18:30:54	3	MORIAH
AA0101	44779	0	0	PS	990901	18:51:47	18:52:02	15	00:00:00	00:00:00	0	AGENT	18:52:02	18:55:30	208	TOVA
AA0101	44780	0	0	PS	990901	19:19:04	19:19:17	13	00:00:00	00:00:00	0	AGENT	19:19:15	19:20:20	65	MEIR
AA0101	44781	0	0	PS	990901	19:39:19	19:39:30	11	00:00:00	00:00:00	0	AGENT	19:39:29	19:41:42	133	BENSION
AA0101	44782	0	0	NW	990901	20:08:13	20:08:25	12	00:00:00	00:00:00	0	AGENT	20:08:28	20:08:41	13	NO_SERVER
AA0101	44783	0	0	PS	990901	20:23:51	20:24:05	14	00:00:00	00:00:00	0	AGENT	20:24:04	20:24:33	29	BENSION
AA0101	44784	0	0	NW	990901	20:36:54	20:37:14	20	00:00:00	00:00:00	0	AGENT	20:37:13	20:38:07	54	BENSION
AA0101	44785	0	0	PS	990901	20:50:07	20:50:16	9	00:00:00	00:00:00	0	AGENT	20:50:15	20:51:32	77	BENSION
AA0101	44786	0	0	PS	990901	21:04:41	21:04:51	10	00:00:00	00:00:00	0	AGENT	21:04:50	21:05:59	69	TOVA
AA0101	44787	0	0	PS	990901	21:25:00	21:25:13	13	00:00:00	00:00:00	0	AGENT	21:25:13	21:28:03	170	AVI
AA0101	44788	0	0	PS	990901	21:50:40	21:50:54	14	00:00:00	00:00:00	0	AGENT	21:50:54	21:51:55	61	AVI
AA0101	44789	9103060	2	NE	990901	22:05:40	22:05:46	6	22:05:46	22:09:52	246	AGENT	22:09:51	22:13:41	230	AVI
AA0101	44790	14558621	2	PS	990901	22:24:11	22:24:17	6	22:24:17	22:26:16	119	AGENT	22:26:15	22:27:28	73	VICKY
AA0101	44791	0	0	PS	990901	22:46:27	22:46:37	10	00:00:00	00:00:00	0	AGENT	22:46:36	22:47:03	27	AVI
AA0101	44792	67158097	2	PS	990901	23:05:07	23:05:13	6	23:05:13	23:05:30	17	AGENT	23:05:29	23:06:49	80	VICKY
AA0101	44793	15317126	2	PS	990901	23:28:52	23:28:58	6	23:28:58	23:30:08	70	AGENT	23:30:07	23:35:03	296	DARMON
AA0101	44794	0	0	PS	990902	00:10:47	00:12:05	78	00:00:00	00:00:00	0	HANG	00:00:00	00:00:00	0	NO_SERVER
AA0101	44795	0	0	PS	990902	07:16:52	07:17:01	9	00:00:00	00:00:00	0	AGENT	07:17:01	07:17:44	43	ANAT
AA0101	44796	0	0	PS	990902	07:50:05	07:50:16	11	00:00:00	00:00:00	0	AGENT	07:50:16	07:53:03	167	STEREN

Beyond Averages: Waiting Times in a Call Center

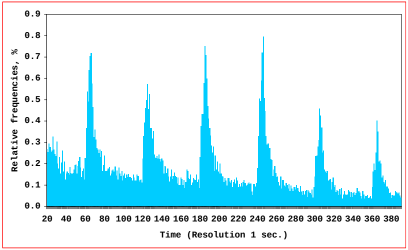
Small Israeli Bank



Large U.S. Bank

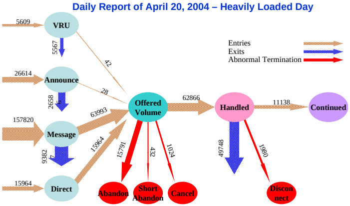


Medium Israeli Bank

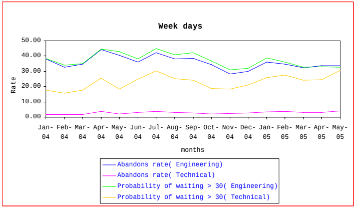


DataMOCCA = MOdels for Call Center Analysis

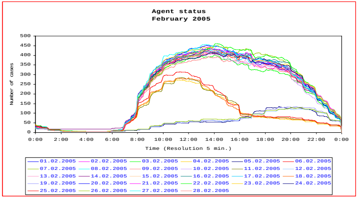
Daily Report



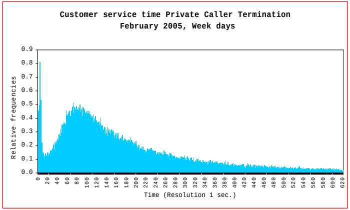
Time Series



Cross Tabulation



Histogram



The Second Prerequisite: (Operational) Models

Through **Examples** Only.

Each example starts with a **Complex Reality** and ends with a **useful** insight due to a **Simple Model**.

"**Theorem"**: A useful model must be simple (yet not too simple).

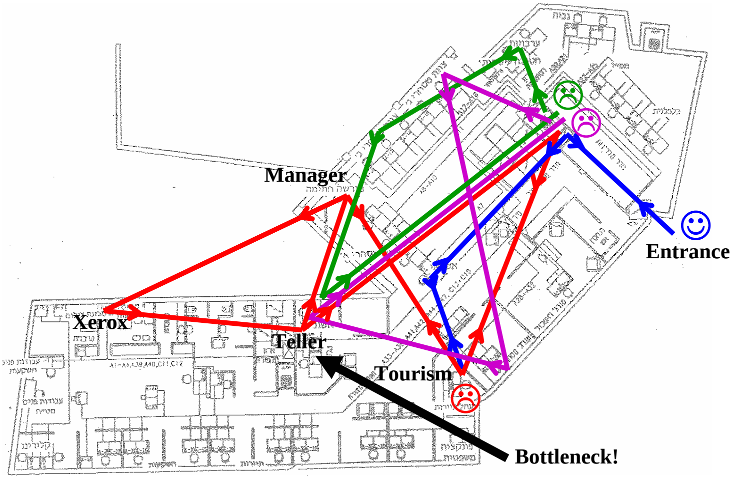
Models in decreasing simplicity-levels:

- **Conceptual**: Service Networks = **Queueing Networks**
- **Descriptive**: Averages, Histograms
- **Explanatory**: Comparative, Regression
- **Analytical/Mathematical**: Little's Law, Fluid Models, Queueing Models, Diffusion Approximations.

"Corollary": To be useful, a simple model sometimes requires deep analysis.

Conceptual Model: Face-to-Face Services

Bank Branch = Queueing Network



Descriptive Model: Transition Probabilities (Averages)

Transition Frequencies Between Units in The Private and Business Sections:

		Private Banking				Business				
	To Unit / From Unit	Bankers	Authorized Personal	Compens - - ations	Tellers	Tellers	Overdrafts	Authorized Personal	Full Service	Exit
Private Banking	Bankers		1%	1%	4%	4%	0%	0%	0%	90%
	Authorized Personal	12%		5%	4%	6%	0%	0%	0%	73%
	Compensations	7%	4%		18%	6%	0%	0%	1%	64%
	Tellers	6%	0%	1%		1%	0%	0%	0%	90%
Services	Tellers	1%	0%	0%	0%		1%	0%	2%	94%
	Overdrafts	2%	0%	1%	1%	19%		5%	8%	64%
	Authorized Personal	2%	1%	0%	1%	11%	5%		11%	69%
	Full Service	1%	0%	0%	0%	8%	1%	2%		88%
	Entrance	13%	0%	3%	10%	58%	2%	0%	14%	0%

Legend:

0%-5%	5%-10%	10%-15%	>15%

Dominant Paths - Business:

Unit / Parameter	Station 1 Tourism	Station 2 Teller	Total Dominant Path
Service Time	12.7	4.8	17.5
Waiting Time	8.2	6.9	15.1
Total Time	20.9	11.7	32.6
Service Index	**0.61**	**0.41**	**0.53**

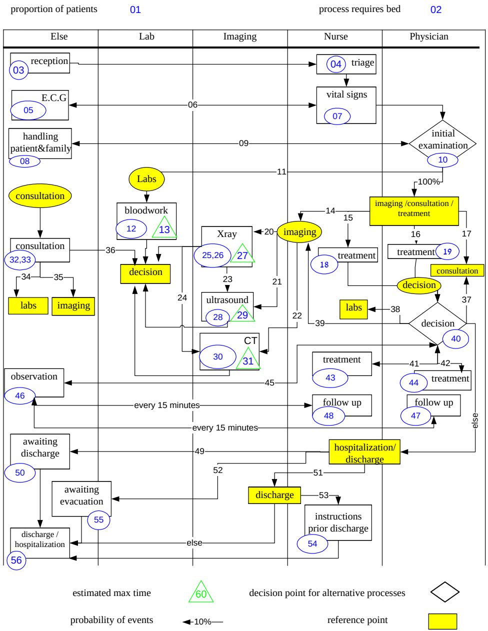
Mapping the Offered Load (Bank Branch)

Department / Time	Business Services		Private Banking	Banking Services	
	Tourism	Teller	Teller	Teller	Comprehensive
8:30 – 9:00					
9:00 – 9:30					
9:30 – 10:00					
10:00 – 10:30					
10:30 – 11:00					
11:00 – 11:30					
11:30 – 12:00					
12:00 – 12:30					
Break					
16:00 – 16:30					
16:30 – 17:00					
17:00 – 17:30					
17:30 – 18:00					

Legend:

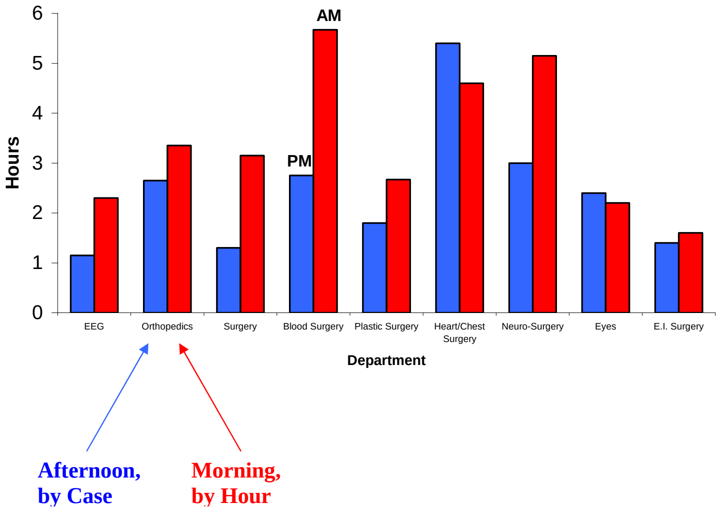
	Not Busy
	Busy
	Very Busy

Conceptual Model: Hospital (ED) Network (Sinreich)



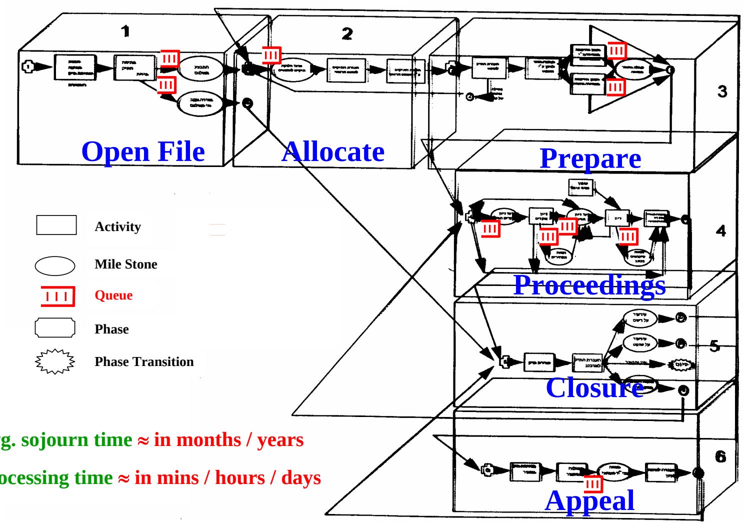
Descriptive Model: Service Times (Averages) or, Even “Doctors" Can Manage

Operations Time - Morning (by Hour) vs. Afternoon (by Case):



Conceptual Model: The “Production of Justice"

The Labor-Court Process in Haifa, Israel

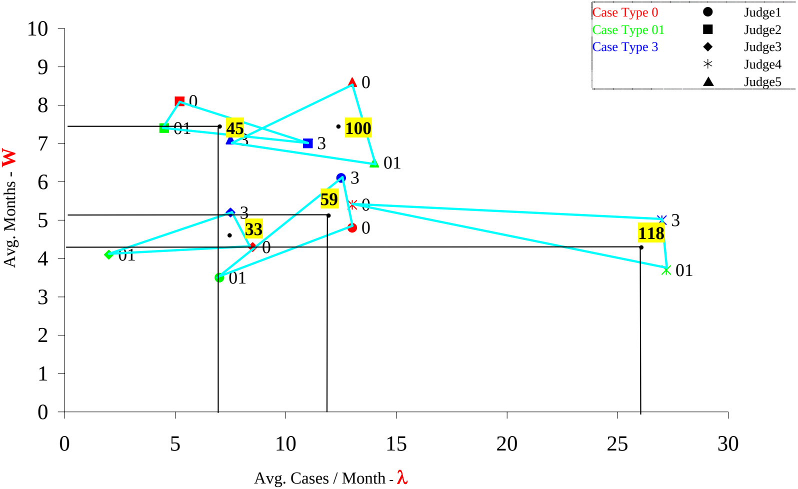


Avg. sojourn time ≈ in months / years

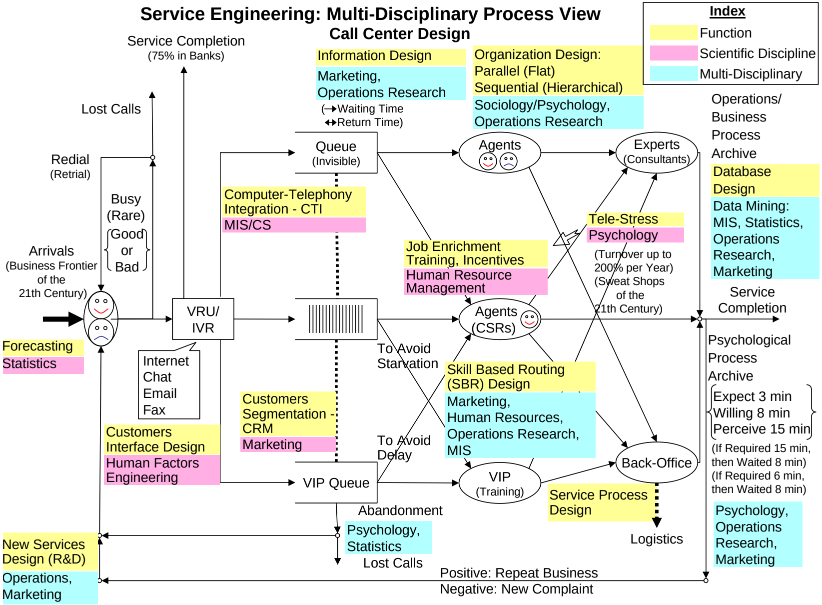
Processing time ≈ in mins / hours / days

Analytical Model: Little's Law in Court (still Averages)

Judges: The Best/Worst (Operational) Performer

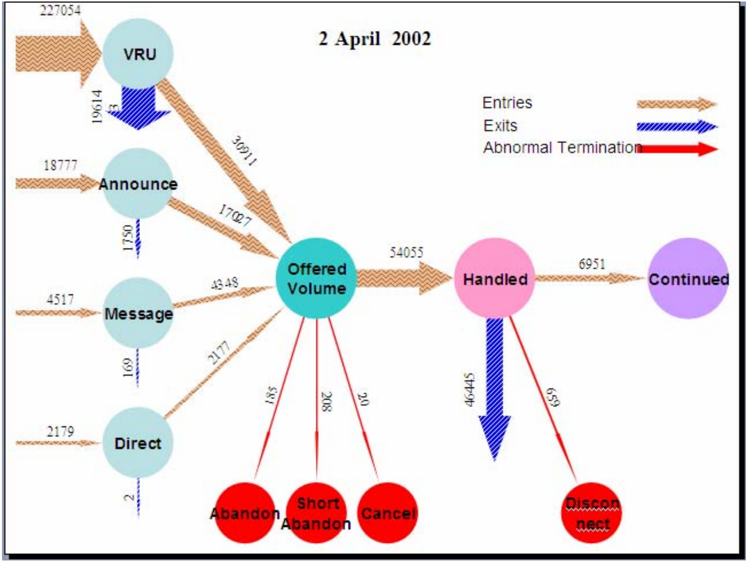


Call-Center Network: Flow, Functions, Disciplines

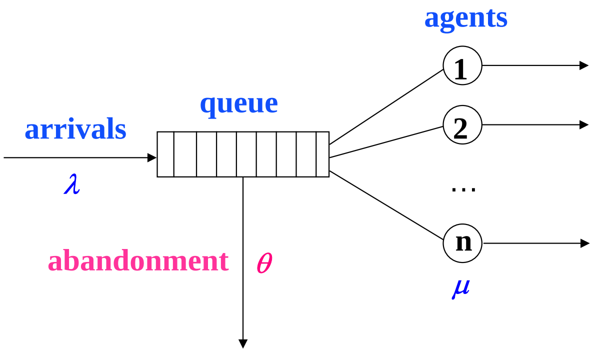


Conceptual Model: Telephone Service

Call-Center = Queueing-Network (U.S. Bank, via DataMOCCA)



The Basic Staffing Model: Erlang-A (M/M/n +M)



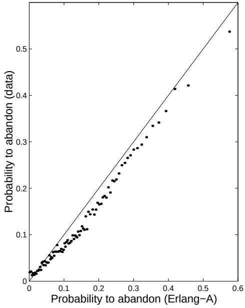
Erlang-A Parameters:

- λ – **Arrival** rate (Poisson)
- μ – **Service** rate (Exponential)
- θ – **Impatience** rate (Exponential)
- n – Number of **Service-Agents**.

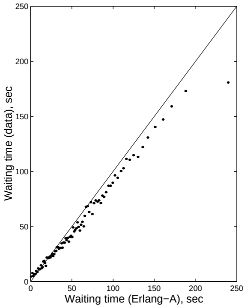
Erlang-A: Fitting a Simple Model to a Complex Reality

Hourly Performance vs. Erlang-A Predictions

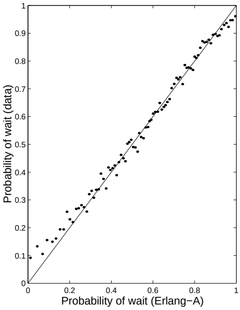
% Abandon



E[*Wait*]



%$\{Wait > 0\}$



- Small Israeli bank (10 agents)
- Empirically-Based Estimation of Patience ($P\{Ab\}/\mathrm{E}[W_q]$)
- **Asymptotic formulae fit even better:**
  Theory – Why so **Robust** wrt size, features? **Boundaries?**
  Practice – eg. few-server time-varying systems (Healthcare, . . .)

Erlang-A: Simple, but Not Too Simple

Experience:

- Arrival process **not pure Poisson** (time-varying, σ^2 too large)
- Service times **not exponential** (typically close to lognormal)
- Patience times **not exponential** (various patterns observed).
- Customers and Servers **not homogeneous** (classes, skills)

Questions naturally arise:

1. Why Erlang-A practically work? Robustness.
2. Why Stochastic-Ignorant staffing work? Special-Case.
3. How to Accommodate Generalizations? Time-Varying, SBR, ...

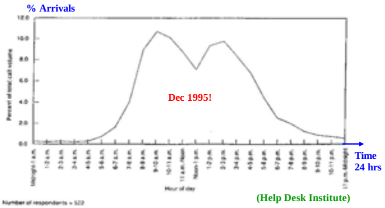
Answers via **Asymptotic Analysis**, as load- and staffing-levels $\uparrow$:

The **QED Regime**, where QED = **Q**uality & **E**fficiency **D**riven.
Erlang (1915-25), Halfin-Whitt (1981); recent surge of research.

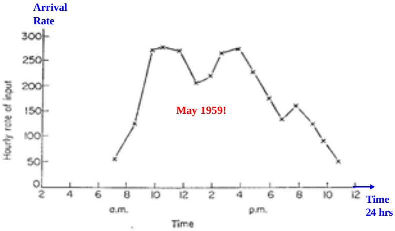
Arrivals to Service: Poisson-Related

Arrival Rate to Three Call Centers

December **1995** (U.S. Helpdesks)



May **1959** (England)



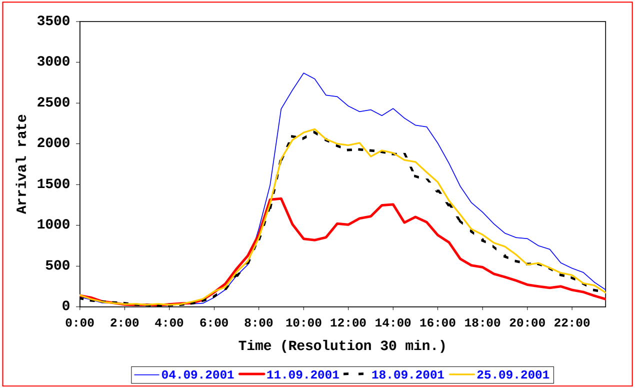
November **1999** (Israel)

Observation:

Peak Loads at **10:00 & 15:00**

Arrivals: Still Poisson-Related, but . . .

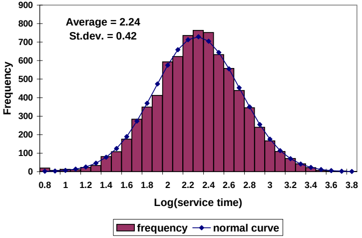
Arrival Rates on Tuesdays in a September – U.S. Bank



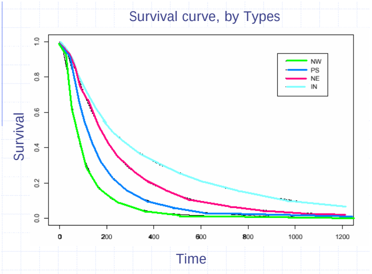
- **Tuesday**, September 4th: **Heavy**, following Labor Day.
- **Tuesdays**, September 18, 25: **Normal**.
- **Tuesday, September 11th, 2001**

Service Durations: LogNormal Prevalent

Israeli Bank Log-Histogram



Survival-Functions by Service-Class



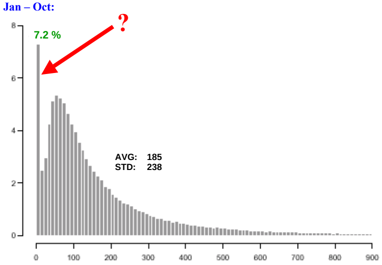
- **New** Customers: 2 min (NW);
- **Regulars**: 3 min (PS);
- **Stock**: 4.5 min (NE);
- Tech-Support: 6.5 min (IN).

Observation: **VIP** require **longer service** times.

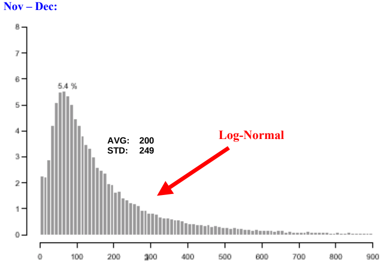
Service Durations: Still LogNormal, but . . .

Service Times in a Typical (?) Call Center

January-October



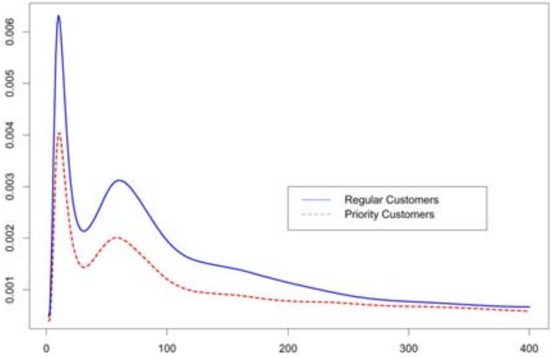
November-December



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

(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 (+Censoring).

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

Erlang-A: Simple, Useful, Robust, Insightful, Optimal

- **Simple:** 4CallCenters calculator (download in our Website)
- **Useful:** Is replacing Erlang-C as the WFM standard
- **Robust:** QED asymptotics (moderate-to-large systems)
- **Insightful:** Square-Root Staffing rules; EOS
- **Optimal:** Could save significant $'s

- **and Generalizable:** Time-Varying, CRM/SBR, . . .,

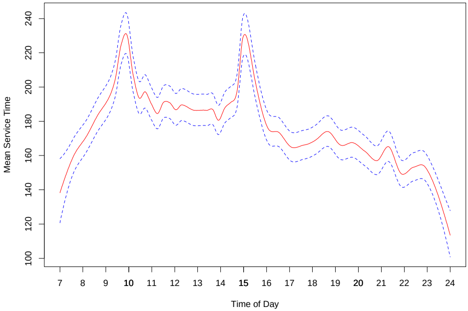
  still has its **Boundaries**, both Theoretical and Practical:

  $\Longrightarrow$ **Current Research**

A "Service-Time" Puzzle at a Small Israeli Bank

Inter-related Building Blocks

Average Service Time over the Day – Israeli Bank

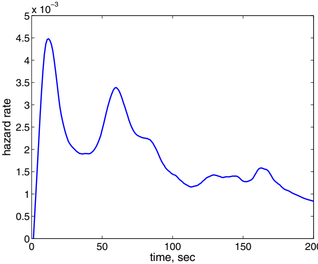
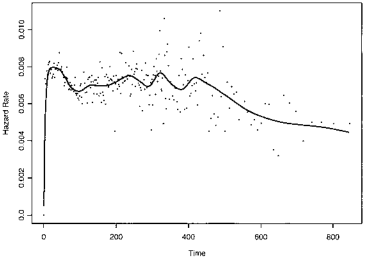
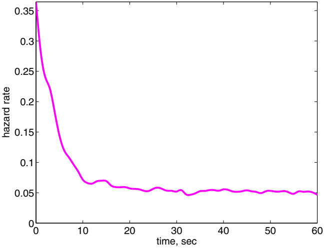
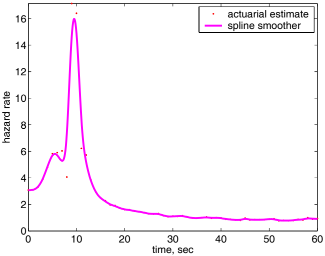


Prevalent: **Longest services** at **peak-loads** (10:00, 15:00). **Why?**

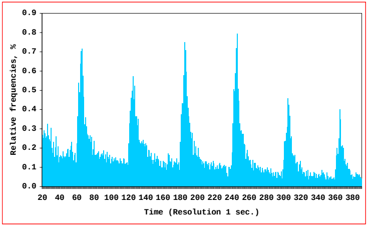
Explanations:

- 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.

Call Center Data: Hazard Rates (Un-Censored)

	(Im)Patience Time	Required/Offered Wait
Israel		
U.S.		

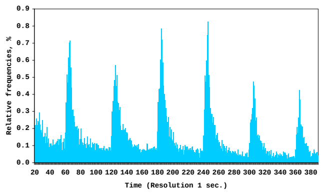
A "Waiting-Times" Puzzle at a Medium Israeli Bank



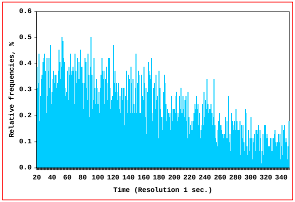
Peaks Every 60 Seconds. Why?

- Human: **Voice-announcement** every 60 seconds.
- System: **Priority-upgrade** (unrevealed) every 60 seconds.

Served Customers



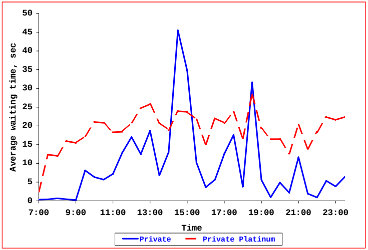
Abandoning Customers



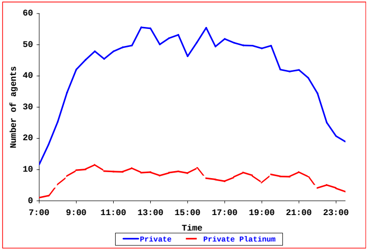
Priorities and Economies-of-Scale

Regular vs. VIP Customers: Cellular – March 23, 2004

Average Wait



Staffing Level

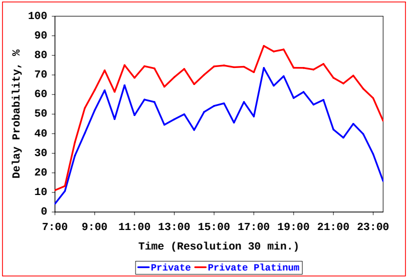


- **Design:** VIP-dedicated agents, Regular-dedicated Agents.
- **VIP's** are **not** served better than **Regular's**
- **Solutions:** Add VIP agents (costly), or Change Design.

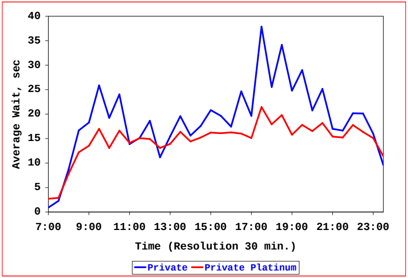
Priorities and Routing Protocols I

Regular vs. VIP Customers: Cellular – October 2004

Delay Probability



Average Wait



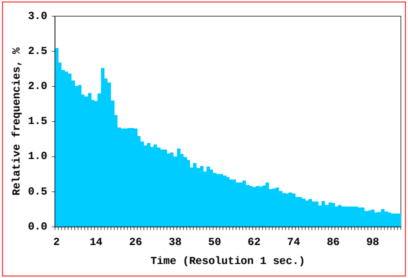
More **VIP's** delayed than **Regular's**, **yet** their average wait is shorter.

What changed since last March?

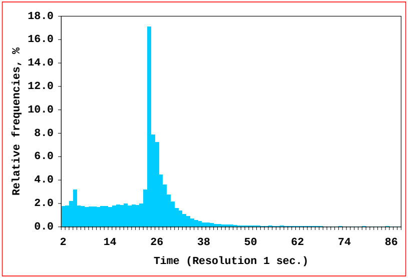
Priorities and Routing Protocols II

Waiting-Time Histograms: Cellular – October 2004

Regular Customers



VIP (Platinum) Customers



After **25 seconds** of wait, **VIP** customers are **routed** with **high priority** to Regular agents. Hence, almost **no long waiting times** for VIP's.

Main Challenges for Research & Practice

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

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

But there is much more: The **Psychology-Operations** Interface.

Consider, as only one example, the “Phases of Waiting" for Service.

The "Phases of Waiting" for Service

Common Experience:

- Expected to wait 5 minutes, Required to 10
- Felt like 20, Actually waited 10 (hence Willing $\geq$ 10)

An attempt at "Modeling the Experience":

1.	Time that a customer	**expects** to wait	
2.		**willing** to wait	((Im)Patience: τ)
3.		**required** to wait	(Offered Wait: V)
4.		**actually** waits	($W_q = \min(\tau, V)$)
5.		**perceives** waiting.	

Experienced customers $\Rightarrow$ Expected = Required

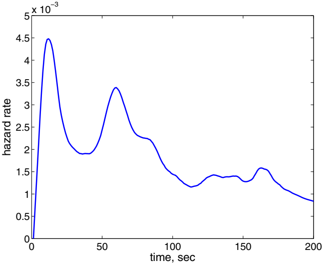
Rational customers $\Rightarrow$ Perceived = Actual.

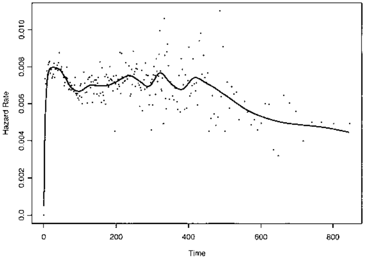
Then left with (τ, V).

Call Center Data: Hazard Rates (Un-Censored)

(Im)Patience Time | Required/Offered Wait

Israel





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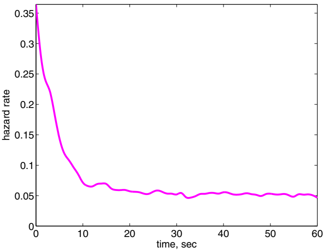
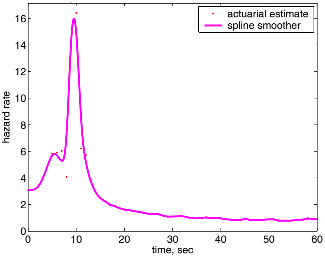




A Patience Index

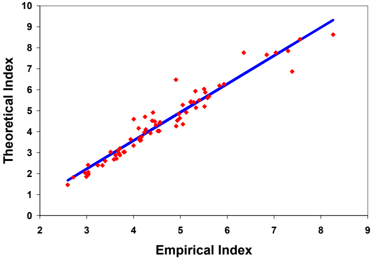
How to quantify (Im)Patience?

$$\textbf{Theoretical}\text{ Patience Index } \triangleq \frac{\textbf{Willing}\text{ to wait}}{\textbf{Expected}\text{ to wait}} = \frac{\mathrm{E}[\tau]}{\mathrm{E}[V]},$$

the last = if Experienced: then calculable but complex, error-prone.
Simple (but not too simple) model suggests the easily-measurable:

$$\textbf{Empirical}\text{ Patience Index } \triangleq \frac{\textbf{\% Served}}{\textbf{\% Abandoning}}$$

Patience Index – Empirical vs. Theoretical (Brown)



Predicting Performance

Model **Primitives**:

- Arrivals to service
- (Im)Patience while waiting τ
- Service times
- Number of Agents.

Model **Output**: ***Offered-Wait V***

Operational Performance Measure calculable in terms of (τ, V).

- eg. Average Wait = $E[\min\{\tau, V\}]$
- eg. % Abandonment = $P\{\tau < V\}$

. . . , and we are back to Erlang-A and relatives, but with lots that's left to do,

which is comforting.

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**.

System Components:

- Clean **Databases**: operational-data of individual calls, agents and operations.
- Friendly yet powerful **Online Interface**: enables convenient fast access to (mostly) operational and (some) administrative data (but no marketing/business data).

Current Databases:

- Medium-sized U.S. Bank (**2.5 years; 220M calls, 40M via agents; 800 agents at peaks**) – Completed.
- Israeli Cell-Phone Company (**2 years; 110M calls, 25M via agents; 700 agents at peaks**) – Ongoing.
- Large Israeli Bank – Pilot.