(How) Will RTLS transform healthcare delivery (research) ?

Strengths & Limitations

Avishai Mandelbaum
August 2019

Search **SEELab Technion**

*Full version

Research Partners (35+ years)

Students & Advisees: Chen Hong, Pats, Zeltyn, Baron Yonit, Garnett, Izhar, Kestelman, Isaeev, Nakibli, Cohen Izik, Khudyaov, Shaikhet, Gurvich, Aldor, Rosenschmidt, Feldman, Yom-Tov, Maman, Tseytlin, Reich, Zviran, Zaied, Marmor, Carmeli Boaz, Luzon, Ghebali, Moldavsky, Koren, Liberman, Senderovich, Zychlinski, Yuviler-Carmeli, …

Theory: Armony, Atar, Azriel, Chen Hong, Cohen Izik, Garnett, Gurvich, Feigin, Gal, Huang Junfei, Jelenkovic, Kaspi, Massey, Momcilovic, Penn, Reiman, Shimkin, Stolyar, Trichakis, Trofimov, Wasserkrug, Whitt, Yechiali, Yom-Tov, Zeltyn, Zhang Jiheng, Zhang Hanqin, …

Data-based (Models, Statistics, EDA, Projects, Sources): Harrison, Wein, van Ackere; Nguyen, Schwerer; Hochberg, Baron Ofer, Nov, Newman, Schwartz, Lieber, Yahalom, Elkin, Roshenberg, Natur, Valin, Paldi, Israeli, Plonski, Durban ; Brown, Gans, Shen Haipeng, Sakov, Zhao Linda; Zeltyn; Ritov, Goldberg, Yefenof; Gurvich, Huang Junfei, Liberman; Liu Nan, Ye Han; Armony, Marmor, Tseytlin, Yom-Tov; Koren, Plonski; Gorfine, Ghebali; Tezcan; Kim Song-Hee, Won Chul Cha; Feigin, Azriel; Rafaeli; Momcilovic, Trichakis; Bunnell, Kadish, Leib; Weinshall, …

Industry: Mizrahi Bank, Fleet Bank, Rambam Hospital, IBM Research, Hapoalim Bank, Pelephone Cellular, Samsung Hospital, Singapore Hospitals, Dana Farber Cancer Institute, LivePerson, Cheetah Labs, Ministries (Justice, Health), …

Technion SEE Laboratory (SEELab): Feigin; Trofimov, Nadjharov, Gavako; Kutsy; Senderovich, Yuviler-Carmeli; Liberman, Koren, Plonsky;
Research Assistants, Visitors, Postdocs, …

Note: In many Western countries, there is a short list of popular "first names," but countless "last names." In China, it is just the reverse. The list of last names is short, and the number of first names is in the billions ("popular" sentence from the web).

Outline

- “Introduction”

- Helpful history

- Strengths, via data

- Limitations, relative to needs

- Examples, that hint at future apps: Research, Practice

- Concluding speculations

Caveats:

- RTLS = Location+ID tracking of <u>human operations</u>, which is automatic, continuous, online
- Technology transparent (RF or IR, US, WIFI, BLT, UWB, Smartphone; passive/active,…)
- General healthcare delivery

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Physics, Biology, . . . : Measure, Model, Experiment, Validate, Refine.

Human-complexity triggered above in Transportation, Economics.

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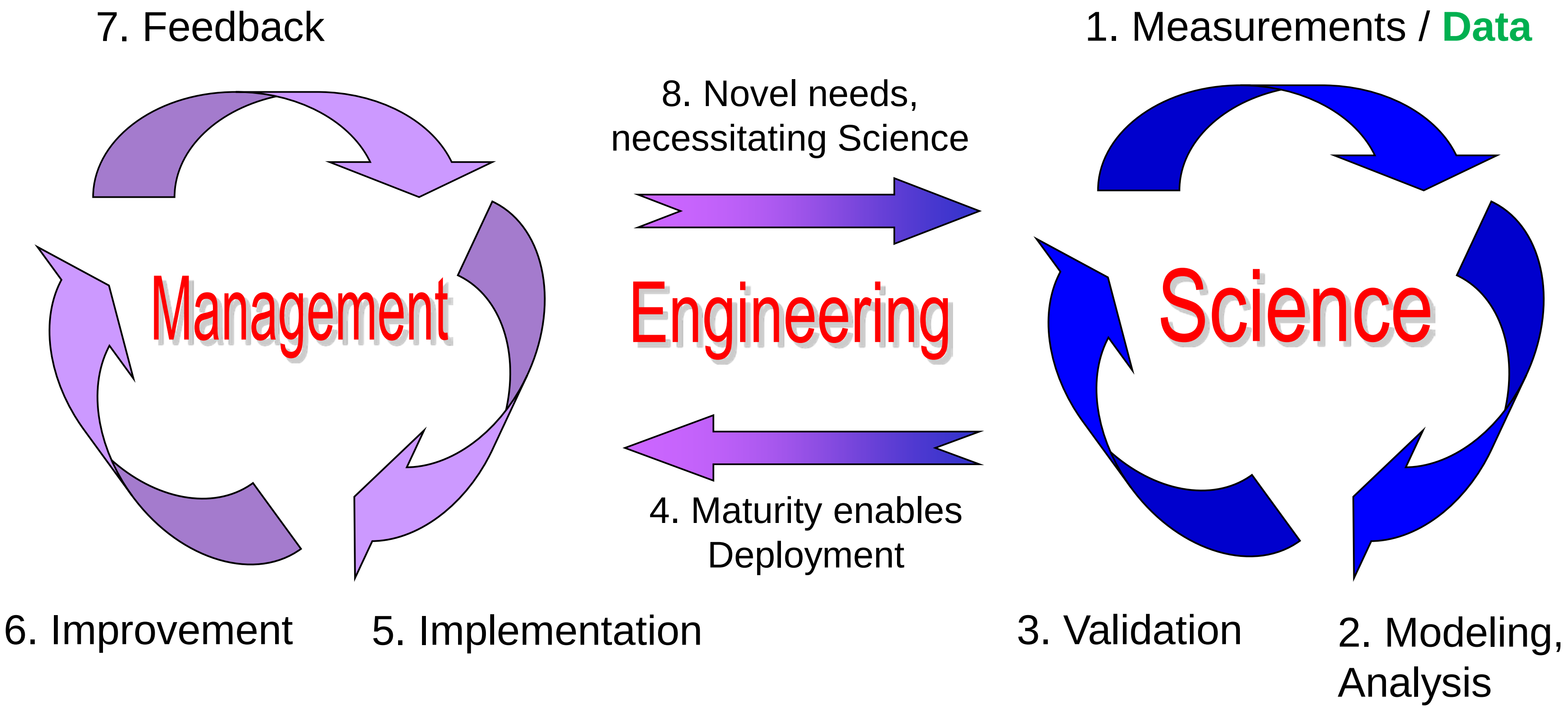
Expand to data-based **OR = OM + IE + DS**



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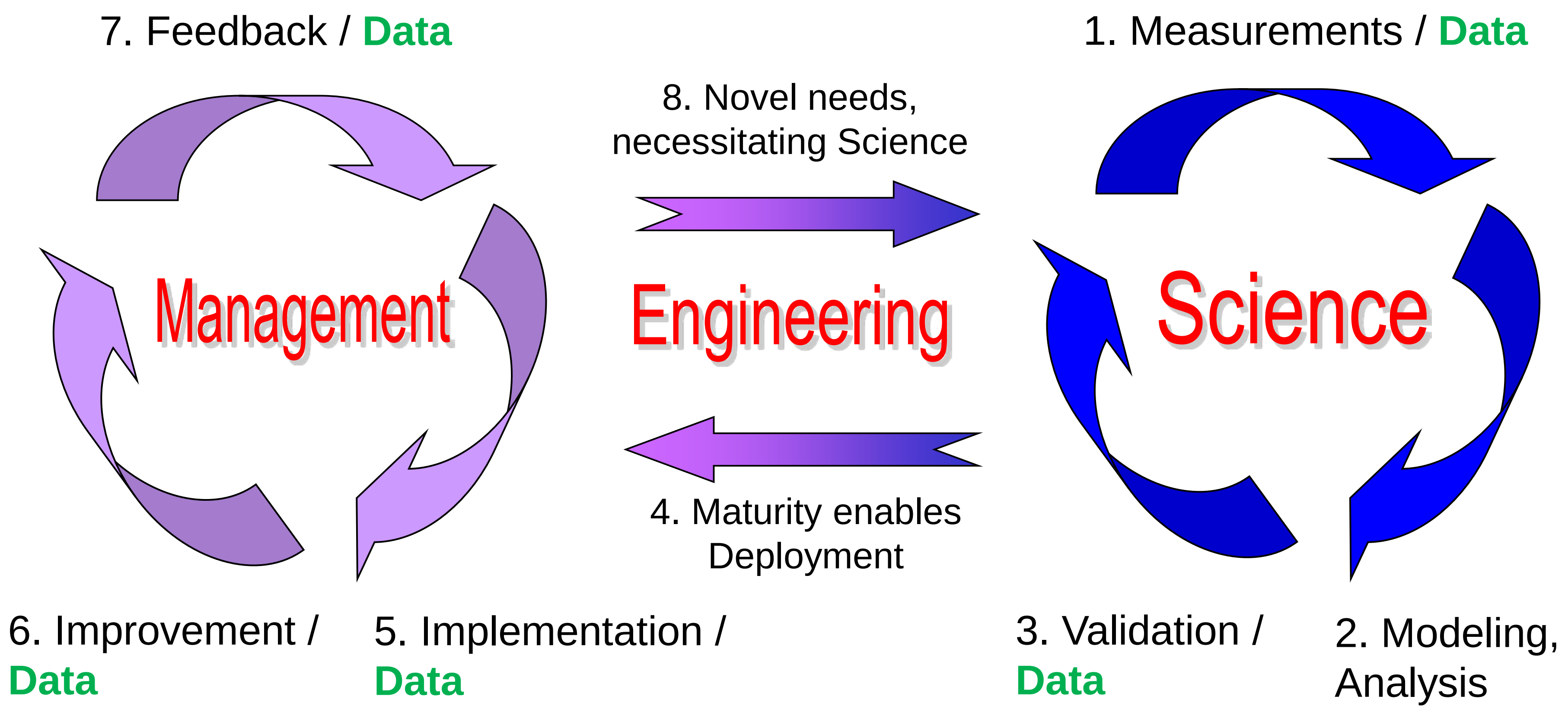

(How) Will RTLS transform healthcare delivery (research) ?

- Widely acknowledged that healthcare delivery, its models and practice and research, must and is due to undergo transformational changes.

- My view is that "RTLS+**DFCI**", by enabling evidence-based modelling / practice / research / partnerships (e.g. **Sarah, Ryan, Craig**), is a prerequisite for such a transformation (e.g. research relevance).

Consider Cost of Care, as one central example:

Cost of Care

- "There is little doubt that the most generally troublesome feature of recent experience with all aspects of medical care in the United States today is the increase in **cost**, however defined, of the hospital component of that care."

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- Cost?
  - Patients (if uninsured, can negotiate down significantly)?
  - Providers (isolated from costs to optimize care)?
  - Hospitals = billing charges?
  - Insurance = reimbursements (?30% of charges, after negotiations)?

True cost?

Cost of Care: by **ICD?**

- **ICD-10** is the 10th revision of **ICD = International Classification** of **Diseases**: medical classification list that contains codes for diseases, signs and symptoms, abnormal findings, complaints, social circumstances, and external causes of injury or diseases.

- There are presently about **140,000** ICD codes (over 70,000 ICD-10-PCS procedure codes and over 69,000 ICD-10-CM diagnosis codes; compared to about 3,800 procedure codes and roughly 14,000 diagnosis codes found in the previous ICD-9-CM).

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- ICD is the basis for **DRG = Diagnosis Related Groups**, which are assigned by a **"grouper" program: 140K → 750 groups**.

- (The World Health Organization (WHO) owns, develops and publishes ICD codes, and national governments and other regulating bodies adopt the system.)

Cost of Care: by **DRG**

"Diagnosis Related Groups (DRGs) originally developed to provide product-definitions for the output of hospitals. …, accounts for diagnoses, procedures, age, sex, discharge status, and the presence of complications or comorbidities …, basis for budgeting, cost control, and quality control in hospitals." Fetter, Interfaces, 1991.

DRGs (originally 467 categories, now over **750** & AllPatients or APRefined) used in the US since 1982 to determine how much Medicare pays the hospital for each "product", since patients within each category are clinically similar and are thus expected to use the same level of hospital resources (providers, equipment, medication, bed, …):

DRG Cost = Standardized amount per discharge x DRG "Resource Intensity" (Relative Weight)

Cost of Care: via **RTLS = Personalized Evidence-based**

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But patients' resource utilization varies significantly by the individual, and here

RTLS can come to the rescue by measuring personalized true costs of care.

This could/would change healthcare (e.g. enabling evidence-based management, market-based models of care, …).

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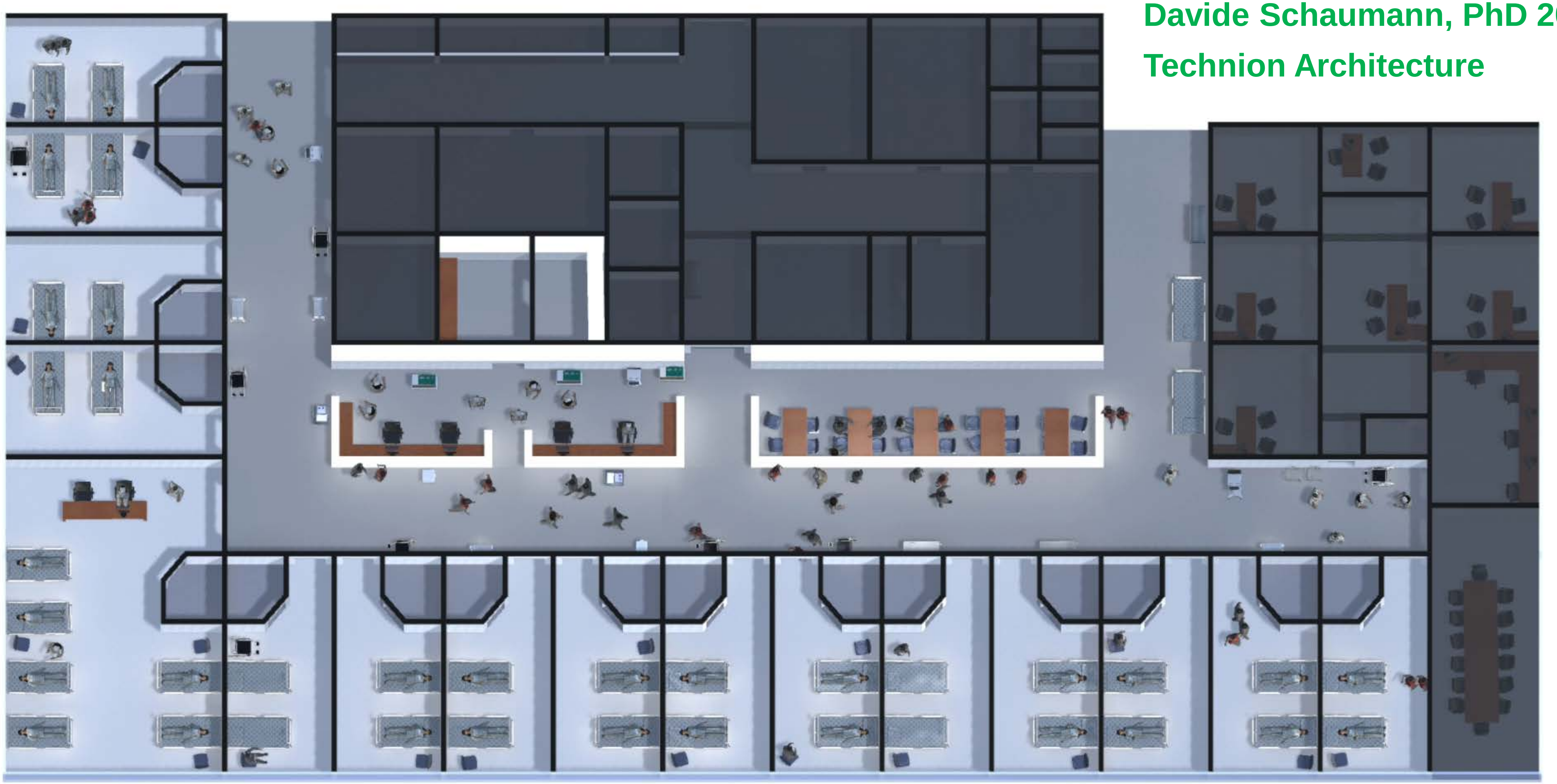
… and consider Process and Spacial Design, as a 2nd central example:

(Physical) Simulation of an Internal Medicine Ward



Davide Schaumann, PhD 2018

Technion Architecture

(Physical) Simulation of an Internal Medicine Ward

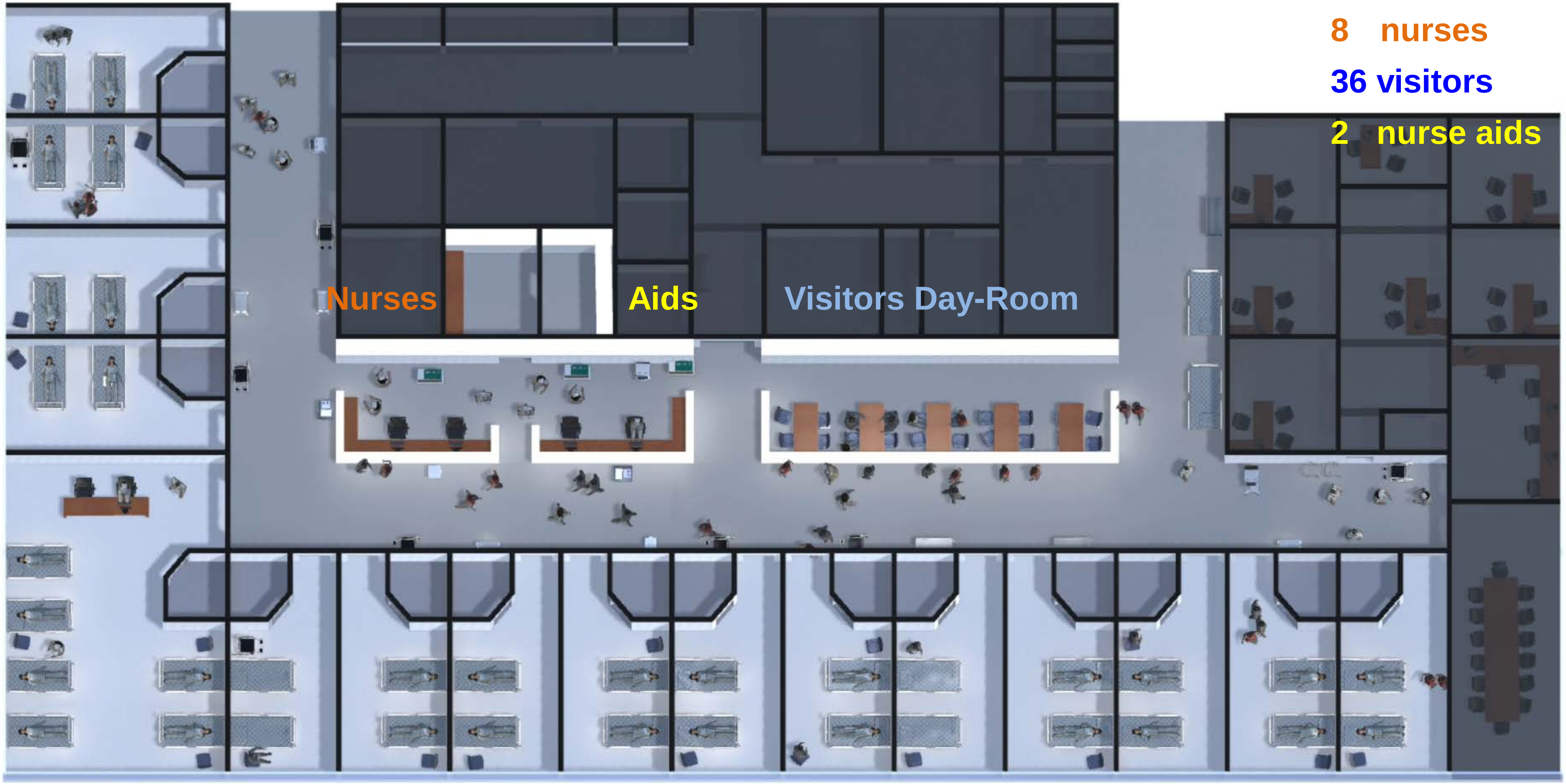
36 patients

6 doctors

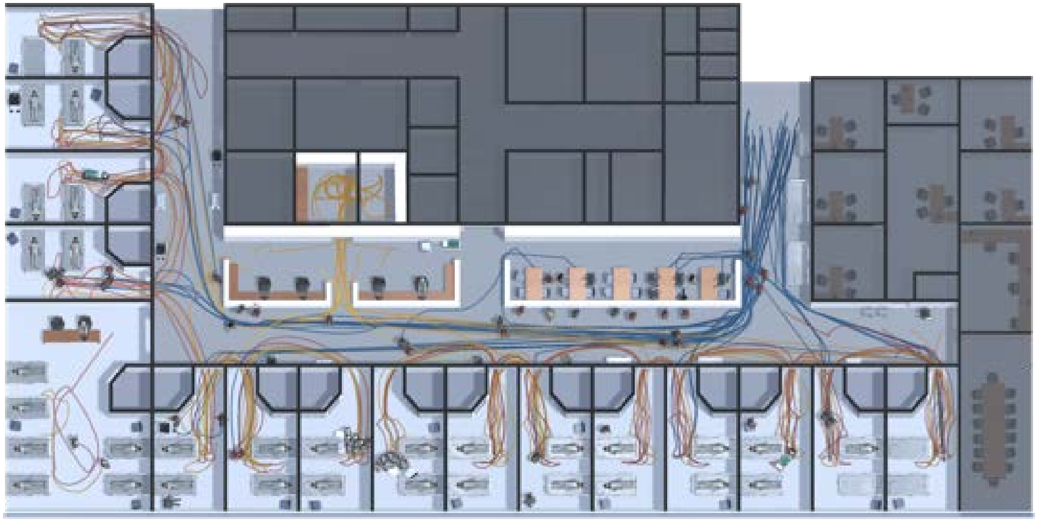
8 nurses

36 visitors

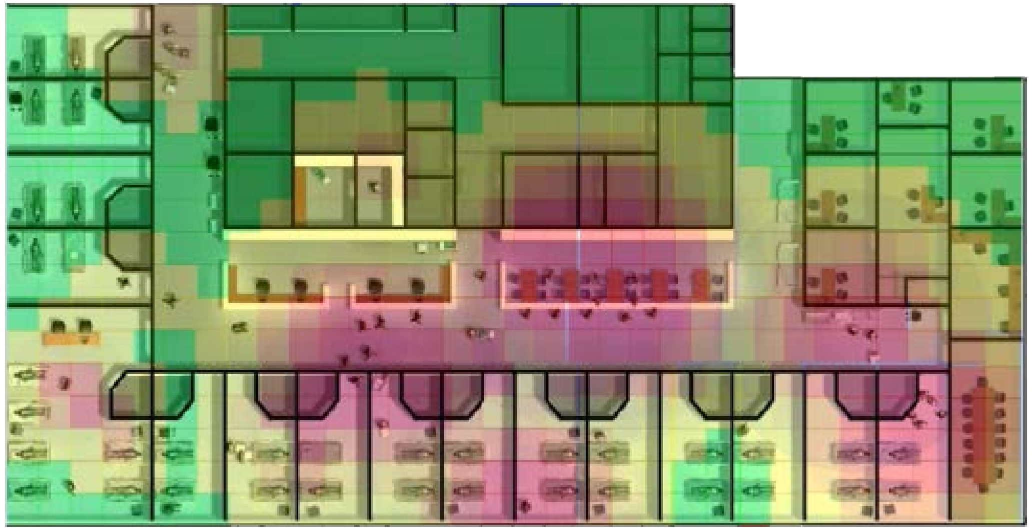
2 nurse aids



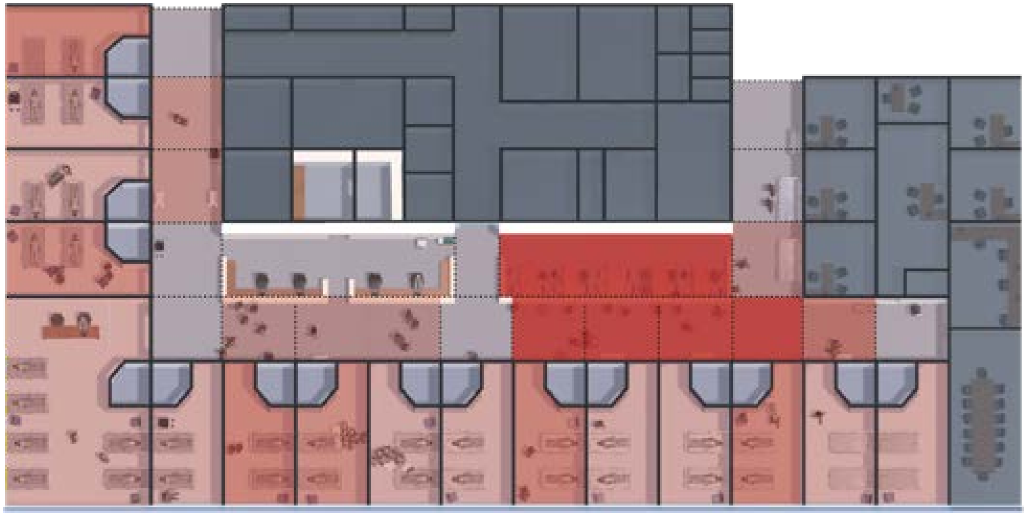
Human-Centric Analysis of Spatial Utilization



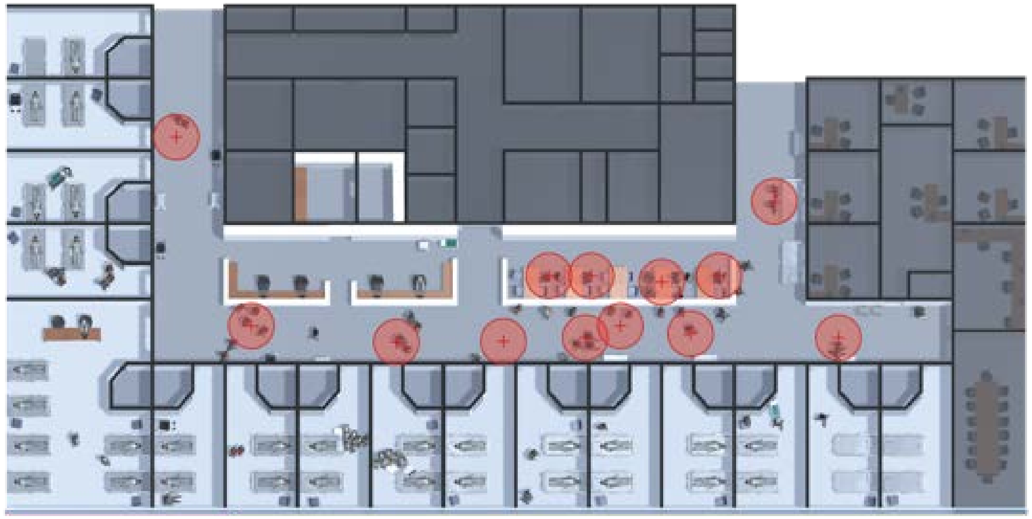
Travelled Paths



Noise (**Talking,** can AC, **…**)



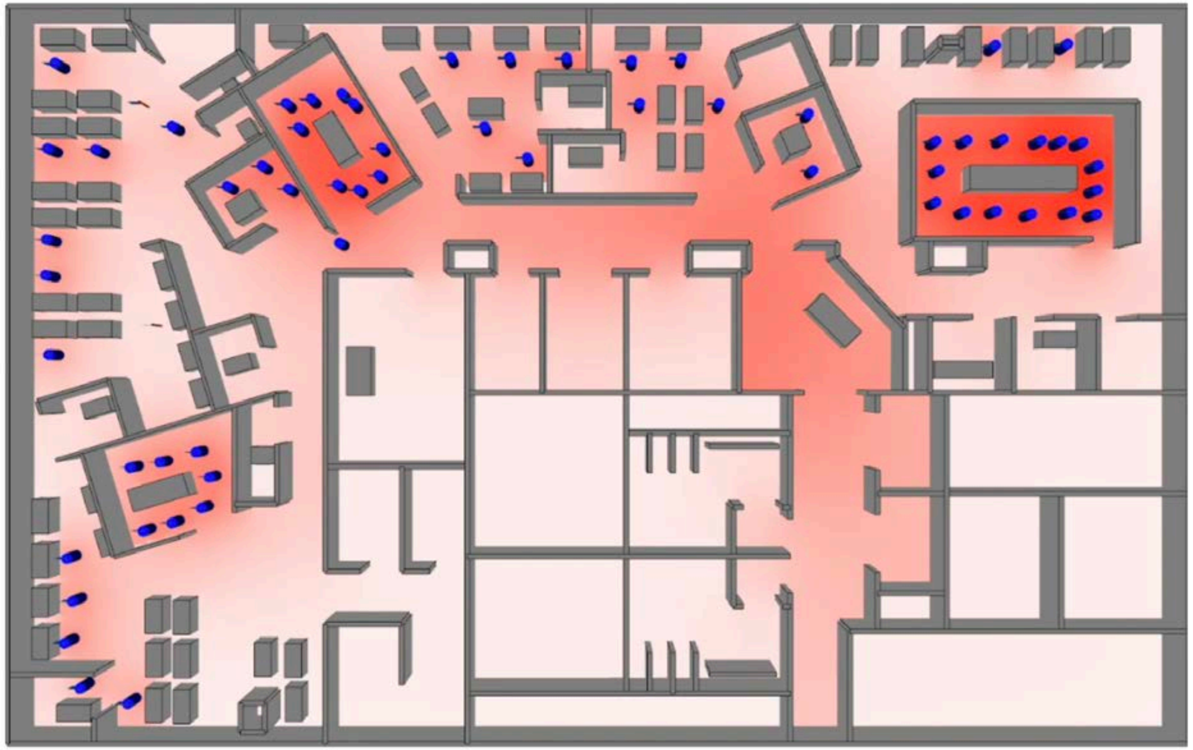
Density of People in Space



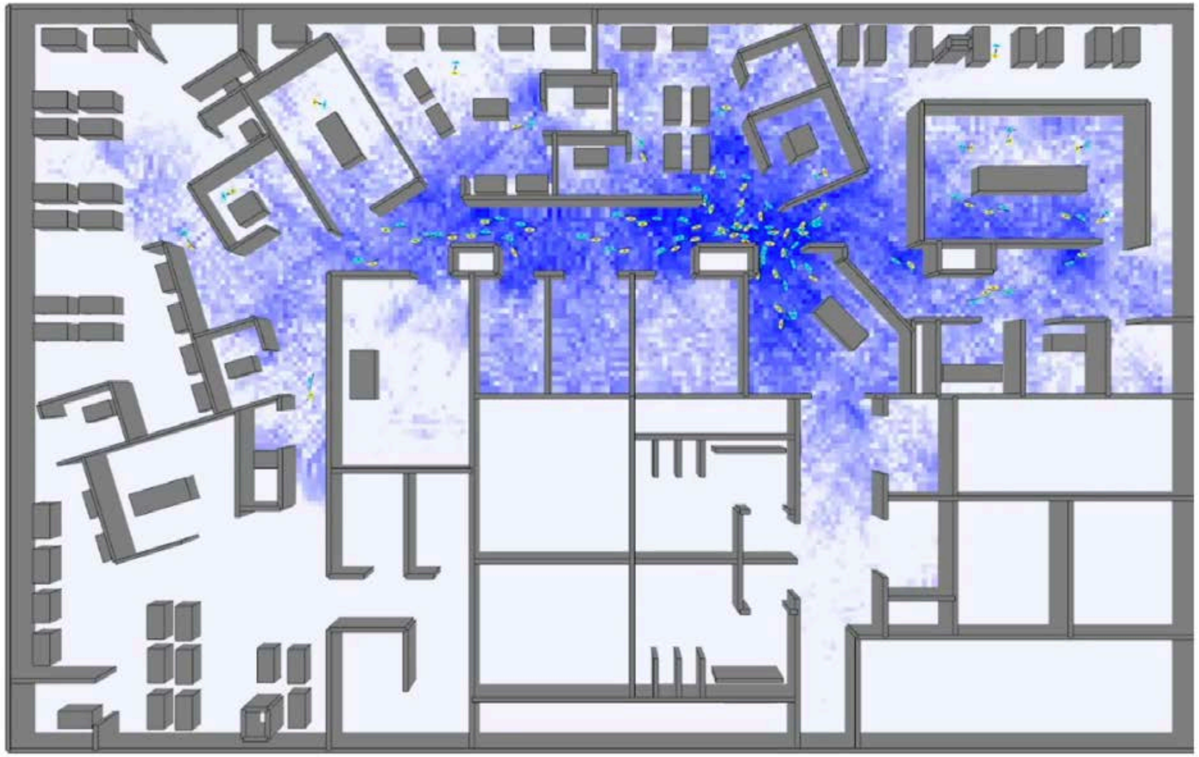
Social Interactions (**Staff-Visitor,** can Staff-Staff)

Schaumann et al. "Simulating the impact of facility design on operations: A study in an internal medicine ward." 2019, *In Press*

Environmental Conditions: Heat, Noise (Refined)

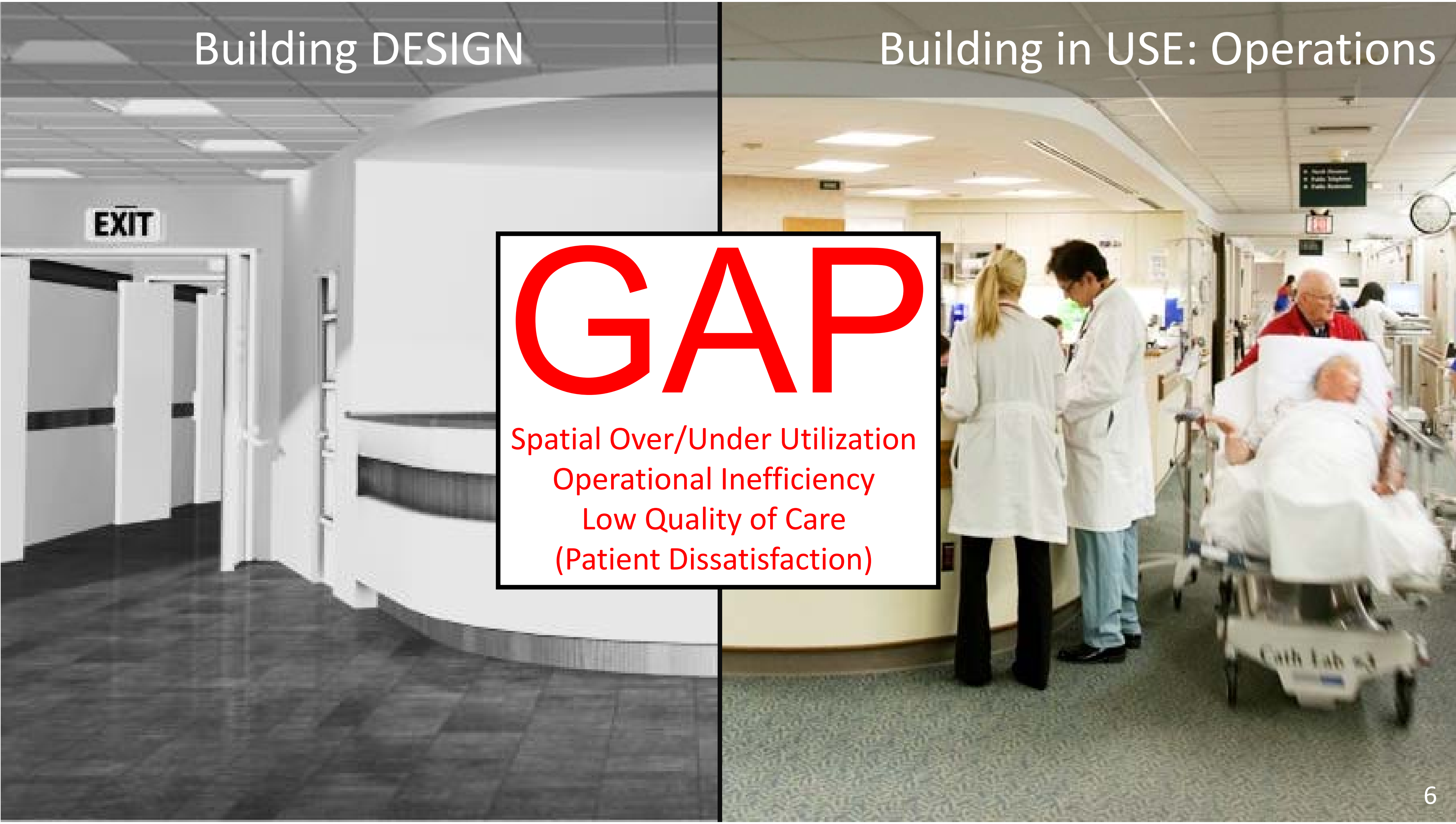


Thermal simulation of occupants' **body heat** (differential equations)



Acoustics simulation of occupant's **footstep** sound = f(floor material, wall absorption,…)

Schaumann et al. "JOIN: An Integrated Platform for Joint Simulation of Occupant-Building Interactions. Architectural Science Review." 2019, in Review


Building DESIGN
Building in USE: Operations
EXIT
GAP
Spatial Over/Under Utilization
Operational Inefficiency
Low Quality of Care
(Patient Dissatisfaction)

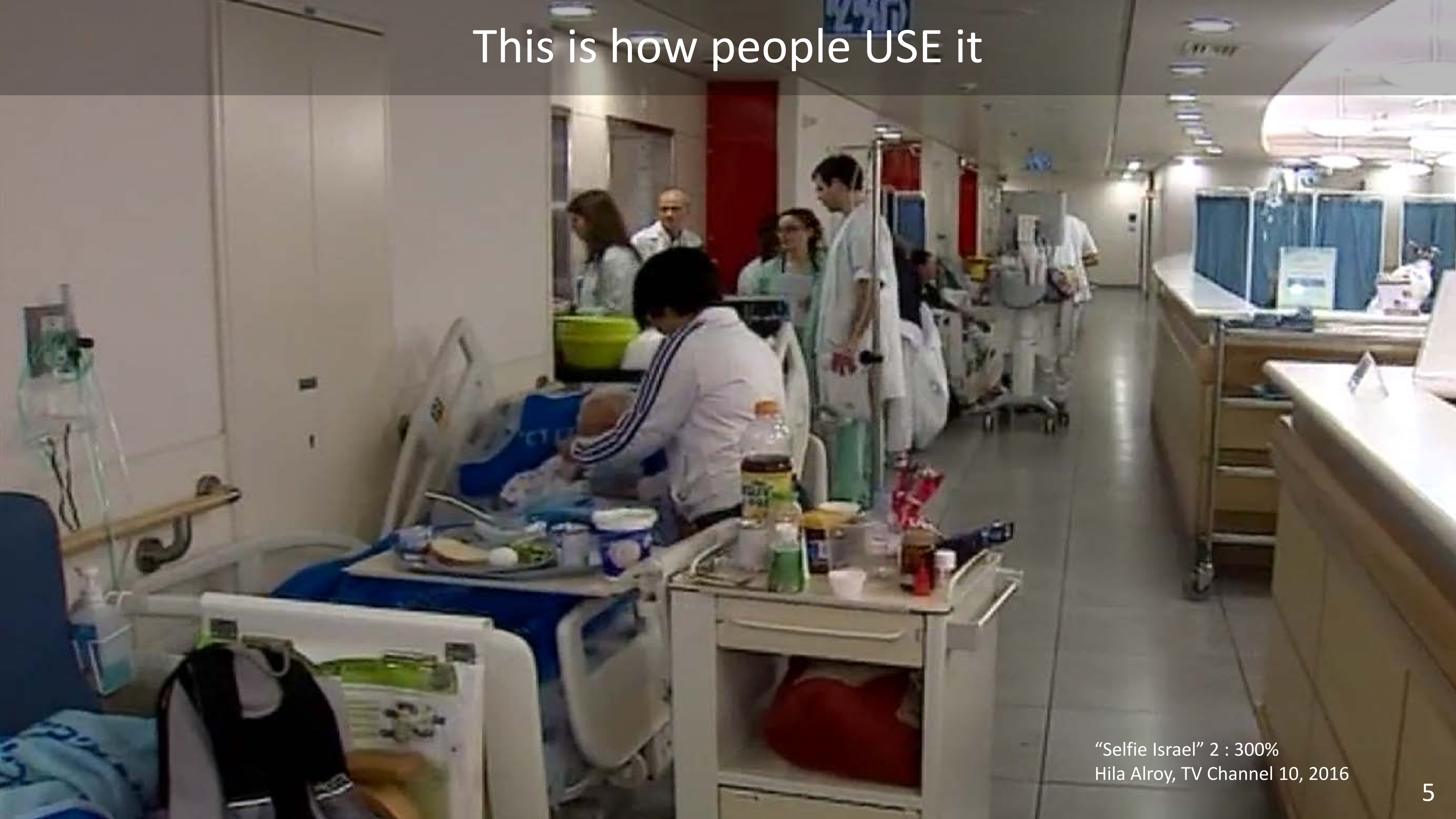
This is how architects DESIGN a hospital

This is how people USE it

This is how architects DESIGN a hospital

Sharon Architects & Ranni Ziss Architects, 2007

This is how people USE it



“Selfie Israel” 2 : 300%
Hila Alroy, TV Channel 10, 2016

Main Takeaways – Practice (Hospital-Centered)

- Operational & within hospital:
  - Personalized evidence-based: resource utilization/cost, patient/infection paths
  - Adherence to “clinical” constraints (e.g. 1-hour door-to-stent time, …)
  - EMR (Epic) integration
- Operational & beyond hospital:
  - Complete (operational) cycle of care (e.g. readmissions, ED blocking, IW boarding), and reduce hospital disconnect from community
  - Outdoor tracking: integrate RTLS with wearables/smartphones (community, home)

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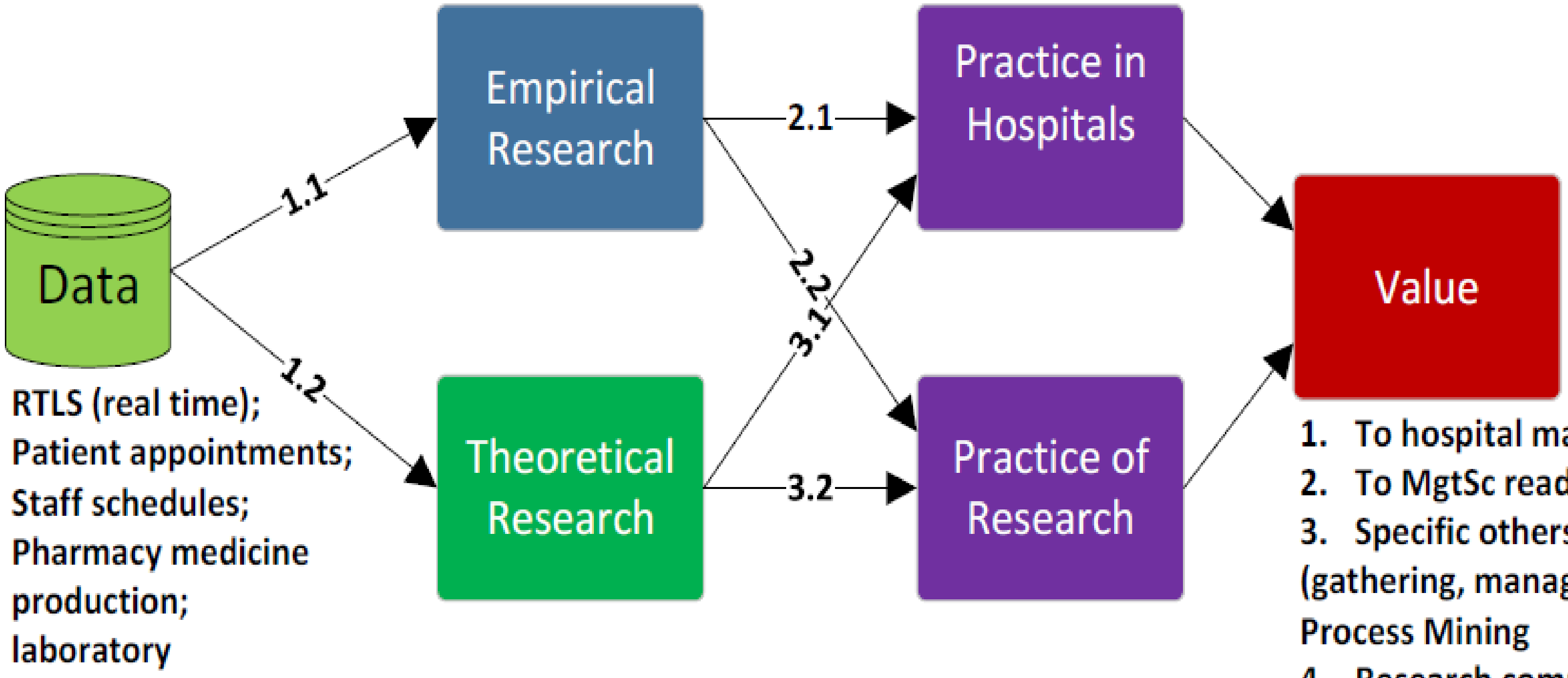
- Beyond operational & within hospital:
  - Smart Hospital: social-networks (multi-directional connection); noise, energy (heat), crowdedness; operational + clinical + psychological + financial dimensions
- Beyond both: technology around the corner
  - Complete cycle of care (community, home), that integrates the physical + above dimensions, …
  - Comparing performance (hospitals, states, city vs. periphery, …)

Real-Time Tracking of Scheduled Operations in an Ambulatory Hospital: From Data to Value through Research and Practice

Incomplete Draft, to Management Science (w/ Nikos, Petar; Craig, Sarah, Ryan)



1. To hospital management
2. To MgtSc readership
3. Specific others: Data Science (gathering, management); BPM, Process Mining
4. Research community at large – via SEELab (scientific value)

Main Takeaways – Research + Practice: OR/DS/OM/IE, (Social) Networks, <>Mining, ML, Ethics, Incentives, …

1. RTLS data affects both
   - Empirical and
   - Theoretical research.
2. RTLS-based Empirical Research is to affect both
   - the Practice in Hospitals and
   - the Practice of Research.
     - e.g. Practice in Hospital: our empirical analysis revealed gaps between the scheduled and the actual, which will help reduce this gap
     - e.g. Practice of Research: ample data will help identify novel research opportunities and validate existing research.
3. RTLS-based Theoretical Research is to affect both
   - The Practice in Hospitals and
   - the Practice of Research.
     - e.g. Practice in Hospital: novel technologies & tools – smartphone; planning, scheduling, control
     - e.g. Practice of Research: this is clear as novel research stimulates further research

(Operations) Research Goal (within reach)

e.g. Specific Emergency-Department, with ample reliable data (or Call Center, or …)

Goal: Create in Real-time, via (semi- or fully-automatic) mining of ED **processes, models** (empirical, statistical, simulation, mathematical,…) and **algorithms** for their analysis.

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This will support, for example:

- Real-time: control of patient-flow (bottlenecks); status-info + prediction (“waze”)
- Short-term: on Monday, set Tuesday’s staffing levels (or next week’s); real cost of care for the individual patient (vs. mean/negotiated costs)
- Long-term: capacity allocation, facility/triage design; social network (e.g. correlated w/ outcomes); change-management (Epic); congestion laws

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Technion SEELab

SEE = Service Enterprise Engineering
Collecting Data for Research and Teaching

Home for all the data in this lecture, and much more

Founded in **2007**
by **Paul Feigin and AM**

$1M seed: **Hal & Inge Marcus**

3 Researches (professionals)
Students, PostDocs, Visitors

Technion SEELab

SEE = Service Enterprise Engineering
Collecting Data for Research and Teaching

Home for all the data in this lecture, and much more

In the making or planning:

SEENYC @ Jacobs Technion-Cornell Inst.
w/ **Itai Gurvich** (PI), …

SEEZHEN @ CUHK-Shenzhen /SRIBD
w/ **Jim Dai, …**

SEELab = Environment for Graphical EDA

Operational histories (customers, servers) at the **individual-transaction level**, e.g.

1. Bank Anonymous Call-Center: **1 year, 350K calls by 15 agents** (during 2000) – started all
2. U.S. Bank Call-Center : **2.5 years, 220M calls, 40M by 1000 agents**
3. Israeli Cellular Company: **2.5 years, 110M calls, 25M calls by 750 agents;**
4. ILBank (2 years)
5. Back to Bank Anonymous: **from January 2010,** daily-deposit at a SEESafe

6. Click-stream data: Service Engineering **internet website** (2 years)

7. *Hospital: Rambam (Home) Hospital : **4 years, 1000 beds**, inter-ward patient flow

8. Hospital: **Emergency Departments** (ED) patient flow
- 5 EDs in Israel: 1-2 years, **late David Sinreich**, ED arrivals & LOS
- ED in Seoul: 2 months, **K. Song-Hee & W. Cha**, pilot
- ED in Singapore: 2 years, pilot

9. RTLS (Real-Time Location System) **U.S. Ambulatory Hospital: Since November 2013**
- **250K events/day (1GB/week): 1000 patients, 300-400 staff (1500 tagged entities), every 3 sec's**
- Infrastructure: **900 readers (sensors) over ceilings of 7 (now 8) clinical floors**
- Both actual and planned (appointment book of resources: staff, patients, rooms)

10-13: Chat Services (Europe); ILBank Warehouse; Smart-City Simulator (Haifa, …); Courts (Israel)

***Open & Free for (reproducible) research and teaching**

Data-Collection Technologies (leaving aside Interfaces)

Operational histories (customers, servers) at the **individual-transaction level**, e.g.

1. ACD: Bank Anonymous Call-Center: 1 year, 350K calls by 15 agents (during 2000) – started all
2. ACD + IVR: U.S. Bank Call-Center : **2.5 years, 220M calls, 40M by 1000 agents**
3. ACD: Israeli Cellular Company: **2.5 years, 110M calls, 25M calls by 750 agents;**
4. IVR + CRM (SBR): ILBank (2 years)
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SEELab History:

Shapes the Present and Informs (Enhances & Constrains) the Future

Started with Call Centers, then Hospitals, …

Data originates in Service Event-Log files:

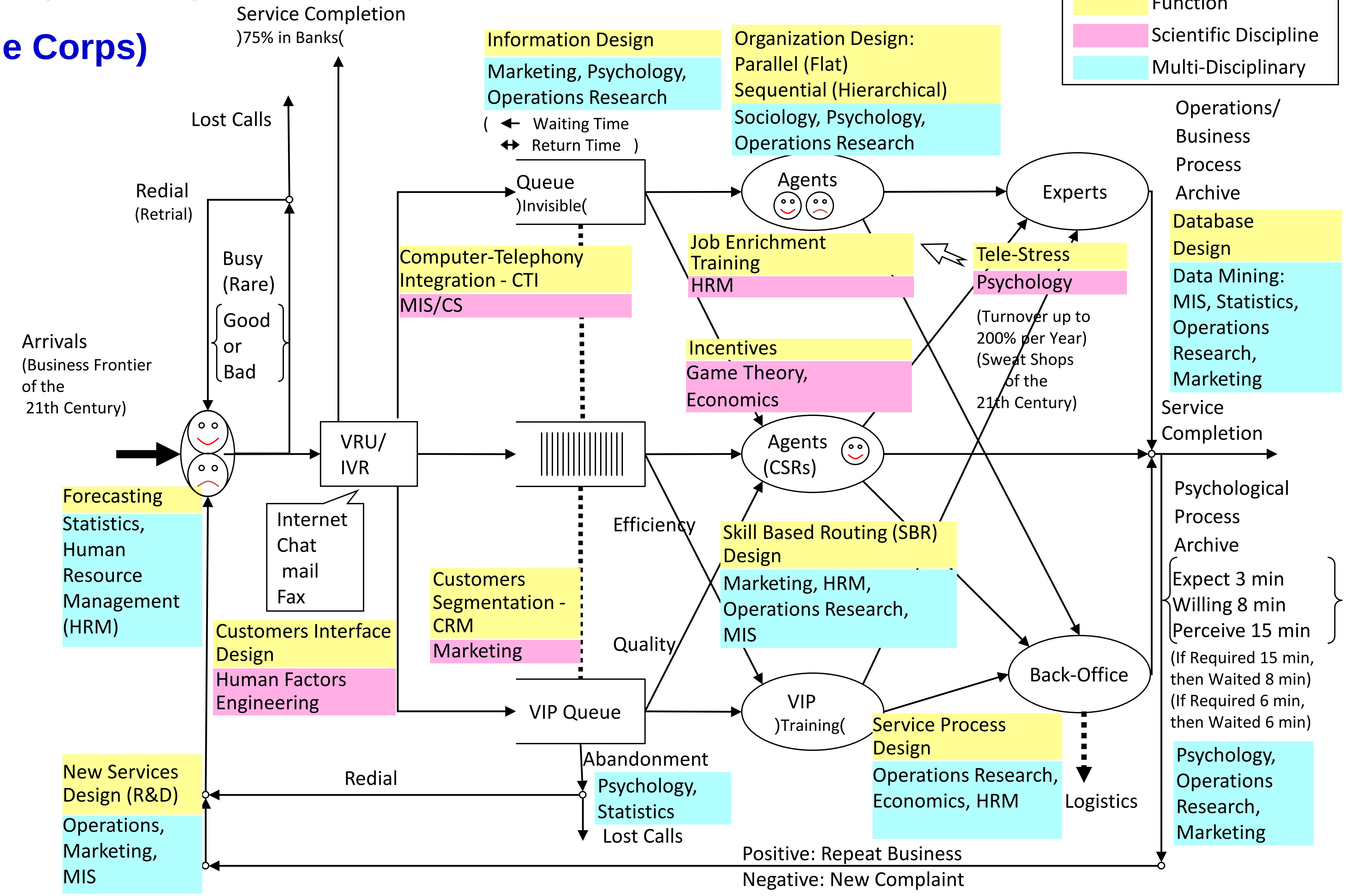
Operational histories (event time stamps), of

both customers & service providers, at the

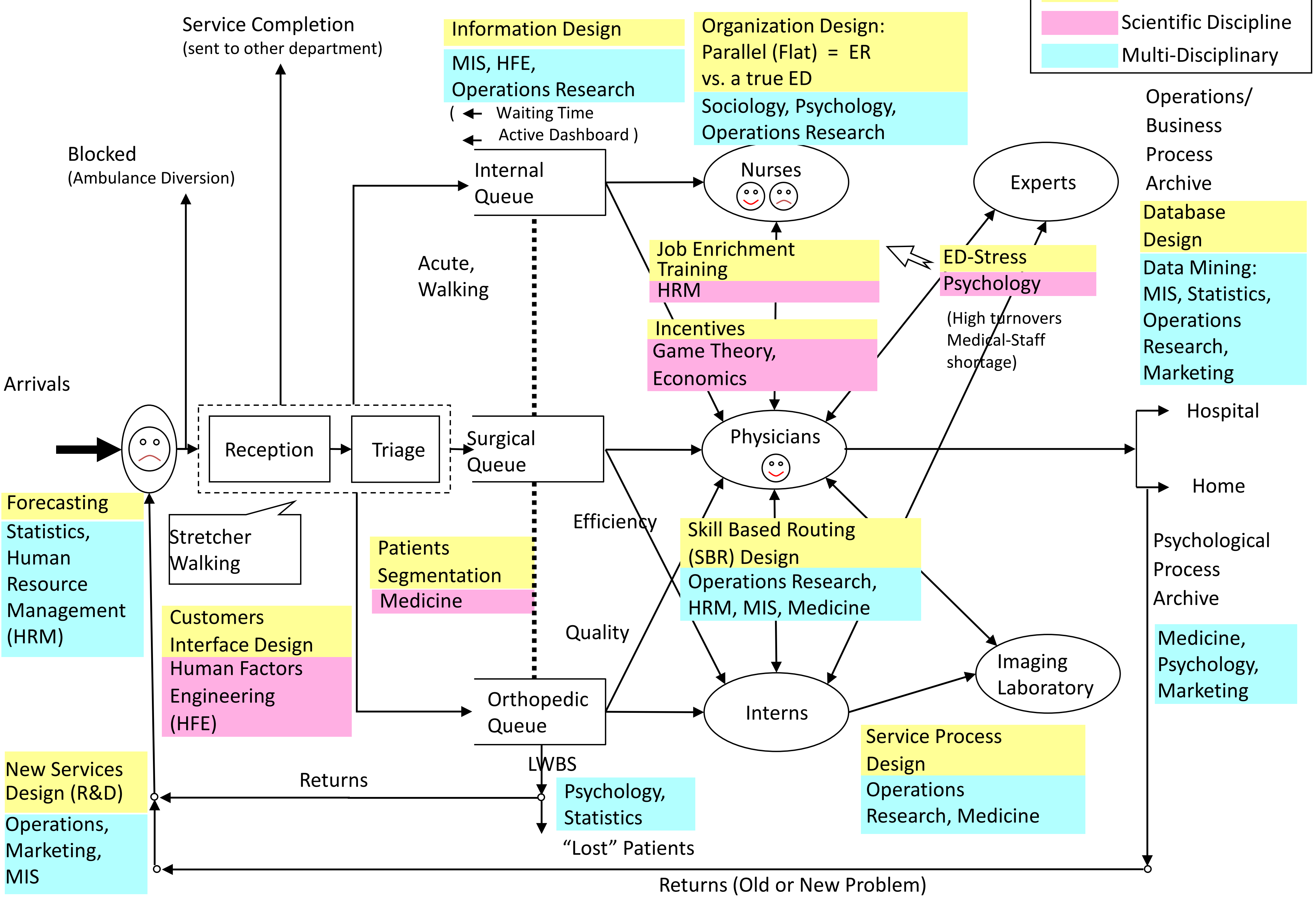
level of the individual transaction

Service Engineering of a Telephone Call Center

(Esprit de Corps)



Service Engineering of …



What defines a call center, back office ...
bizjournals.com

global AI industry Financial Times ...
salonurody.info

Pinterest
pinterest.com

Admission Essays Service - Smart ...
hydrocreditunion.com

Call Center: Call Center Environment

Tech 911 Headquarters - Event Sponsor ...

Isometric Call Center Office Royalty ...

Company Business News Latest Indian ...

Event-Logs in a Call Center (from ACD)

A Data Sample (Excel worksheet)

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
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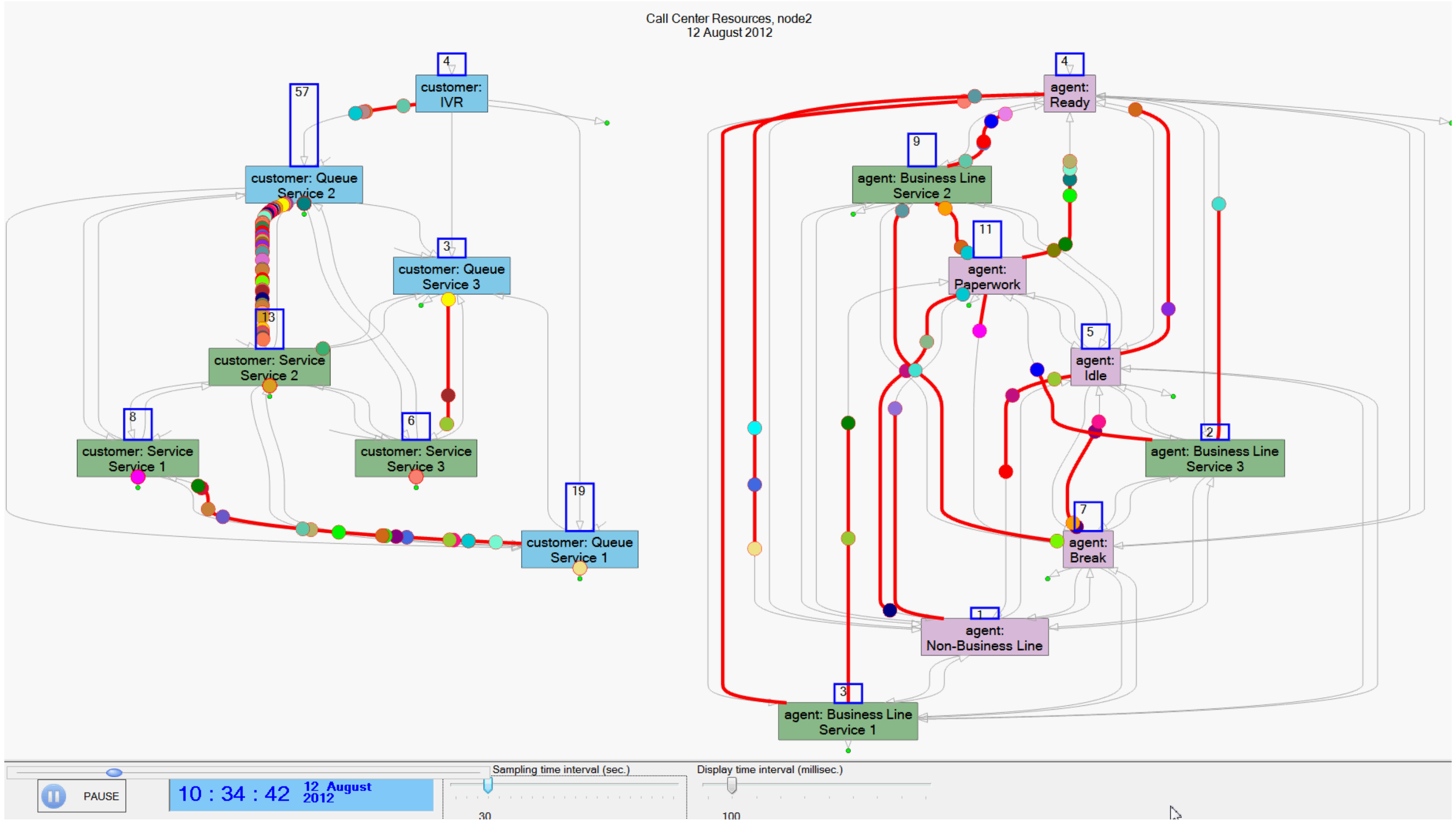
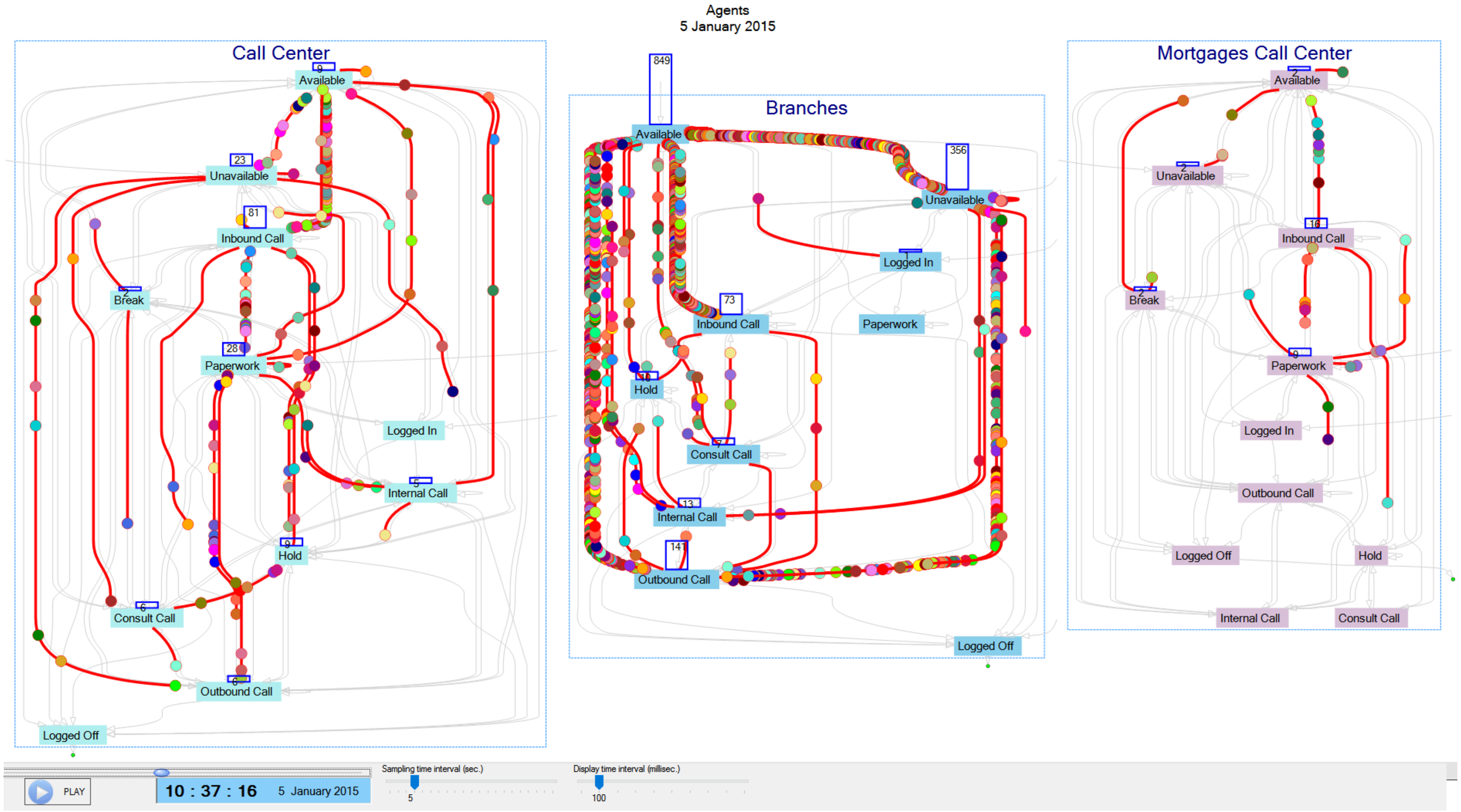
AA0101	44768	0	0	PS	990901	15:46:30	15:46:39	9	00:00:00	00:00:00	0	AGENT	15:46:38	15:51:51	313	ANAT
AA0101	44769	78191137	2	PS	990901	15:56:03	15:56:09	6	15:56:09	15:56:28	19	AGENT	15:56:28	15:59:02	154	MORIAH
AA0101	44770	0	0	PS	990901	16:14:31	16:14:46	15	00:00:00	00:00:00	0	AGENT	16:14:44	16:16:02	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

- Unsynchronized transition times, consistently

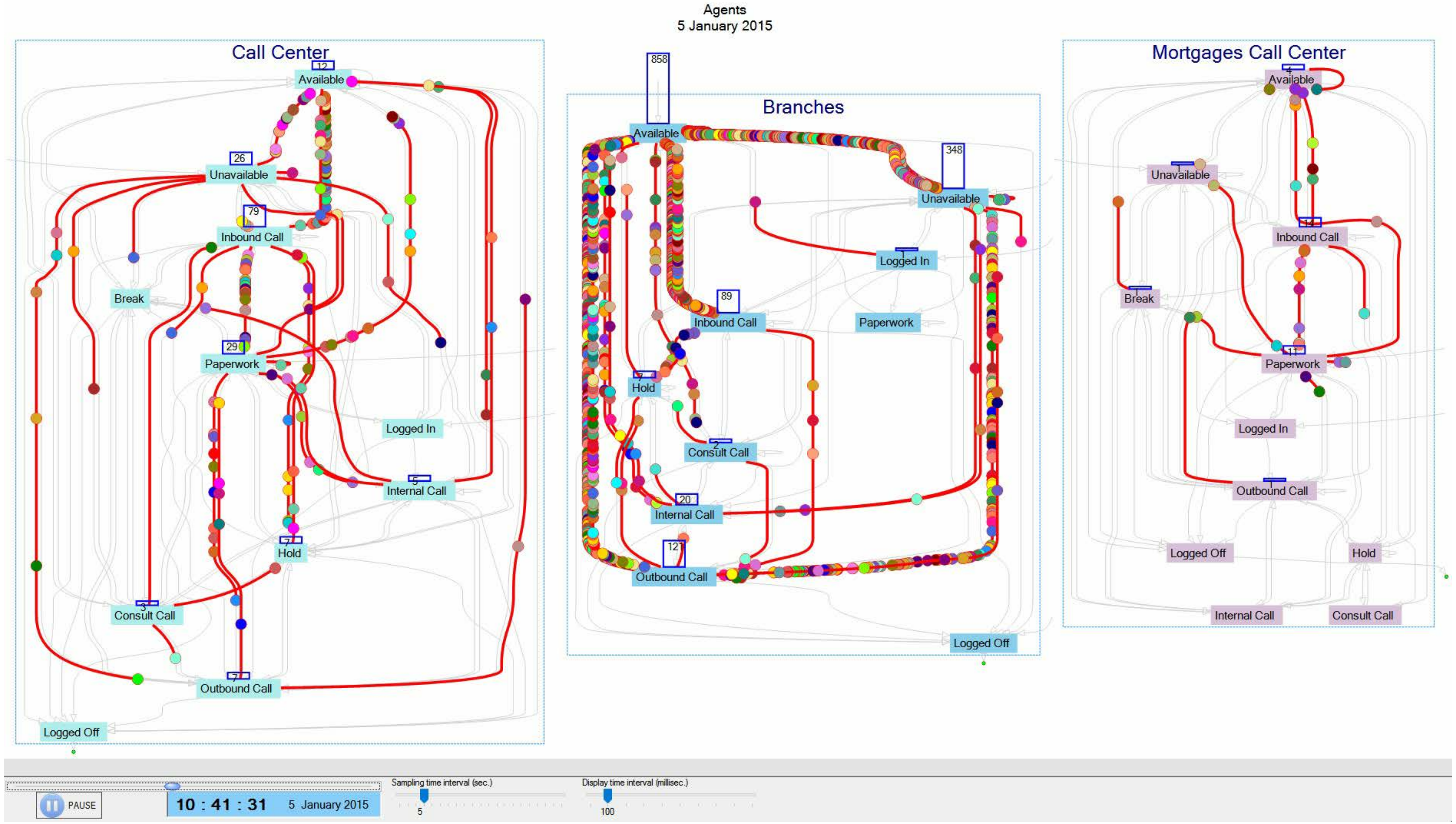
Operational Histories of Customers and Agents



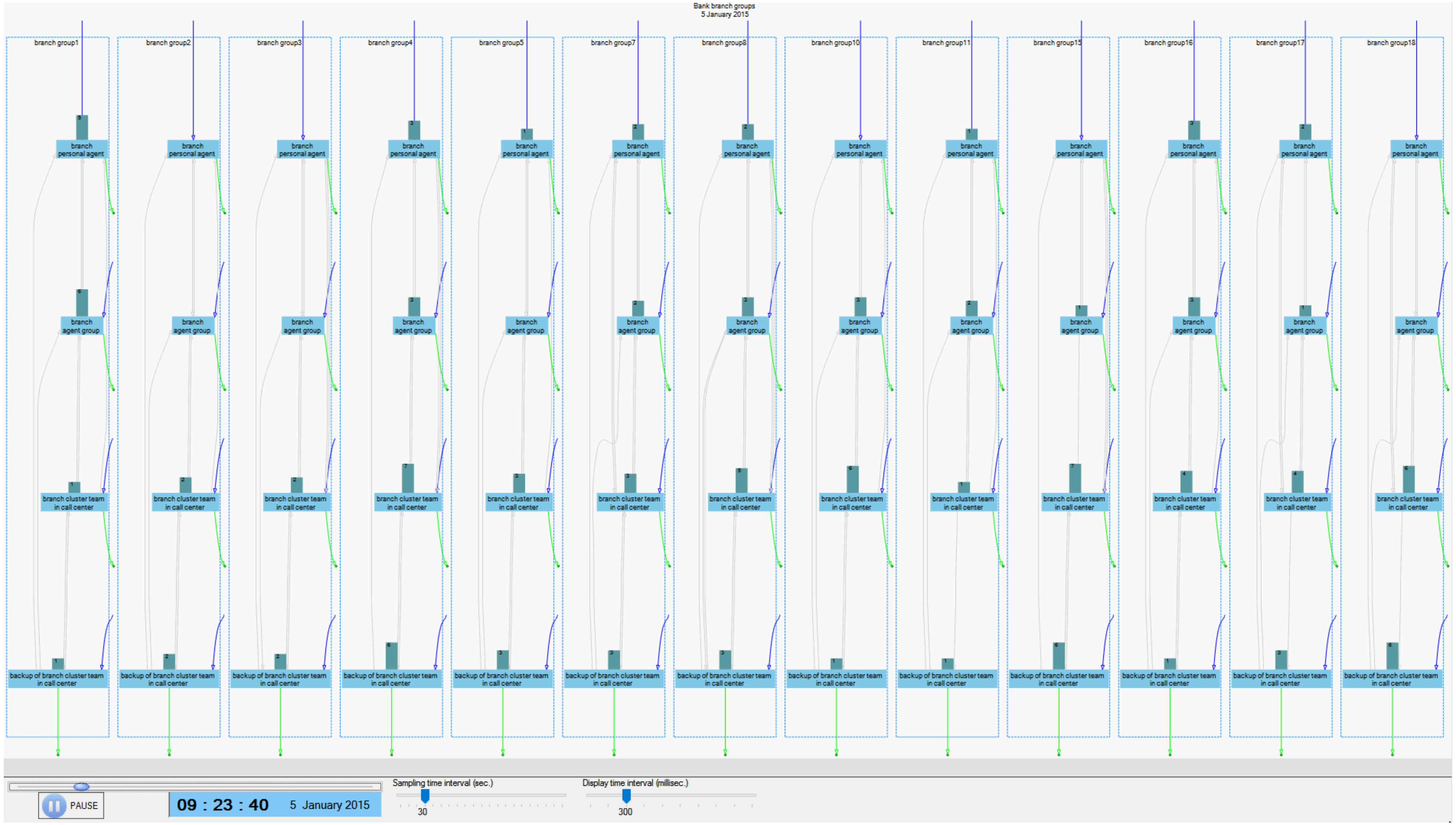
Agents (2000): Branches (1700) and Call Centers - Commercial (270), Mortgages (50)



Agents: Branches, Commercial and Mortgages Call Centers



Mining Telephone Queues: 2000 Bank-Agents, in Call-Centers + Branches (ILDU Bank)




What defines a call center, back office ...


global AI industry Financial Times ...


Pinterest


Admission Essays Service - Smart ...

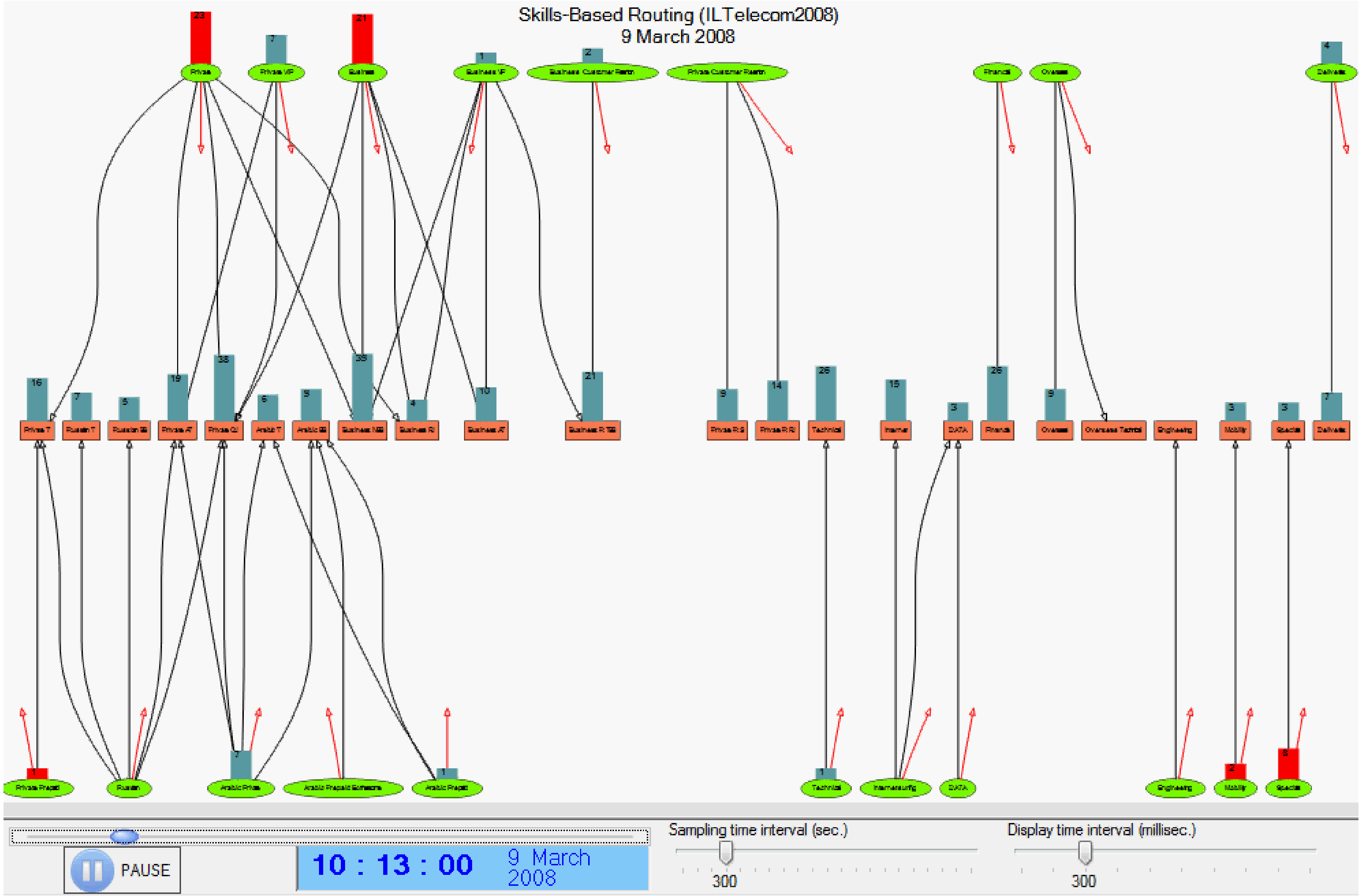
"Courage & Strength" from Call-Centers = Fruit-Flies of Hospitals

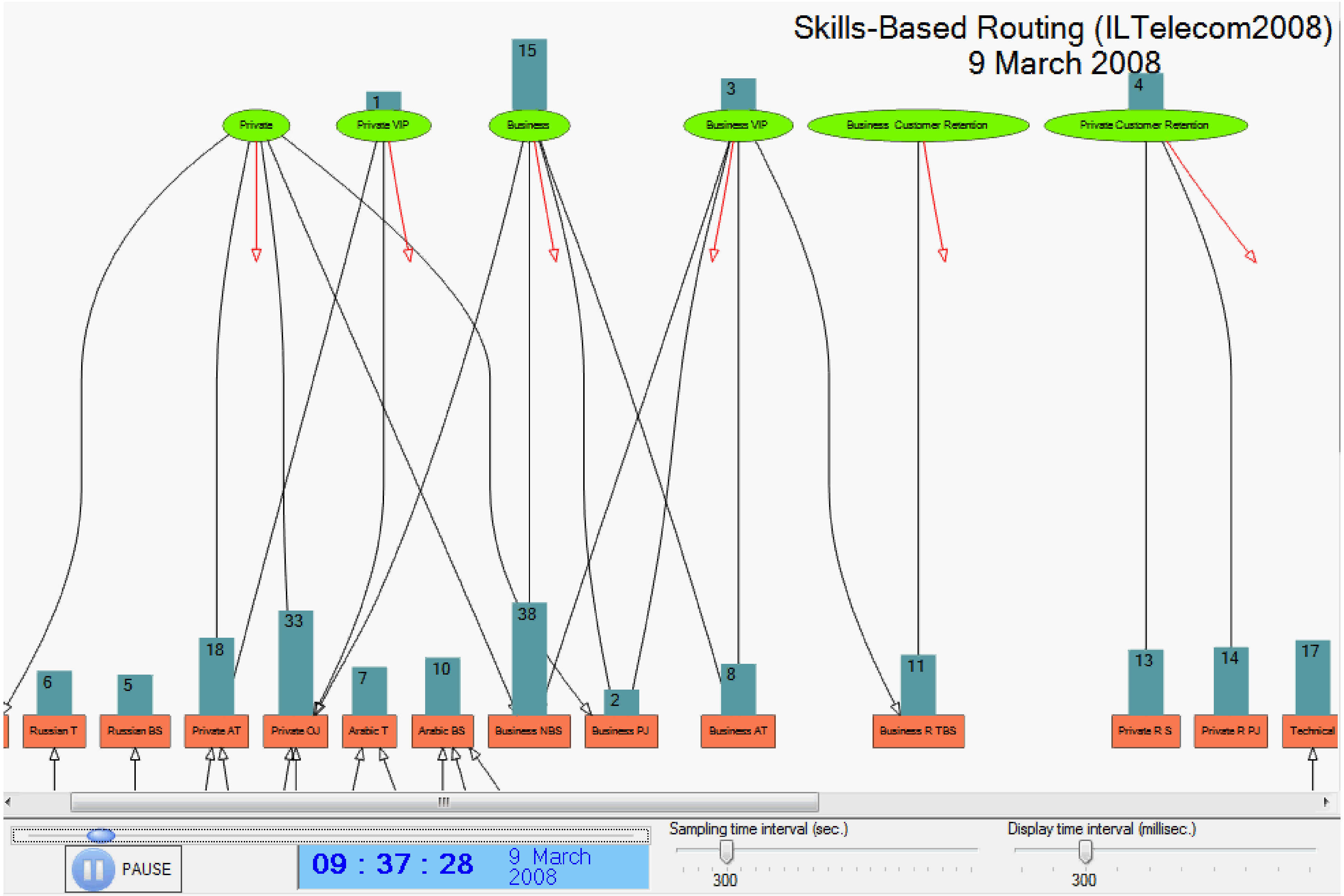

Call Center: Call Center Environment


Tech 911 Headquarters - Event Sponsor ...

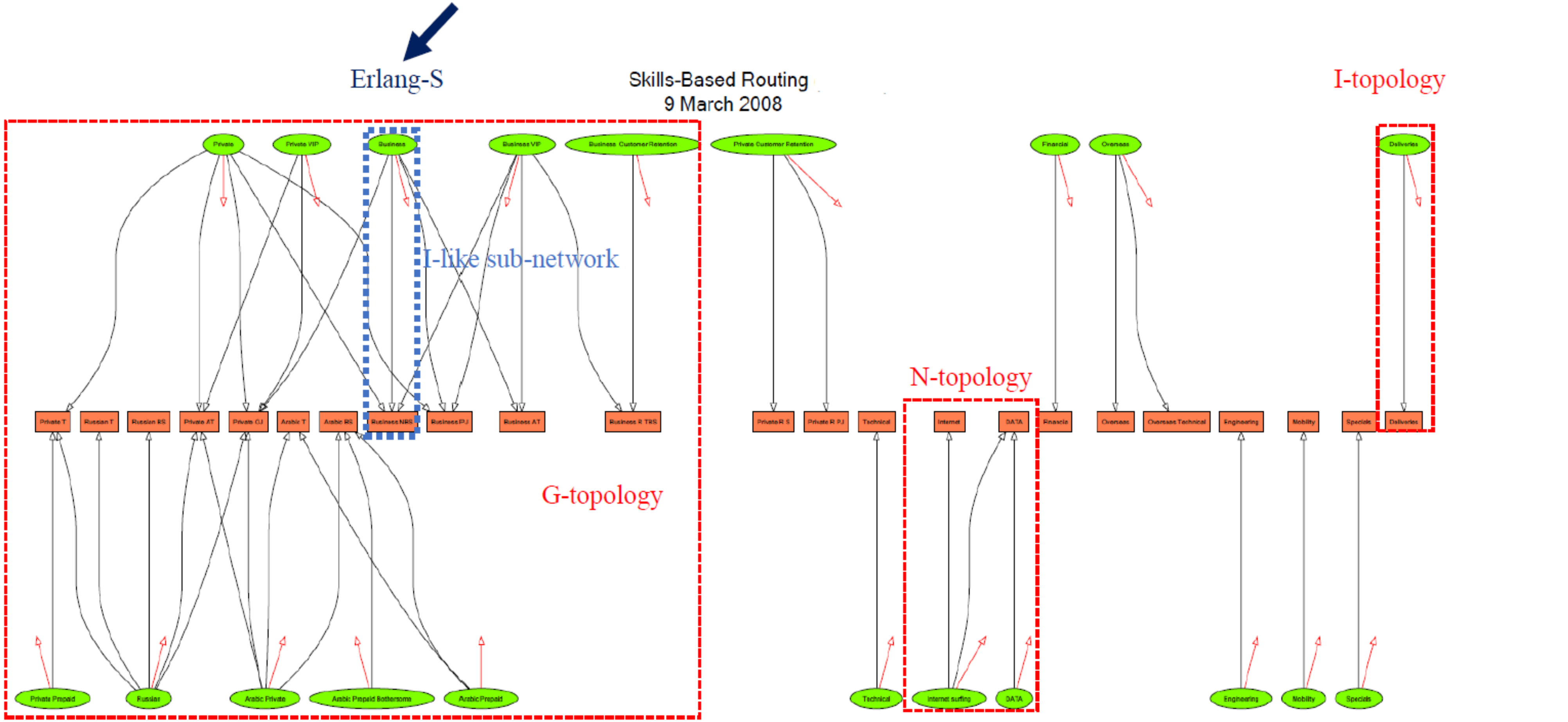

Isometric Call Center Office Royalty ...


Company Business News Latest Indian ...


Skills-Based Routing (ILTelecom2008)
9 March 2008
PAUSE
10 : 13 : 00
9 March
2008
Sampling time interval (sec.)
300
Display time interval (millisec.)
300


Skills-Based Routing (ILTelecom2008)
9 March 2008
Private
Private VIP
Business
Business VIP
Business Customer Retention
Private Customer Retention
Russian T
Russian BS
Private AT
Private OJ
Arabic T
Arabic BS
Business NBS
Business PJ
Business AT
Business R TBS
Private R S
Private R PJ
Technical
PAUSE
09 : 37 : 28
9 March 2008
Sampling time interval (sec.)
300
Display time interval (millisec.)
300

Call Center = Matching Customers & Agents (Skills-Based Routing)
Hospital = Patients Wards (Off-service Placement, Outlying)



Topology of a call center:
Server-queues are in the rectangles and customer-queues are in the ovals

Outline

- "Introduction"

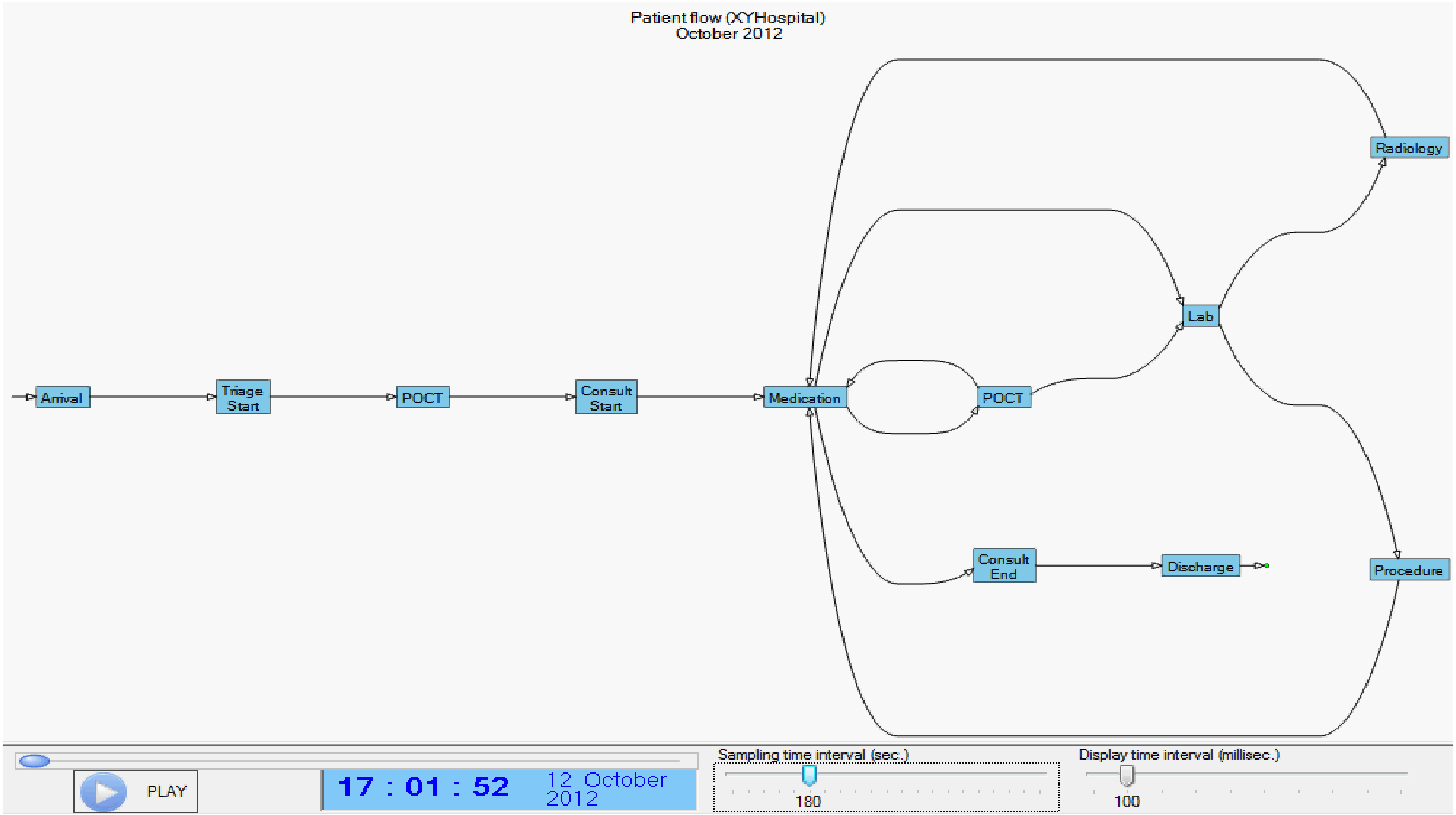
- Helpful history

- Strengths, via data

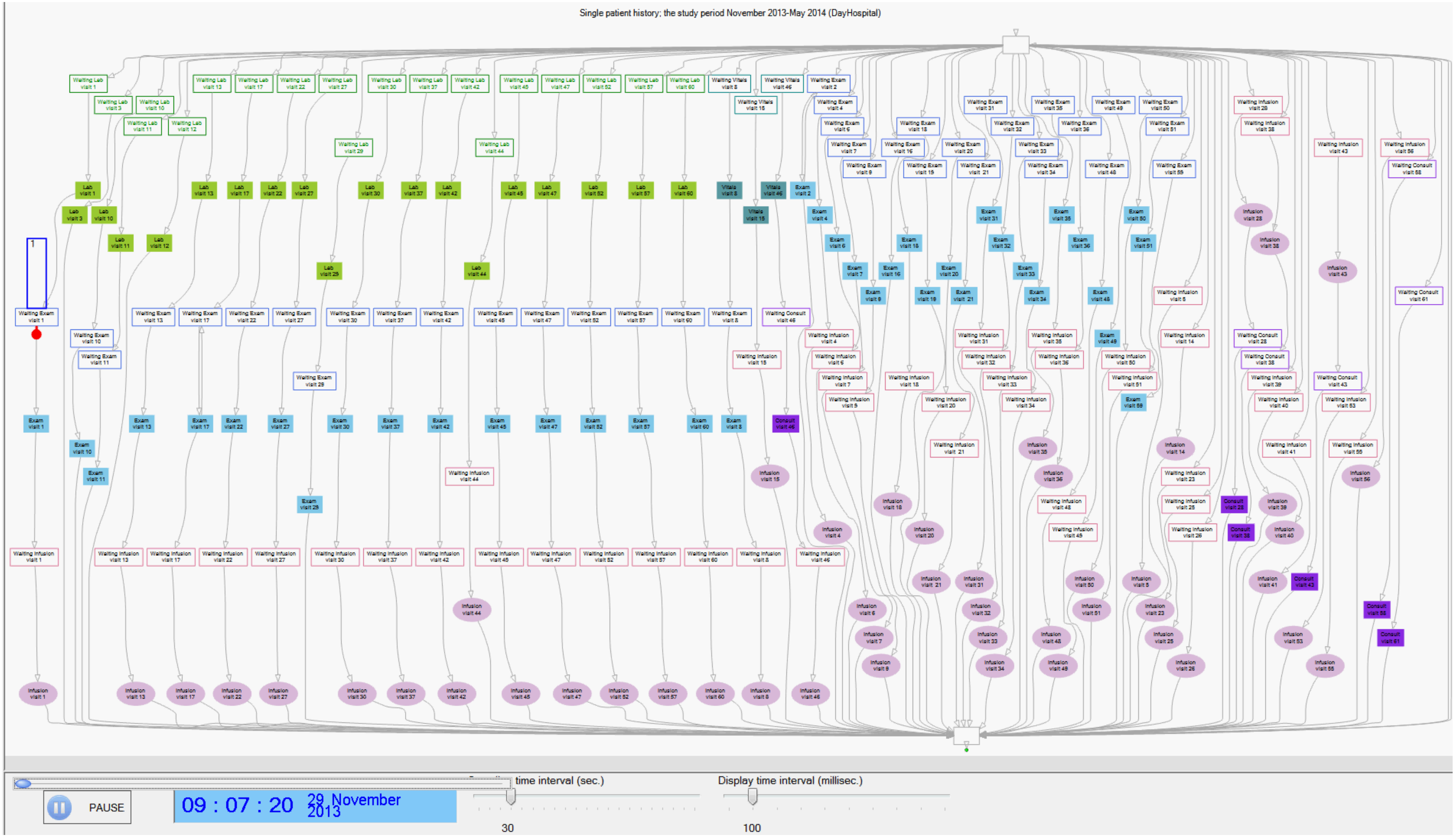
- Limitations, relative to needs

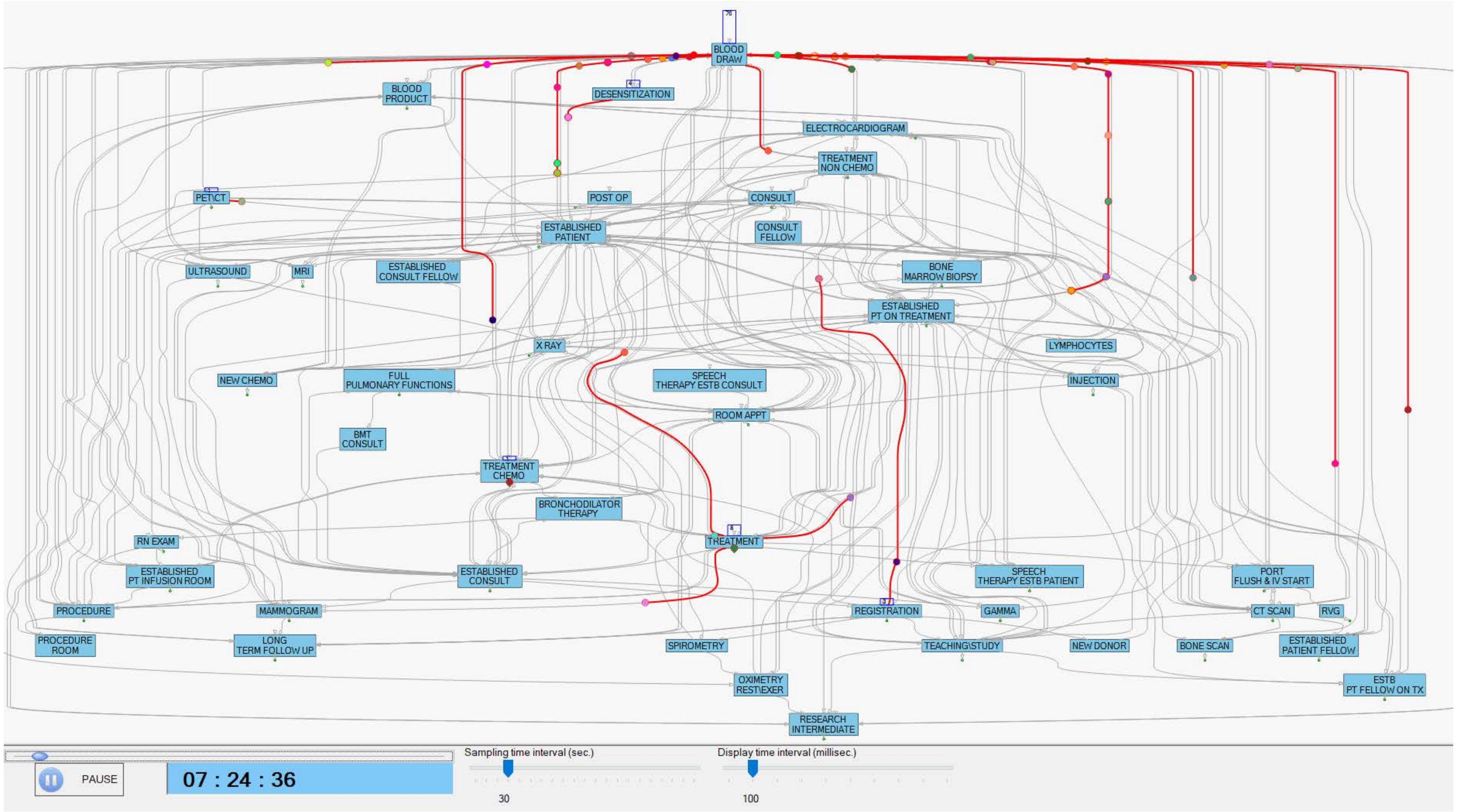
- Examples, that hint at future apps: Research, Practice

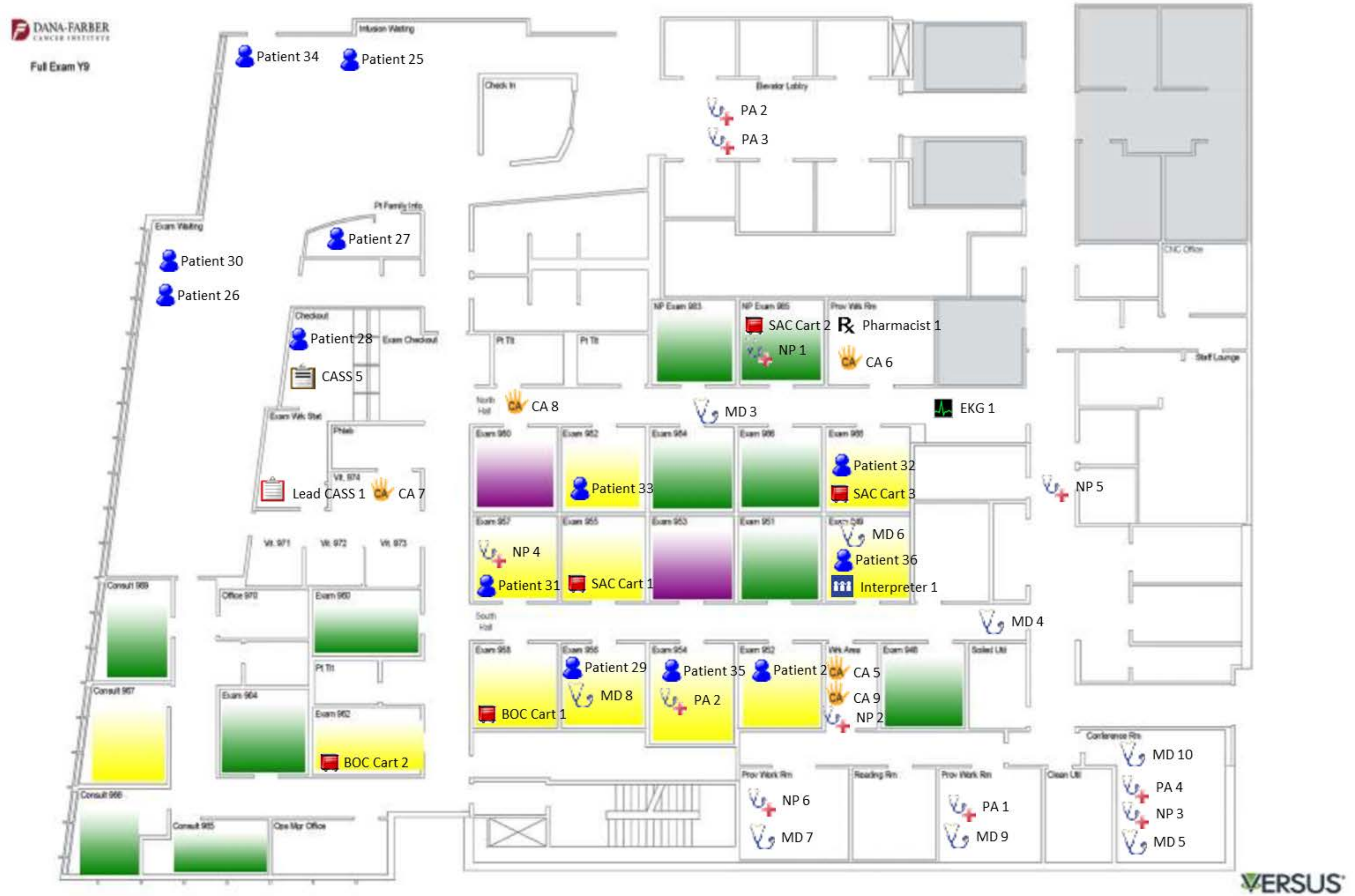
- Concluding speculations



Patient flow (XYHospital)
October 2012
Arrival
Triage Start
POCT
Consult Start
Medication
POCT
Lab
Radiology
Procedure
Consult End
Discharge
PLAY
17 : 01 : 52
12 October 2012
Sampling time interval (sec.)
180
Display time interval (millisec.)
100


Single patient history; the study period November 2013-May 2014 (DayHospital)
PAUSE
09 : 07 : 20
29 November 2013
time interval (sec.)
30
Display time interval (millisec.)
100


BLOOD DRAW
BLOOD PRODUCT
DESENSITIZATION
ELECTROCARDIOGRAM
TREATMENT NON CHEMO
PET\CT
POST OP
CONSULT
ESTABLISHED PATIENT
CONSULT FELLOW
ULTRASOUND
MRI
ESTABLISHED CONSULT FELLOW
BONE MARROW BIOPSY
ESTABLISHED PT ON TREATMENT
X RAY
LYMPHOCYTES
NEW CHEMO
FULL PULMONARY FUNCTIONS
SPEECH THERAPY ESTB CONSULT
INJECTION
ROOM APPT
BMT CONSULT
TREATMENT CHEMO
BRONCHODILATOR THERAPY
RN EXAM
TREATMENT
ESTABLISHED PT INFUSION ROOM
ESTABLISHED CONSULT
SPEECH THERAPY ESTB PATIENT
PORT FLUSH & IV START
PROCEDURE
MAMMOGRAM
REGISTRATION
GAMMA
CT SCAN
RVG
PROCEDURE ROOM
LONG TERM FOLLOW UP
SPIROMETRY
TEACHING\STUDY
NEW DONOR
BONE SCAN
ESTABLISHED PATIENT FELLOW
OXIMETRY REST\EXER
ESTB PT FELLOW ON TX
RESEARCH INTERMEDIATE
PAUSE
07 : 24 : 36
Sampling time interval (sec.)
30
Display time interval (millisec.)
100

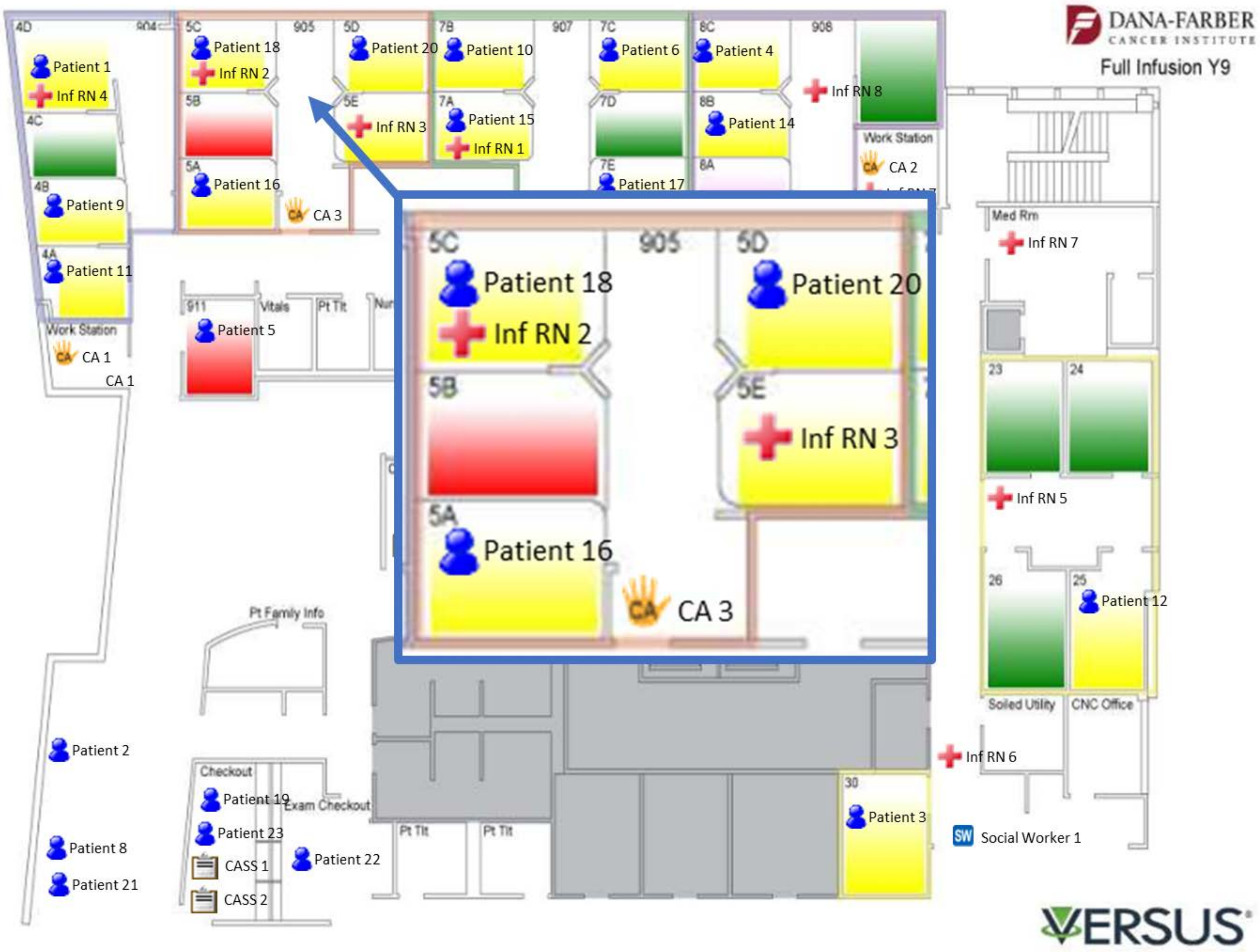


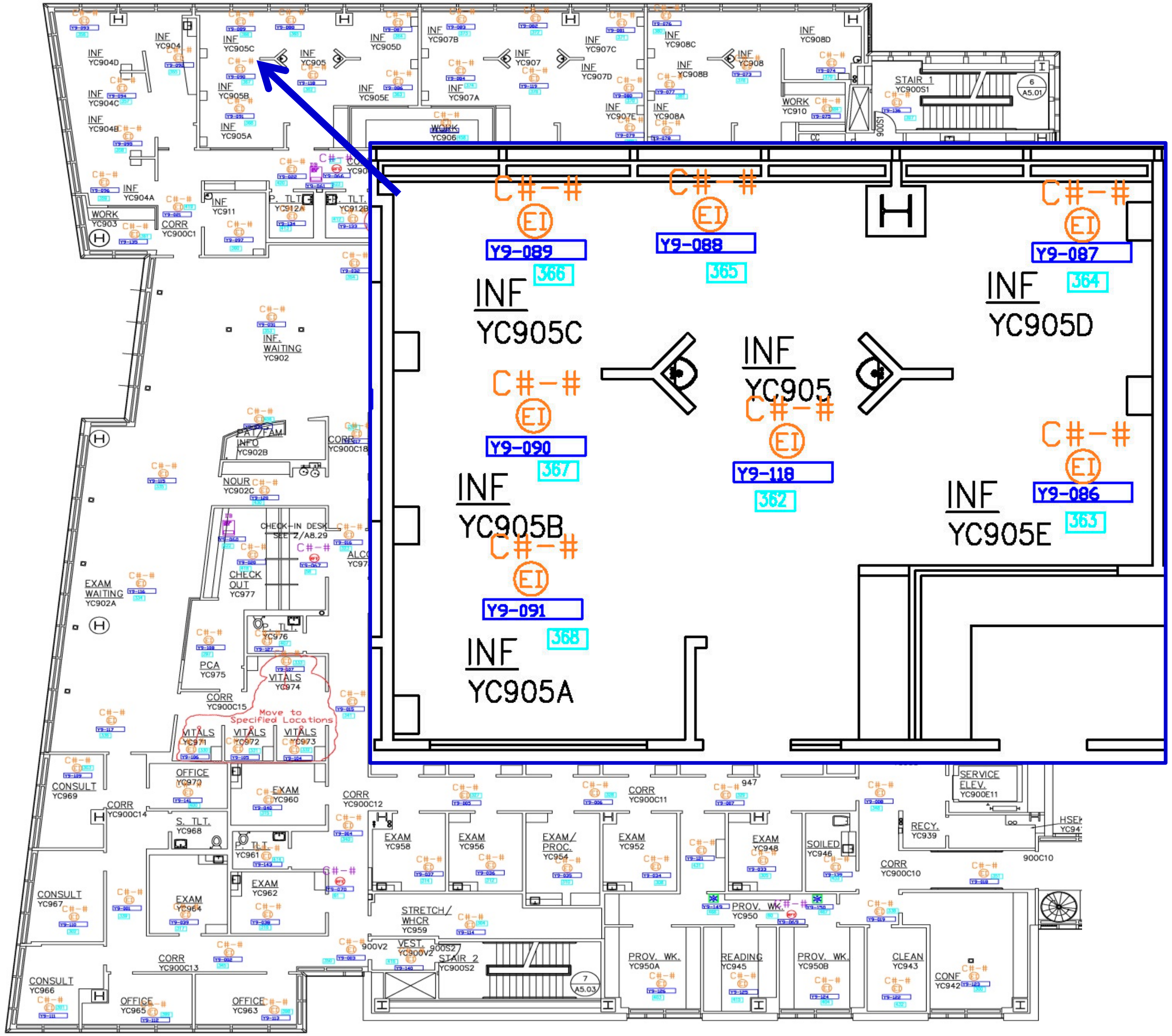
DANA-FARBER CANCER INSTITUTE
Full Exam Y9
Patient 34
Patient 25
Patient 27
Patient 30
Patient 26
Patient 28
CASS 5
Lead CASS 1
CA 7
CA 8
PA 2
PA 3
SAC Cart 2
Pharmacist 1
NP 1
CA 6
MD 3
EKG 1
Patient 32
SAC Cart 3
Patient 33
NP 5
MD 6
Patient 36
Interpreter 1
NP 4
Patient 31
SAC Cart 1
MD 4
Patient 29
MD 8
Patient 35
Patient 2
CA 5
CA 9
NP 2
PA 2
BOC Cart 1
BOC Cart 2
MD 10
PA 4
NP 3
MD 5
NP 6
MD 7
PA 1
MD 9
VERSUS

DANA-FARBER CANCER INSTITUTE

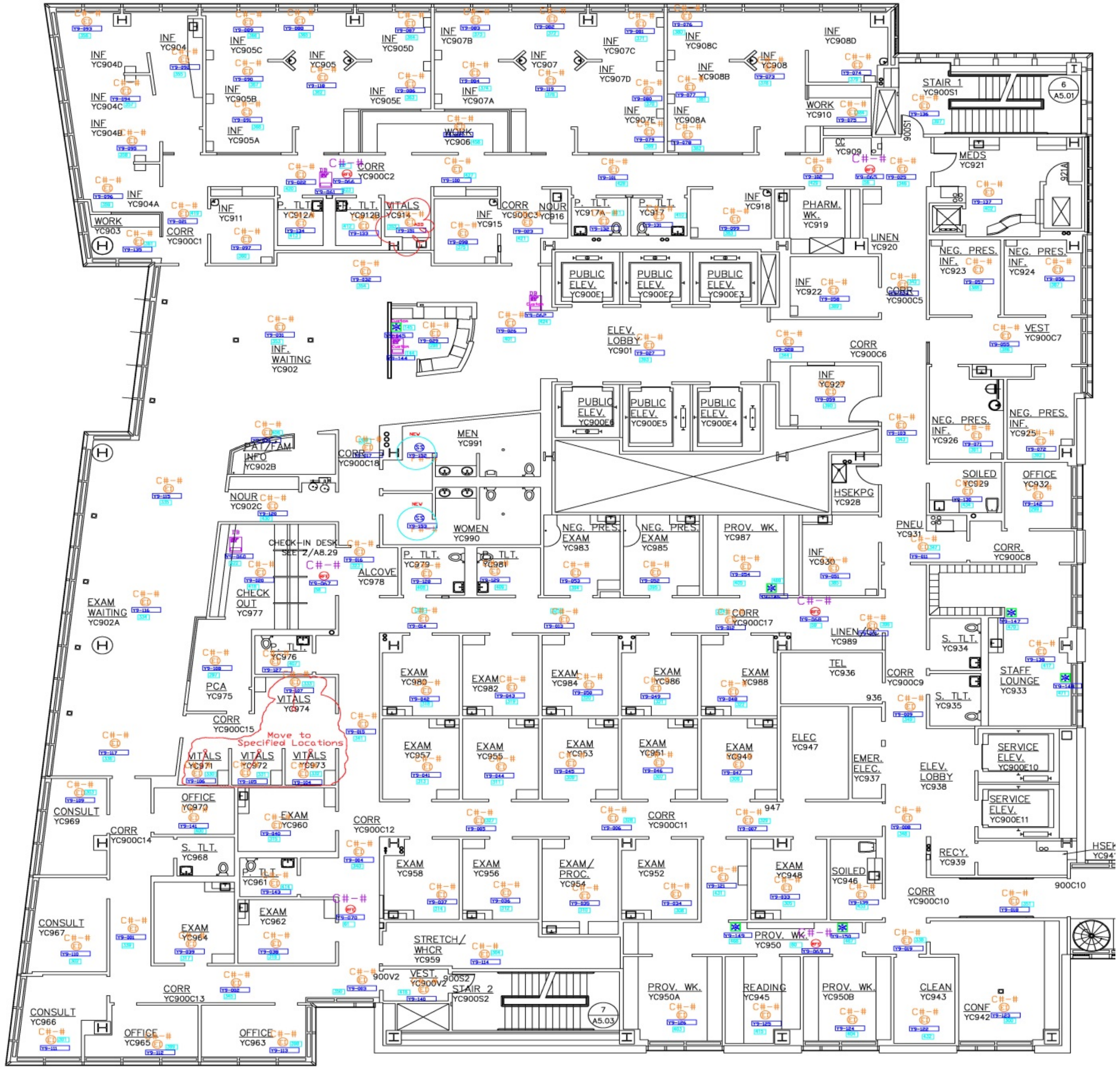
Full Infusion Y9

VERSUS


DANA-FARBER CANCER INSTITUTE
Full Infusion Y9
4D
904
5C
905
5D
7B
907
7C
8C
908
Patient 1
Inf RN 4
4C
4B
Patient 9
4A
Patient 11
Work Station
CA 1
CA 1
Patient 18
Inf RN 2
5B
5A
Patient 16
CA 3
Patient 20
5E
Inf RN 3
Patient 10
7A
Patient 15
Inf RN 1
Patient 6
7D
7E
Patient 17
Patient 4
8B
Patient 14
8A
Inf RN 8
Work Station
CA 2
Med Rm
Inf RN 7
911
Vitals
Pt Tlt
Patient 5
23
24
Inf RN 5
26
25
Patient 12
Soiled Utility
CNC Office
Pt Family Info
Patient 2
Patient 8
Patient 21
Checkout
Patient 19
Exam Checkout
Patient 23
CASS 1
CASS 2
Patient 22
Pt Tlt
Pt Tlt
30
Patient 3
Inf RN 6
SW
Social Worker 1
VERSUS

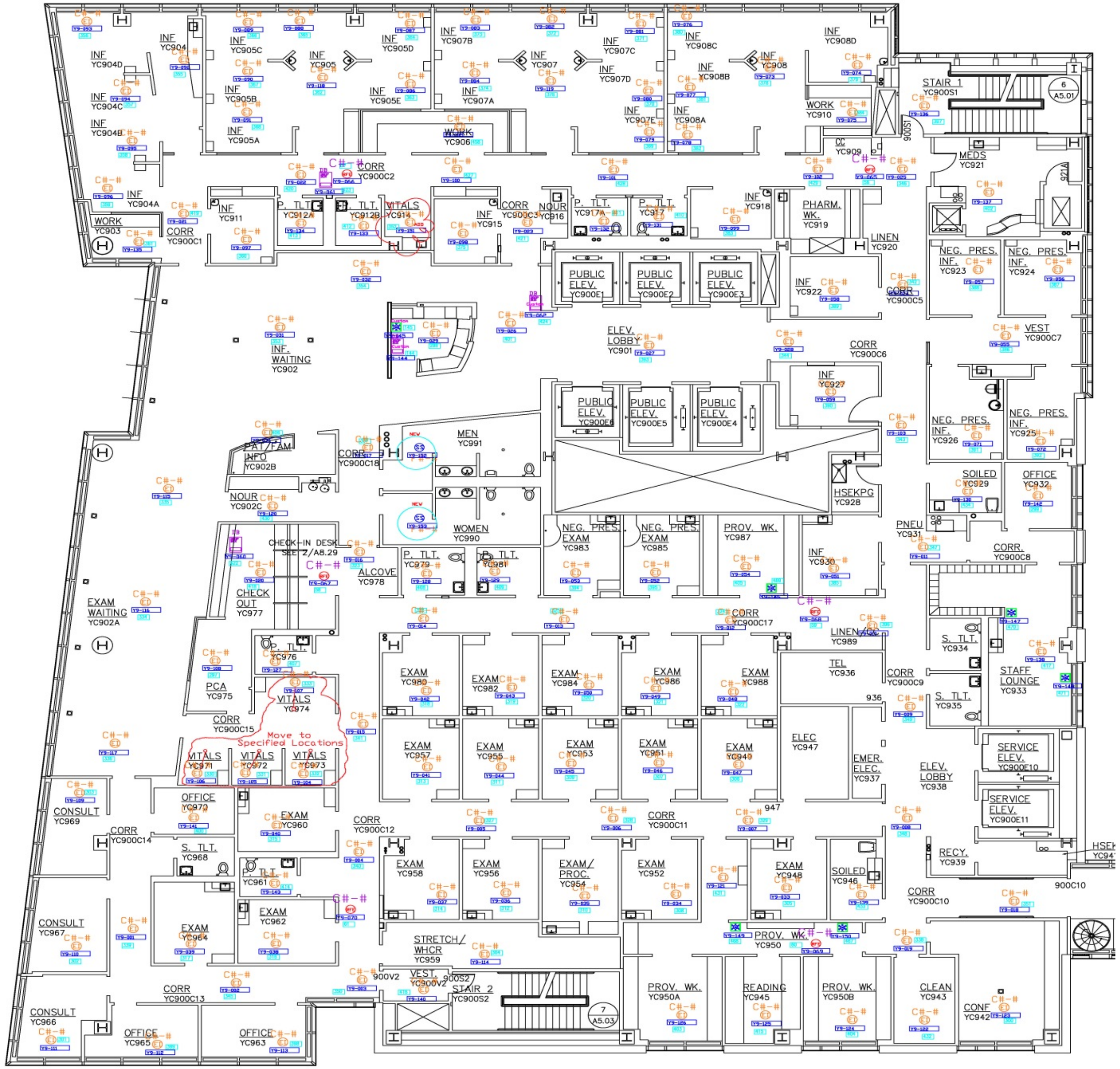

C#-#
EI
Y9-089
366
INF
YC905C
Y9-088
365
Y9-087
364
INF
YC905D
INF
YC905
Y9-090
367
Y9-118
362
INF
YC905B
Y9-086
363
INF
YC905E
Y9-091
368
INF
YC905A

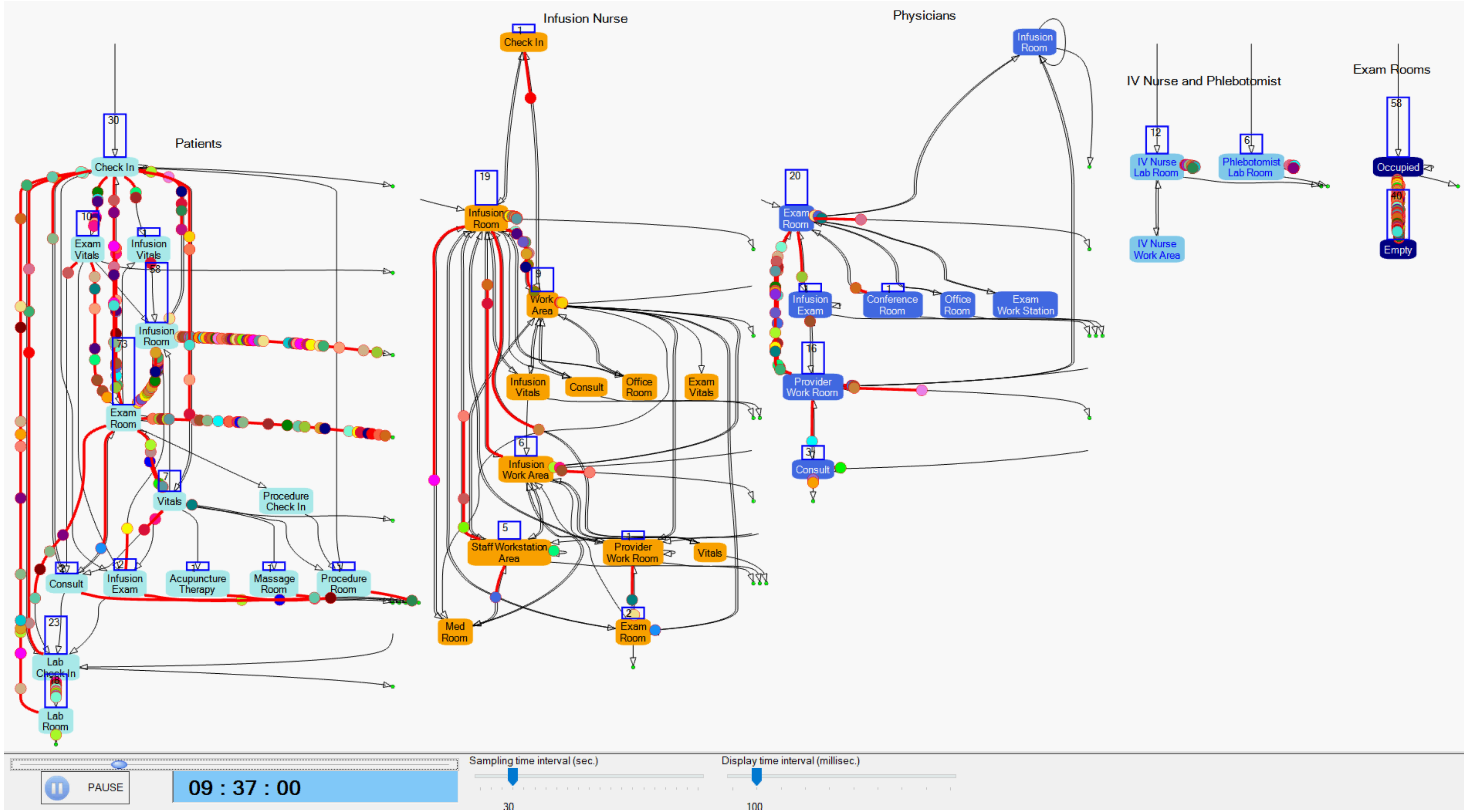
900 RTLS sensors
Location every 3 seconds
1GB per week
Since November 2013

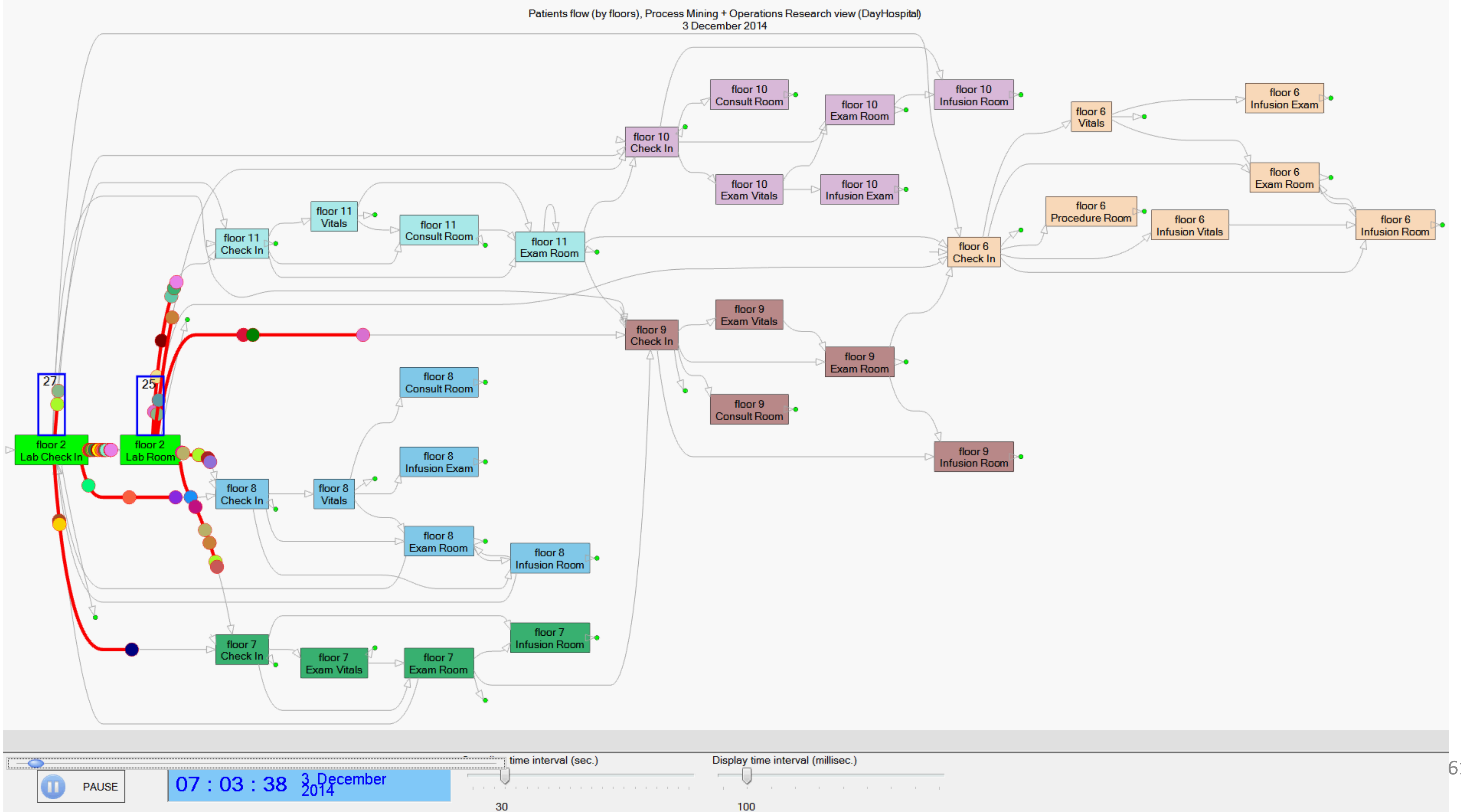


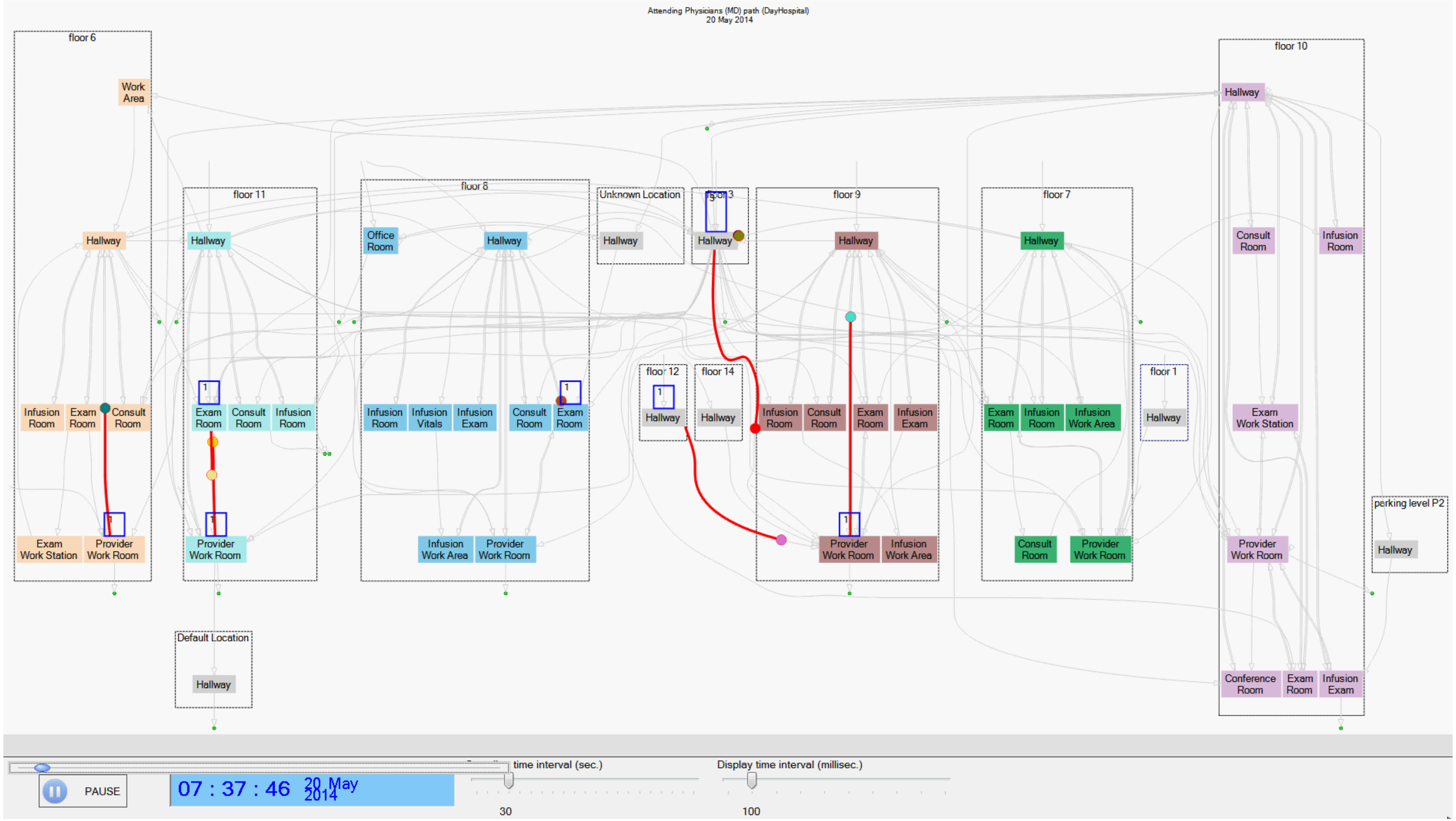
900 RTLS sensors
Location every 3 seconds
1GB per week
Since November 2013

900-1000 patients per day
300-400 doctors & nurses
8 clinical floors

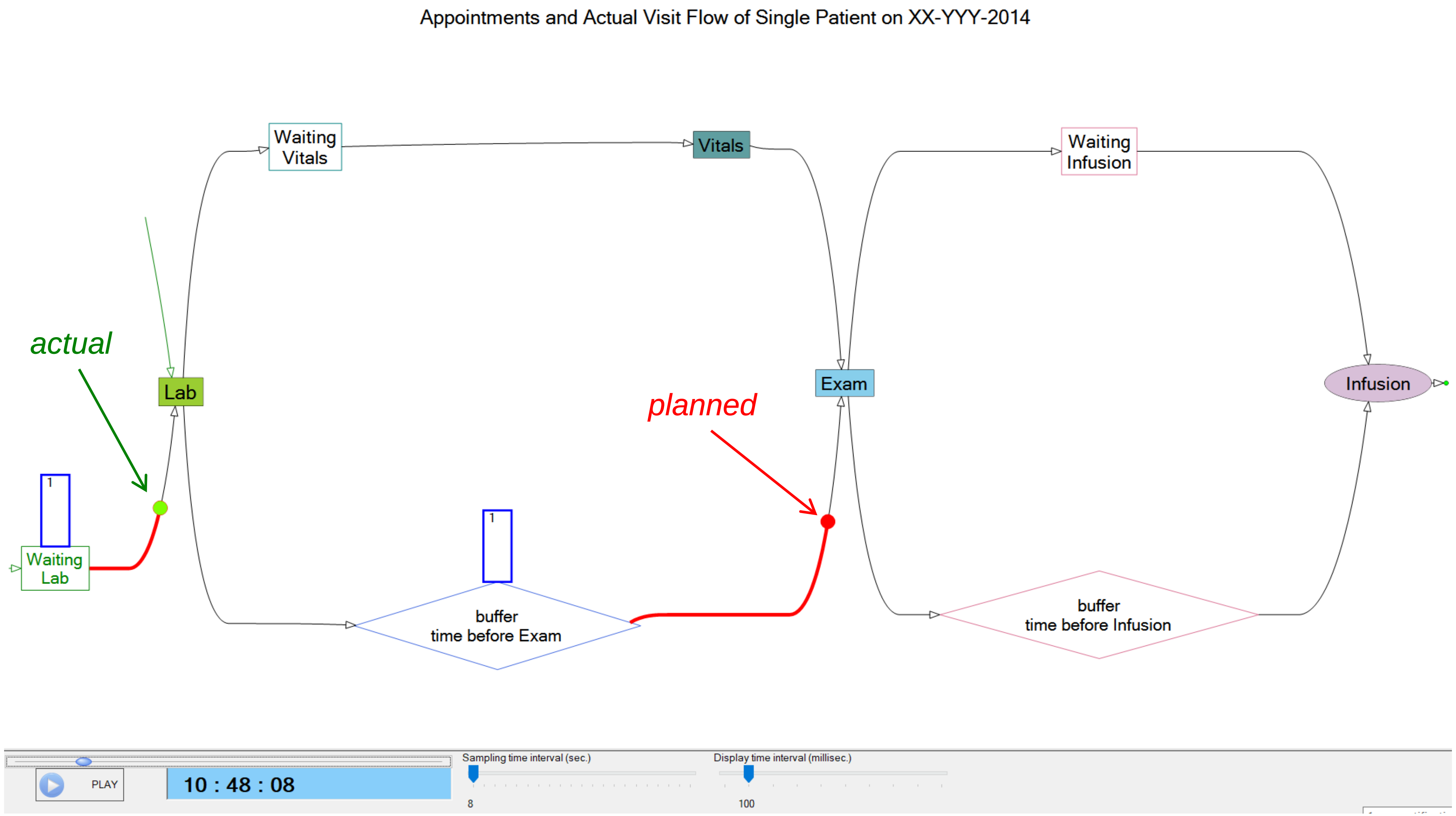


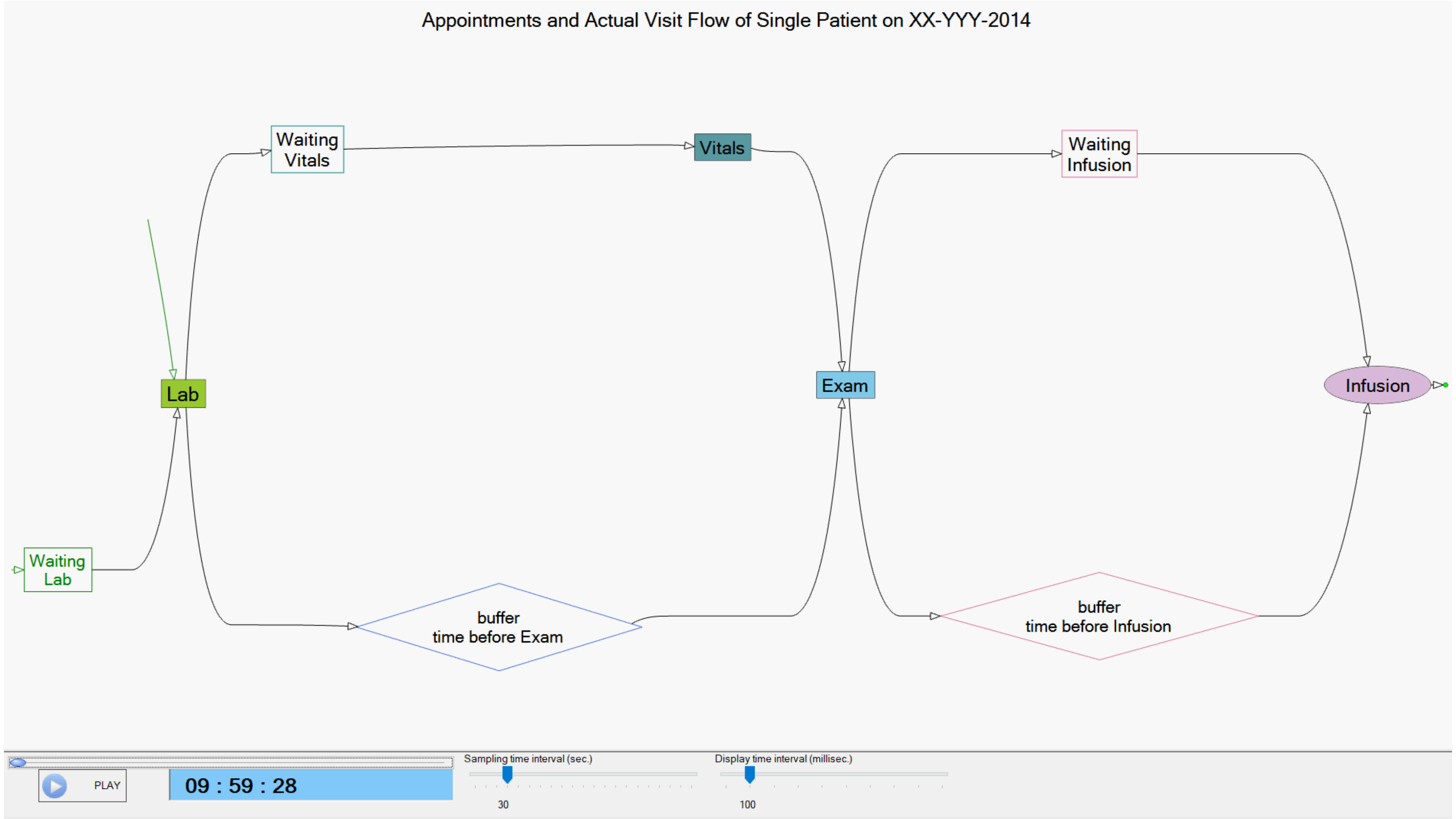

Patients
Check In
Exam Vitals
Infusion Vitals
Infusion Room
Exam Room
Vitals
Procedure Check In
Consult
Infusion Exam
Acupuncture Therapy
Massage Room
Procedure Room
Lab Check In
Lab Room
Infusion Nurse
Check In
Infusion Room
Work Area
Infusion Vitals
Consult
Office Room
Exam Vitals
Infusion Work Area
Staff Workstation Area
Provider Work Room
Vitals
Med Room
Exam Room
Physicians
Infusion Room
Exam Room
Infusion Exam
Conference Room
Office Room
Exam Work Station
Provider Work Room
Consult
IV Nurse and Phlebotomist
IV Nurse Lab Room
Phlebotomist Lab Room
IV Nurse Work Area
Exam Rooms
Occupied
Empty
PAUSE
09 : 37 : 00
Sampling time interval (sec.)
30
Display time interval (millisec.)
100


Patients flow (by floors), Process Mining + Operations Research view (DayHospital)
3 December 2014
floor 10
Consult Room
floor 10
Exam Room
floor 10
Infusion Room
floor 6
Vitals
floor 6
Infusion Exam
floor 10
Check In
floor 10
Exam Vitals
floor 10
Infusion Exam
floor 6
Exam Room
floor 6
Procedure Room
floor 6
Infusion Vitals
floor 6
Infusion Room
floor 11
Vitals
floor 11
Consult Room
floor 11
Check In
floor 11
Exam Room
floor 6
Check In
floor 9
Exam Vitals
floor 9
Check In
floor 9
Exam Room
floor 9
Consult Room
floor 9
Infusion Room
floor 8
Consult Room
floor 8
Infusion Exam
27
25
floor 2
Lab Check In
floor 2
Lab Room
floor 8
Check In
floor 8
Vitals
floor 8
Exam Room
floor 8
Infusion Room
floor 7
Infusion Room
floor 7
Check In
floor 7
Exam Vitals
floor 7
Exam Room
time interval (sec.)
Display time interval (millisec.)
PAUSE
07 : 03 : 38
3 December
2014
30
100

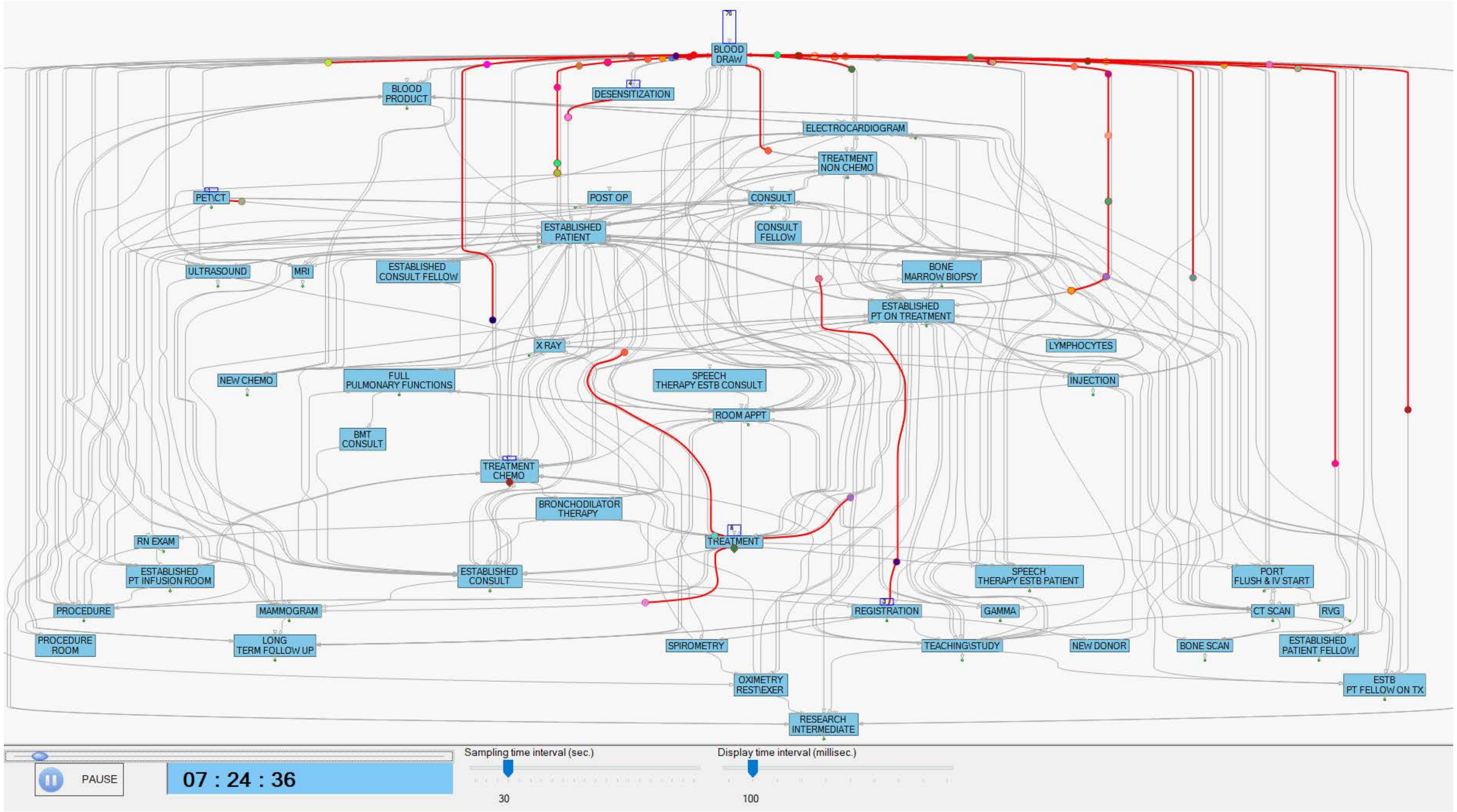

Attending Physicians (MD) path (DayHospital)
20 May 2014
floor 6
Work Area
Hallway
Infusion Room
Exam Room
Consult Room
Exam Work Station
Provider Work Room
floor 11
Hallway
Exam Room
Consult Room
Infusion Room
Provider Work Room
floor 8
Office Room
Hallway
Infusion Room
Infusion Vitals
Infusion Exam
Consult Room
Exam Room
Infusion Work Area
Provider Work Room
Unknown Location
Hallway
floor 3
Hallway
floor 12
Hallway
floor 14
Hallway
floor 9
Hallway
Infusion Room
Consult Room
Exam Room
Infusion Exam
Provider Work Room
Infusion Work Area
floor 7
Hallway
Exam Room
Infusion Room
Infusion Work Area
Consult Room
Provider Work Room
floor 1
Hallway
floor 10
Hallway
Consult Room
Infusion Room
Exam Work Station
Provider Work Room
Conference Room
Exam Room
Infusion Exam
parking level P2
Hallway
Default Location
Hallway
time interval (sec.)
Display time interval (millisec.)
PAUSE
07 : 37 : 46
20 May 2014
30
100

Appointment-Net vs. Actual-Net
Single Patient





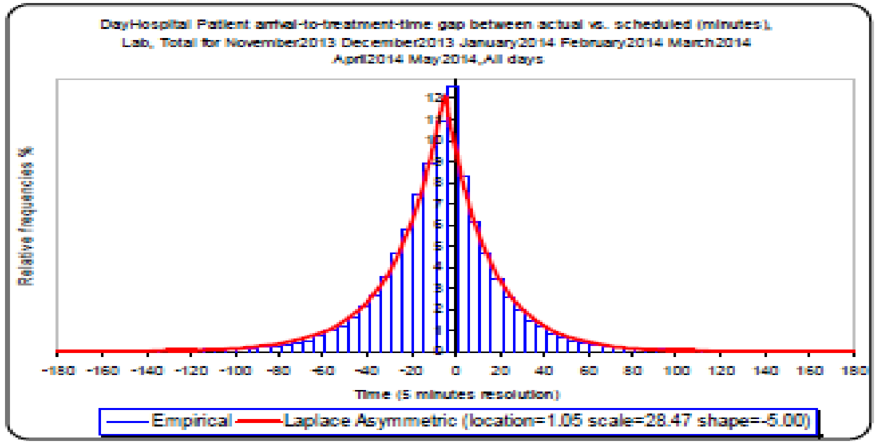
Appointments and Actual Visit Flow of Single Patient on XX-YYY-2014
Waiting Vitals
Vitals
Waiting Infusion
Lab
Exam
Infusion
Waiting Lab
buffer time before Exam
buffer time before Infusion
PLAY
09 : 59 : 28
Sampling time interval (sec.)
30
Display time interval (millisec.)
100



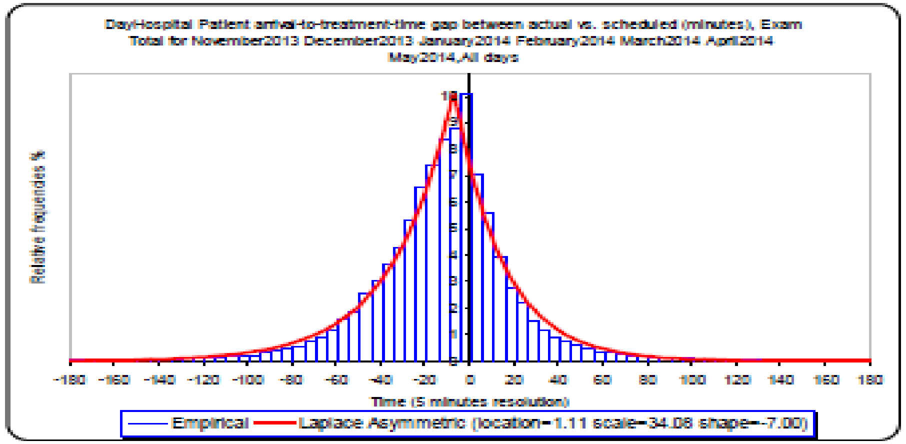
BLOOD DRAW
BLOOD PRODUCT
DESENSITIZATION
ELECTROCARDIOGRAM
TREATMENT NON CHEMO
PET\CT
POST OP
CONSULT
ESTABLISHED PATIENT
CONSULT FELLOW
ULTRASOUND
MRI
ESTABLISHED CONSULT FELLOW
BONE MARROW BIOPSY
ESTABLISHED PT ON TREATMENT
X RAY
LYMPHOCYTES
NEW CHEMO
FULL PULMONARY FUNCTIONS
SPEECH THERAPY ESTB CONSULT
INJECTION
ROOM APPT
BMT CONSULT
TREATMENT CHEMO
BRONCHODILATOR THERAPY
RN EXAM
TREATMENT
ESTABLISHED PT INFUSION ROOM
ESTABLISHED CONSULT
SPEECH THERAPY ESTB PATIENT
PORT FLUSH & IV START
PROCEDURE
MAMMOGRAM
REGISTRATION
GAMMA
CT SCAN
RVG
PROCEDURE ROOM
LONG TERM FOLLOW UP
SPIROMETRY
TEACHING\STUDY
NEW DONOR
BONE SCAN
ESTABLISHED PATIENT FELLOW
OXIMETRY REST\EXER
ESTB PT FELLOW ON TX
RESEARCH INTERMEDIATE
PAUSE
07 : 24 : 36
Sampling time interval (sec.)
30
Display time interval (millisec.)
100

Primitives: Punctuality
Planned vs. Actual Arrival to Service
@ Stations 1, 2, 3 in a Hospital

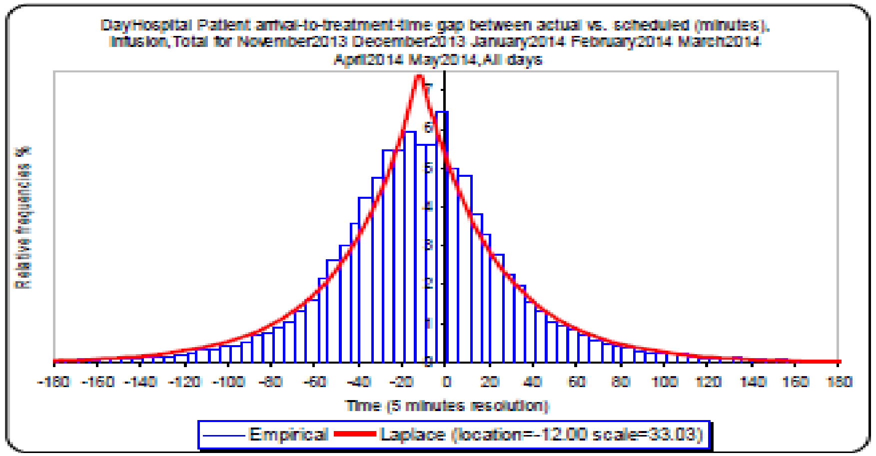
Lab (mean = -7 min)



Exam (mean = -12 min)



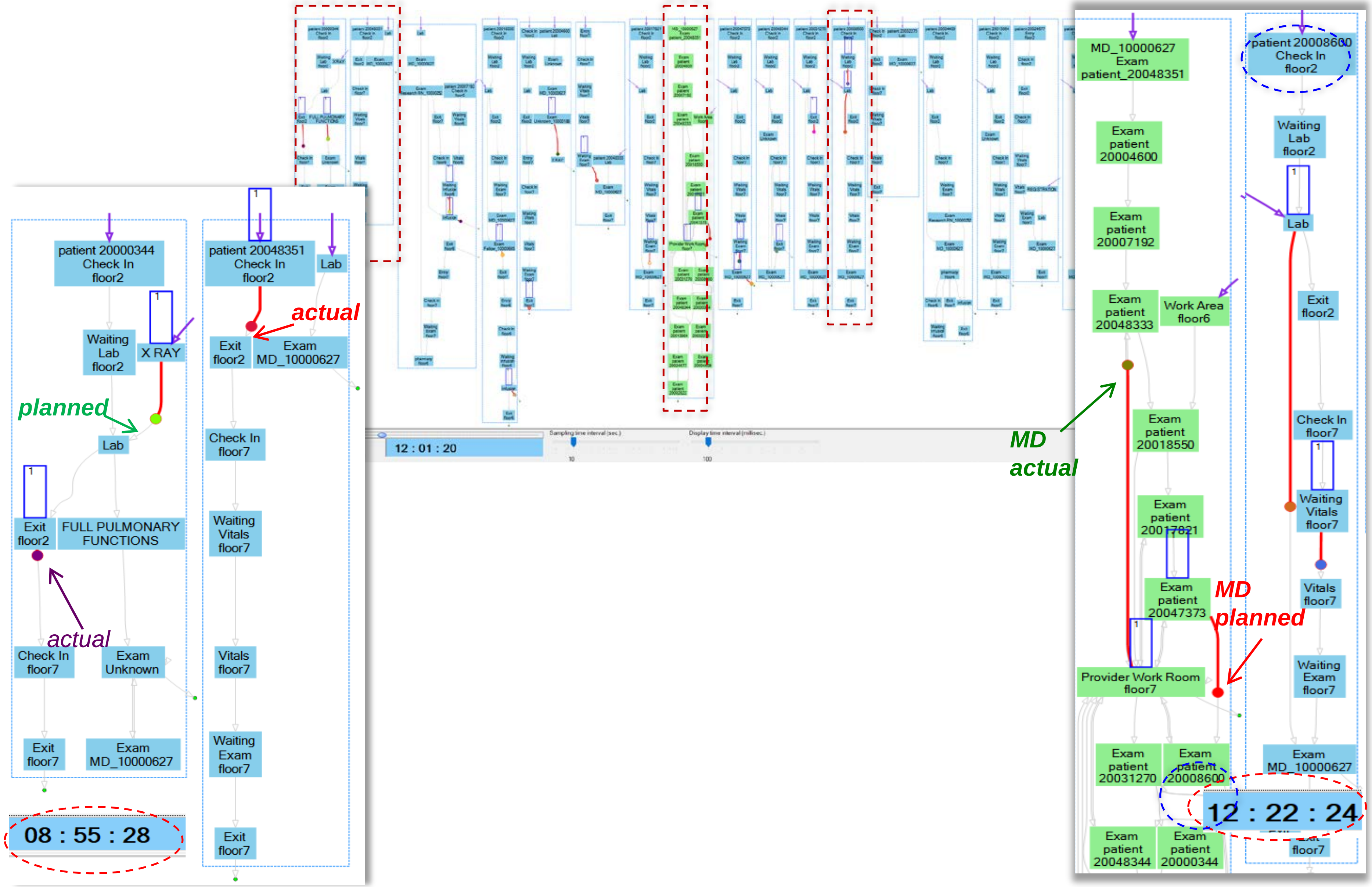
Infusion (mean = -12 min)

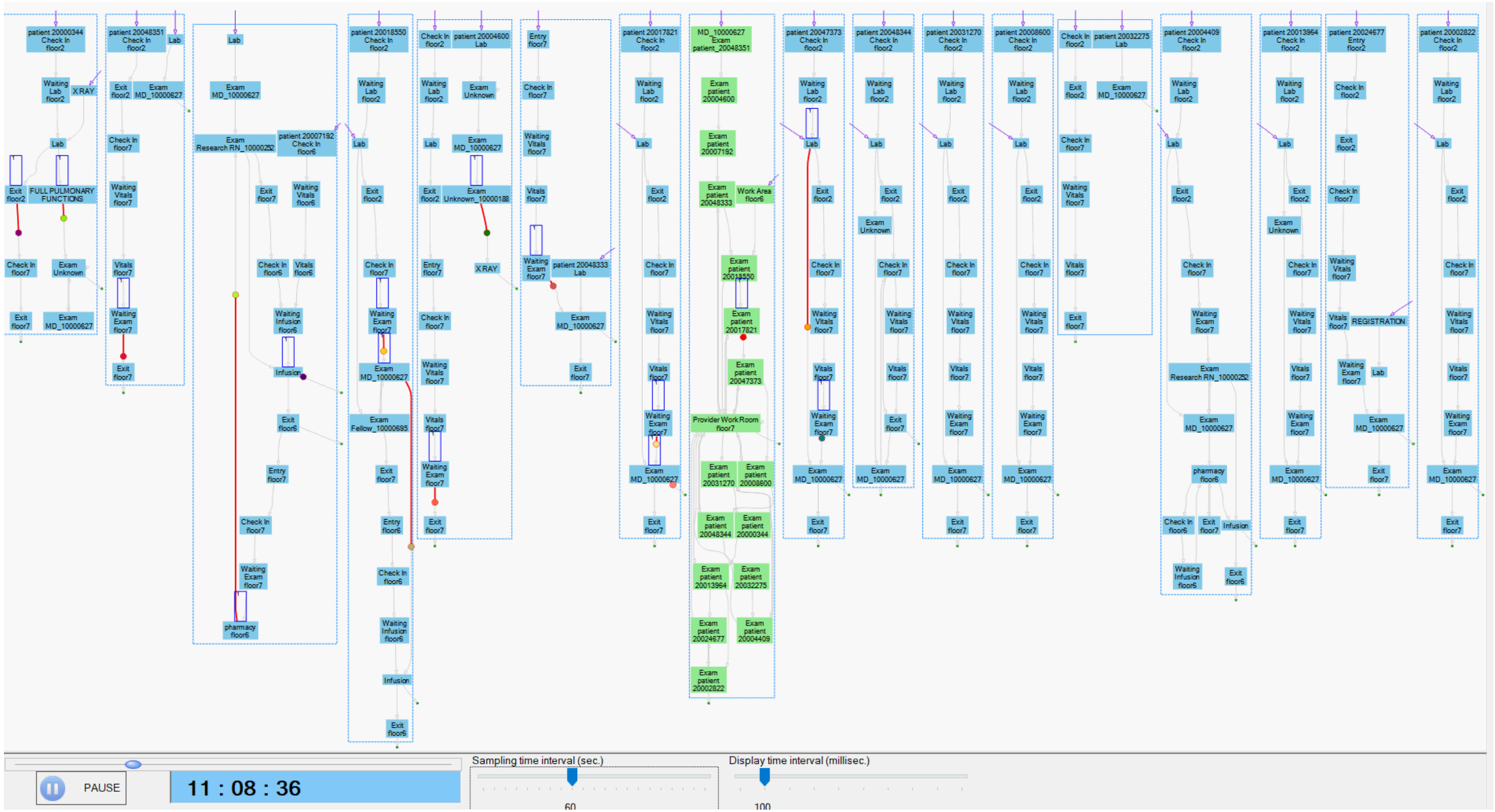


Technion S.E.E Center Service Enterprise Engineering

Appointment-Net vs. Actual-Net

Doctor + Daily Panel (16 patients)




PAUSE
11 : 08 : 36
Sampling time interval (sec.)
60
Display time interval (millisec.)
100

Outline

- “Introduction”

- Helpful history

- Strengths, via data

- Limitations, relative to needs

- Examples, that hint at some future apps: Research, Practice

- Concluding speculations

Applications in DFCI, ...

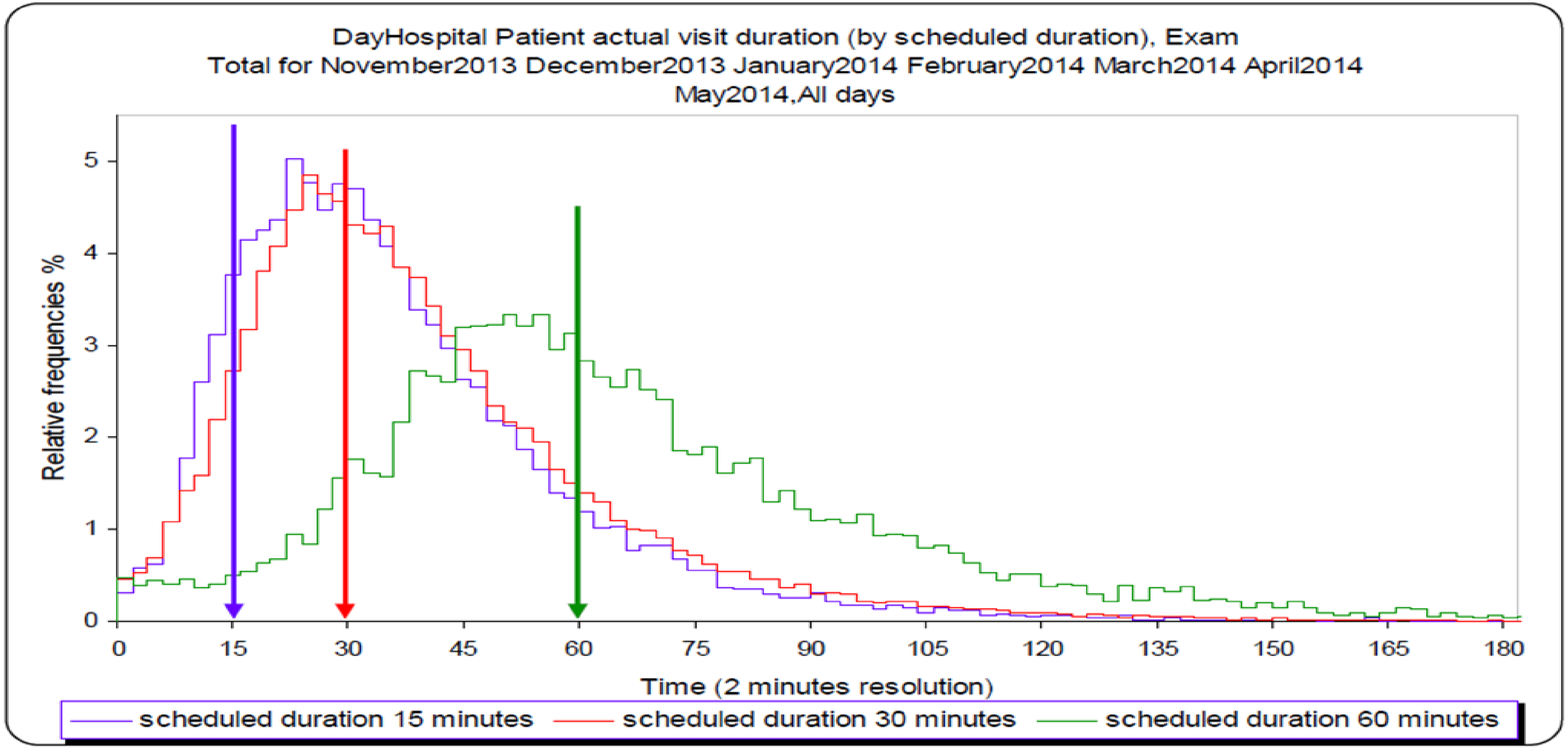
Control: rooms status, physicians location, long wait times

Planning: number infusion chairs, load-balancing among floors

Management: evidence-based (e.g. room for physician vs. for patient)

Building Blocks: Exam Durations
Planned (Deterministic) vs. Actual (Stochastic)
CMO of Hospital: Why do we have short services? Change Practice

Exam: actual duration for 15, 30 and 60 min scheduled-duration



Applications in DFCI, ...

Control: rooms status, physicians location, long wait times

Planning: number infusion chairs, load-balancing among floors

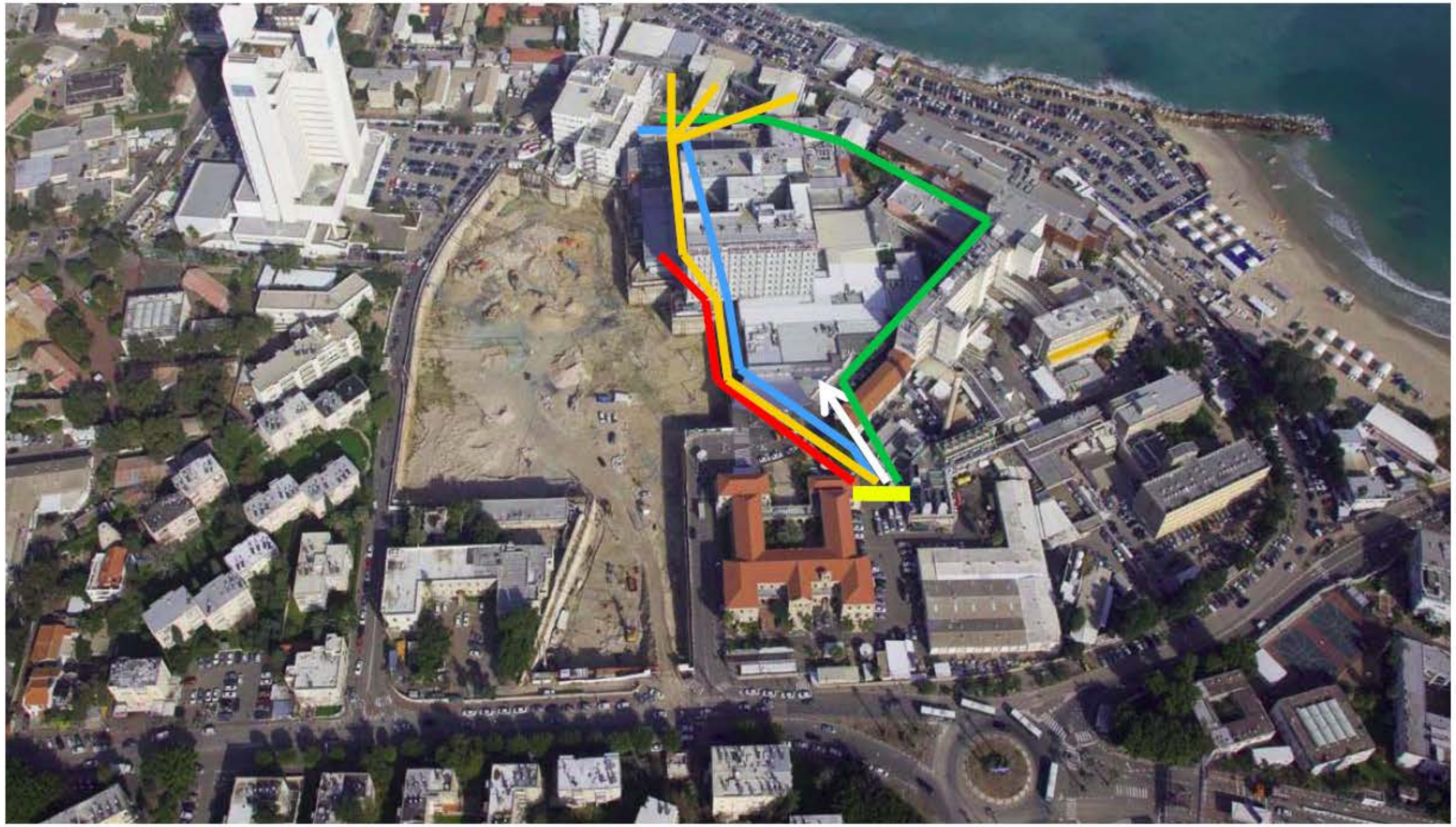
Management: evidence-based (e.g. room for physician vs. for patient)

Why stop?

- **Appointment Systems**: 30% cost reduction ⇨ planned pilot
- **Time & Motion Studies** (IE of the 21st century): cost of care
- **Mining Social Networks**: relate to outcomes (treatment, learning)
- **Prediction**: “waze” (times on a given care-path, predict path)
- …

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

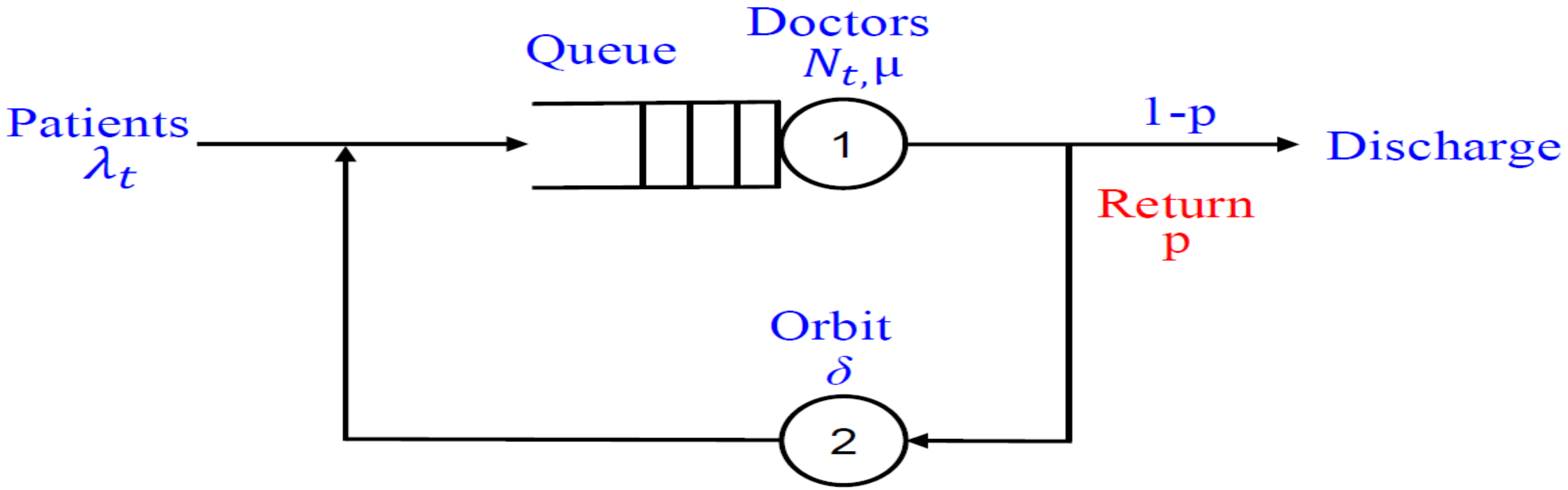
Drill: Chemical MCE, Rambam Hospital, May 2010



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

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

Erlang-R ↔ Fluid Model, w/ Galit Yom-Tov



Functional Strong Law of Large Numbers, for a 2-station QNet. BUT

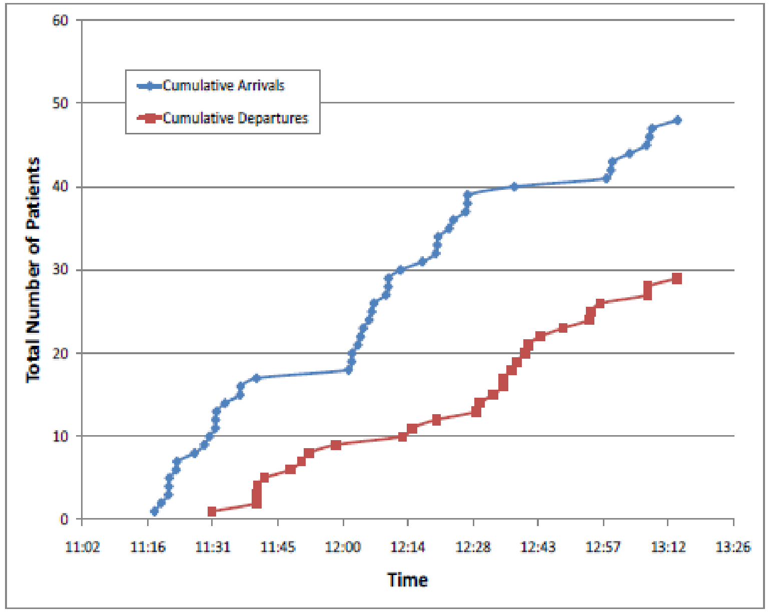
FNet = ODE: derived **directly** (no QNet), spreadsheet "solution"

$$\frac{d}{dt} q_t^1 = \lambda_t - \mu \cdot (q_t^1 \wedge N_t) + \delta \cdot q_t^2$$
$$\frac{d}{dt} q_t^2 = p \cdot \mu \cdot (q_t^1 \wedge N_t) - \delta \cdot q_t^2$$

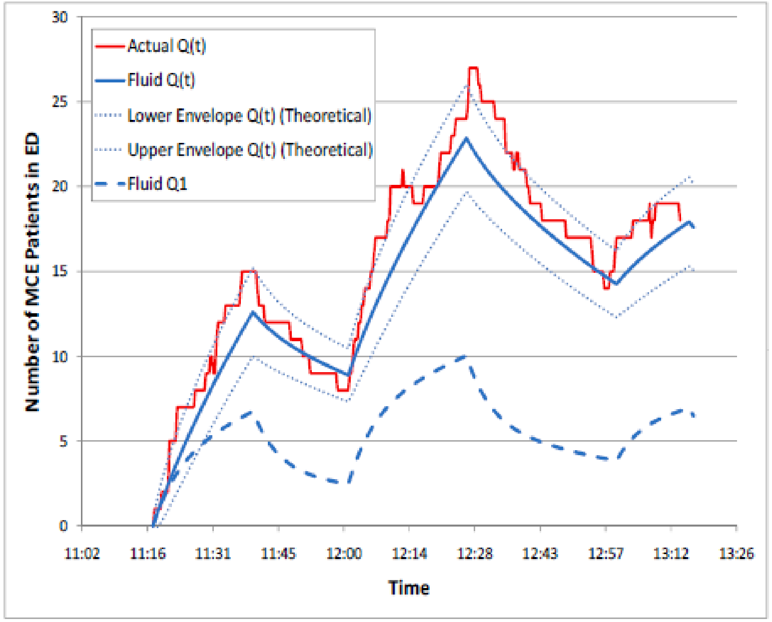
Erlang-R Value: FNet vs. Data

Chemical MCE Drill (Israel, May 2010, 11:00-13:00)

Arrivals & **Departures** (RFID)



Erlang-R (**Fluid** , **Diffusion**)



- **Recurrent/Repeated** services in Chemical MCE: injection every 15/30/60 min
- **Fluid** = ODE
- **Diffusion** (confidence band), via F. Central Limit Theorem: Usefully narrow

Applications in MCE & Day-to-Day

Prediction: When will MCE end? (via Fnet+SimNet)
Based on tragic Isaeli experiences, summarized by arrival rates

Staffing: How many doctors? nurses? during a routine day (via FNet+DNet)
In order to stabilize operational performance
Based on the time-varying offered-load

Cost of Care

- "There is little doubt that the most generally troublesome feature of recent experience with all aspects of medical care in the United States today is the increase in **cost**, however defined, of the hospital component of that care."

From "A System for Cost and Reimbursement Control in Hospitals," Yale U.

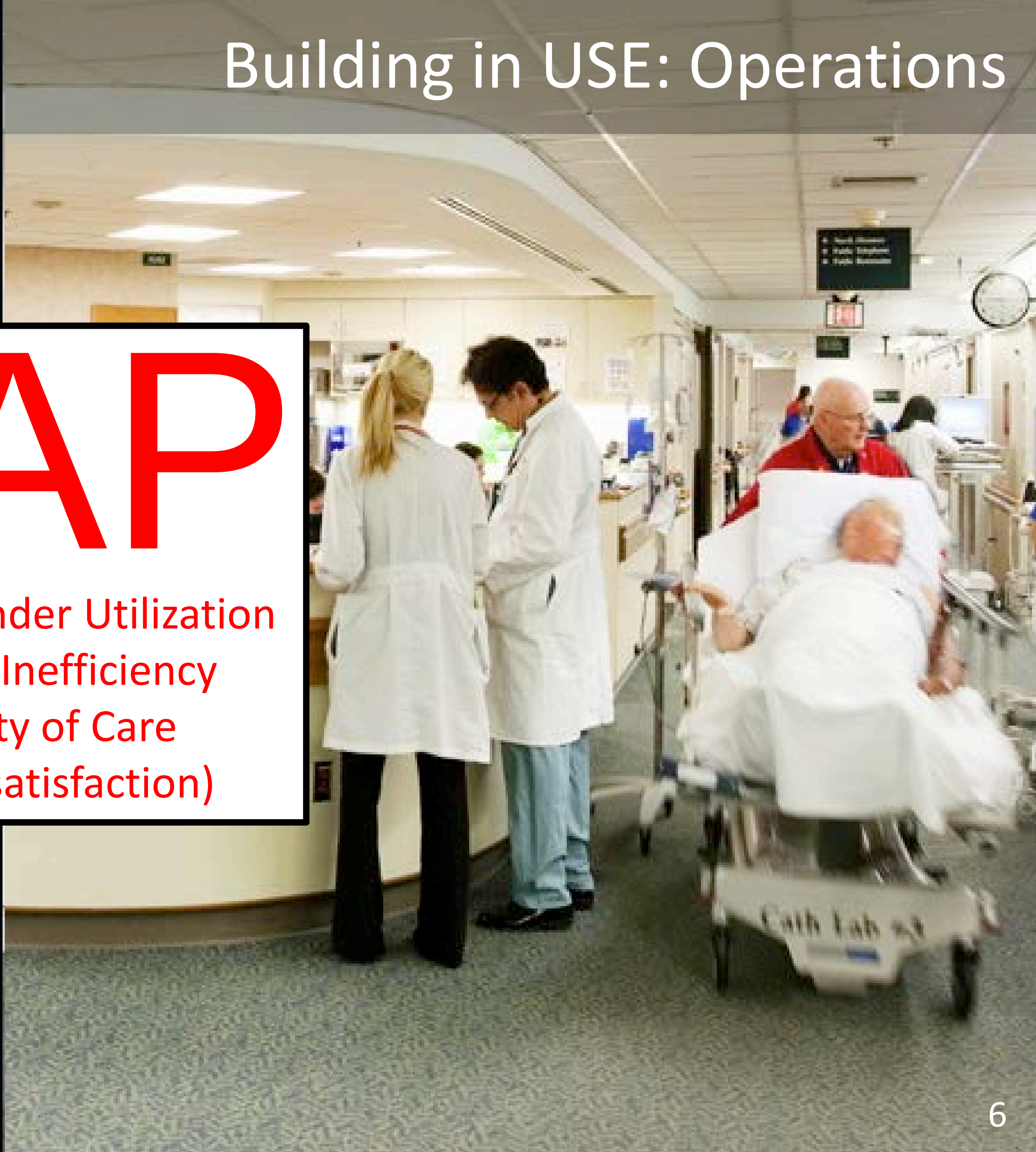
1975, Fetter et al = inventors of DRG (see Interfaces 1991).

- Cost?
  - Patients (if uninsured, can negotiate down significantly)?
  - Providers (isolated from costs to optimize care)?
  - Hospitals = billing charges?
  - Insurance = reimbursements (?30% of charges, after negotiations)?

True cost?

Building DESIGN

Building in USE: Operations



GAP

Spatial Over/Under Utilization
Operational Inefficiency
Low Quality of Care
(Patient Dissatisfaction)

Research: Open Problems, New Directions, Uncharted Territories – a sample

- What causes long delays/queues? (in open or appointment-driven systems)
- Building-blocks & Congestion Laws: why LN (via NLP), Laplace, Logistics, Pareto, Cauchy? Call Center arrivals are over-dispersed but not so in Emergency Departments, …
- Model selection:
  - Piecewise-stationary models (noise vs. bias)
  - Scale and scope: Do we need complex models, for example covering a complete-hospital? Or suffices to fit simple models (via divide & conquer or aggregation)
- Personalized Queueing Theory (sample realization <u>before</u> action): value of information; service-durations depends on the pair (doctor, patient); KPI's adapted to data resolution

Further Research: Guiding Questions
(Think in terms of your "favorite" service system)

Answer the following via processing-network data:

Q1. Can we do it (via capacity analysis)?

Q2. How long will it take? (prediction)

Q3. Can we do better? (counterfactual; sensitivity & parametric analysis)

Q4. What is the best we can do? (optimization of design, planning, control)

- Do "models" help (are necessary) for answering the above (e.g. Q2, Q4)?
- How much data is required: quantity, granularity, quality (less w/ modes)?

Outline

- “Introduction”
- Helpful history
- Strengths, via data
- **Limitations, relative to needs**
- Examples, that hint at future apps: Research, Practice
- Concluding speculations

Limitations = Gaps relative to some “broader picture”

- Operational state within Hospital
  - *EMR + RTLS (EPIC at DFCI)
  - *Inefficiencies, waste (preventable ED visits), costs (B’s); excellence
  - *Uncovered areas: complete via appointments or alternative technologies
  - *Unobservables: complete via statistical models (ML,…; e.g. impatience, workload by those LWBS (Ritov et al)

- Still operational but beyond hospital: wearables / smartphones / EPIC
  - *Process beyond: ED blocking, IW boarding (Zychlinski et al), readmissions; Full cycle of care (from onset of symptoms, …) - reduces hospital disconnect
  - Physically beyond: (Rambam: Garage = 700-bed hospital; *MCEs, …)
  - Novel models: shift from hospital to step-down then community then home-health & home-based-care; integrated care; subscriptions (a-la “amazon-prime”); virtual clinics, …

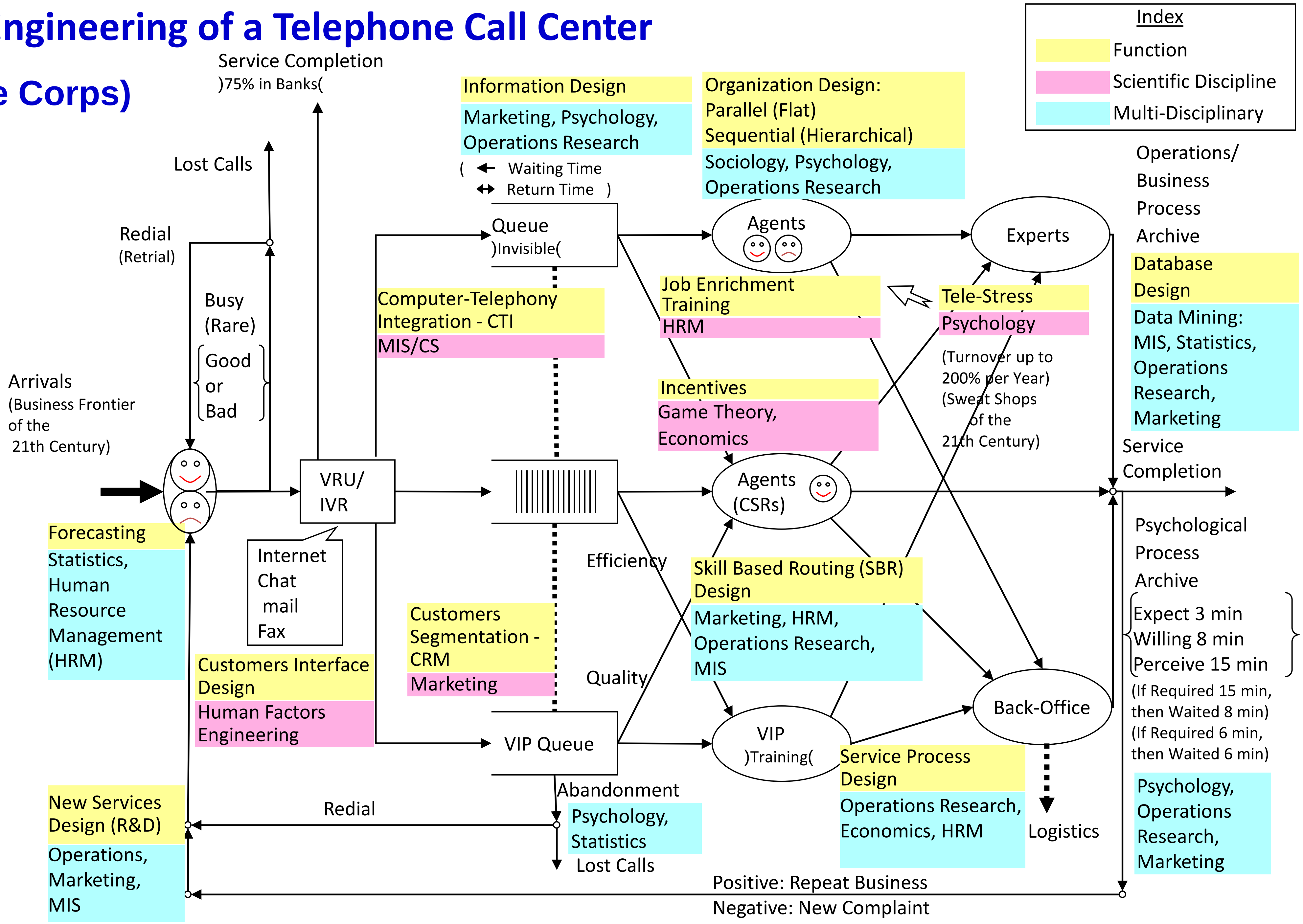
Limitations (Gaps relative to some “broader picture”) – cont’d

- Beyond operational but still within hospital: towards “smart hospital”
  - *Comparison of ED & Call Center; richer offered-load (Carmeli et al)
  - *Anatomy of Waiting
  - *People-centric multi-directional connections: patient+patient, patient+provider, provider+provider; within floor, disease-center, interest-group
  - *Design/Architecture: spatial over- and under-utilization, energy (NYP ↓30%?), noise, …
  - *Designing, managing, monitoring time-constraints (“1-hour-door-to-ballon”, …)
  - *Clinical (EMR) integrated with Operational (Senderovich et al)

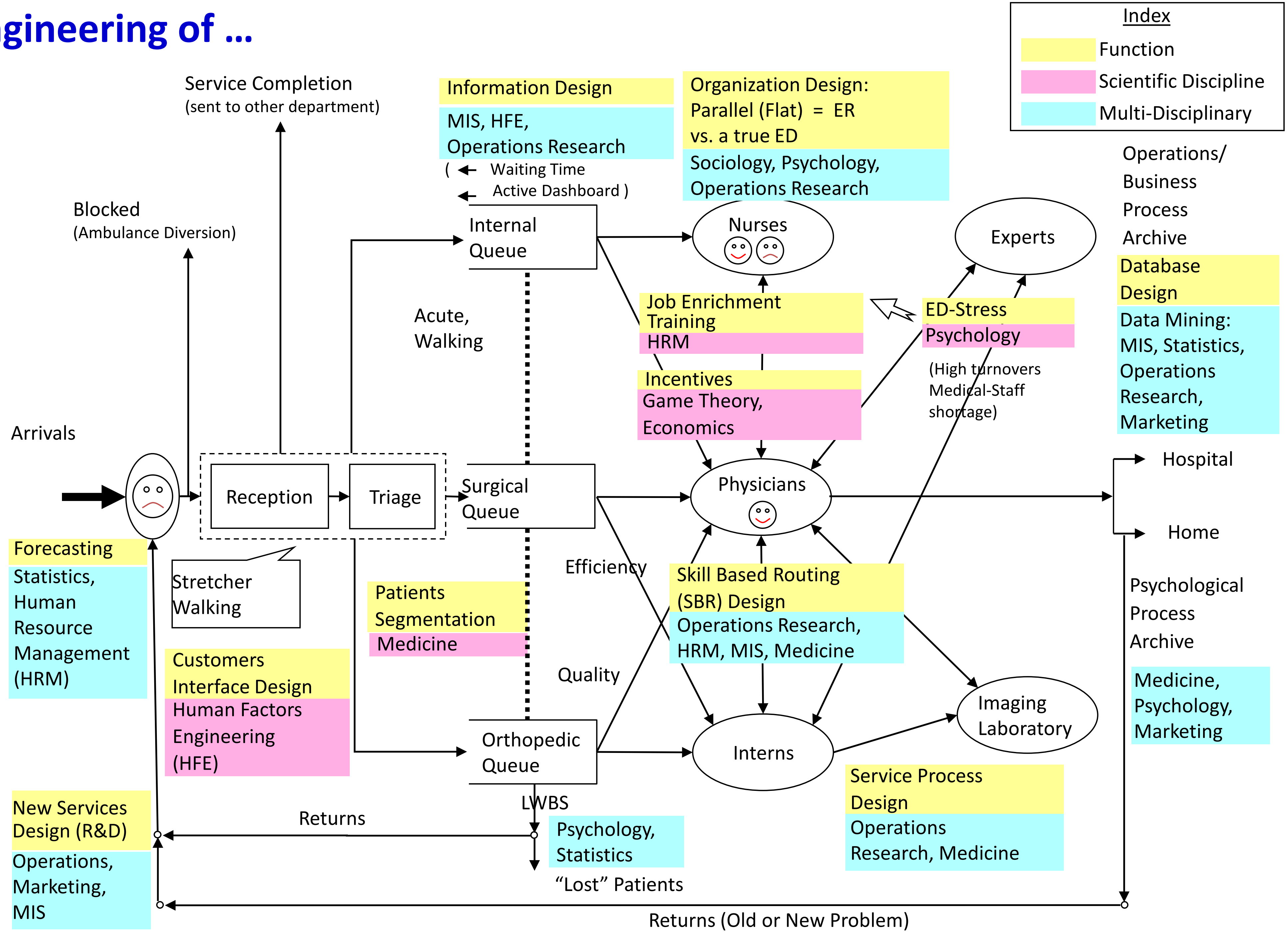
- Beyond operational or beyond hospital
  - *Incentives, *Ethics (in tracking humans), …
  - *Complete people-centered state, that integrates the physical, operational, clinical, psychological, financial, …
    - *For example, MSK Josie Robertson Surgery Center: out of 20K MSK yearly operations, over half are performed here as outpatient (or overnight at the most); accompanied by 14-days home-tracking (daily reports by patient, and feedback when called for; e.g. reduced opioid consumption.
  - *ROI comparison against cheaper technologies (WIFI, BT, smartphone)

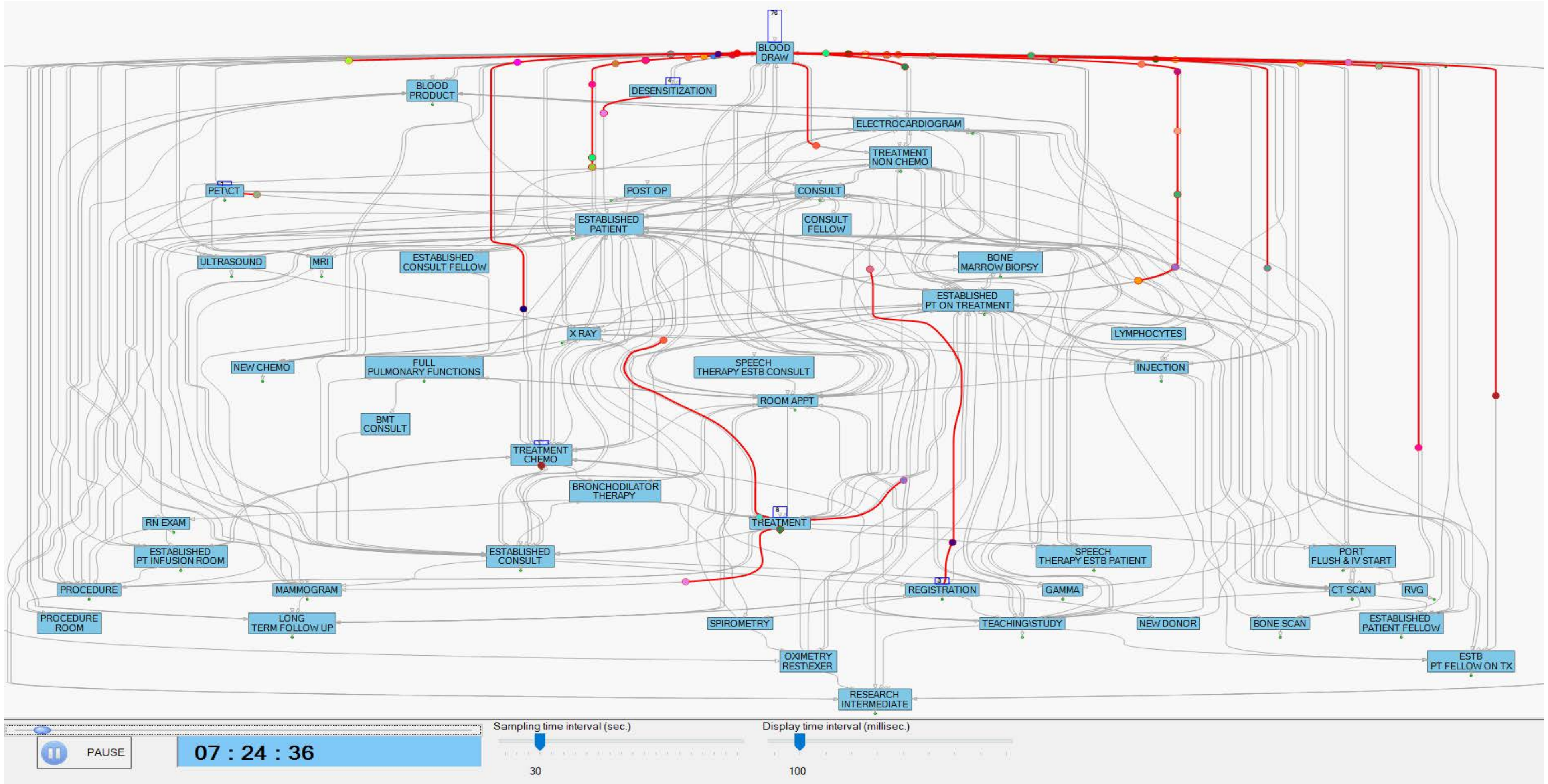
Service Engineering of a Telephone Call Center

(Esprit de Corps)



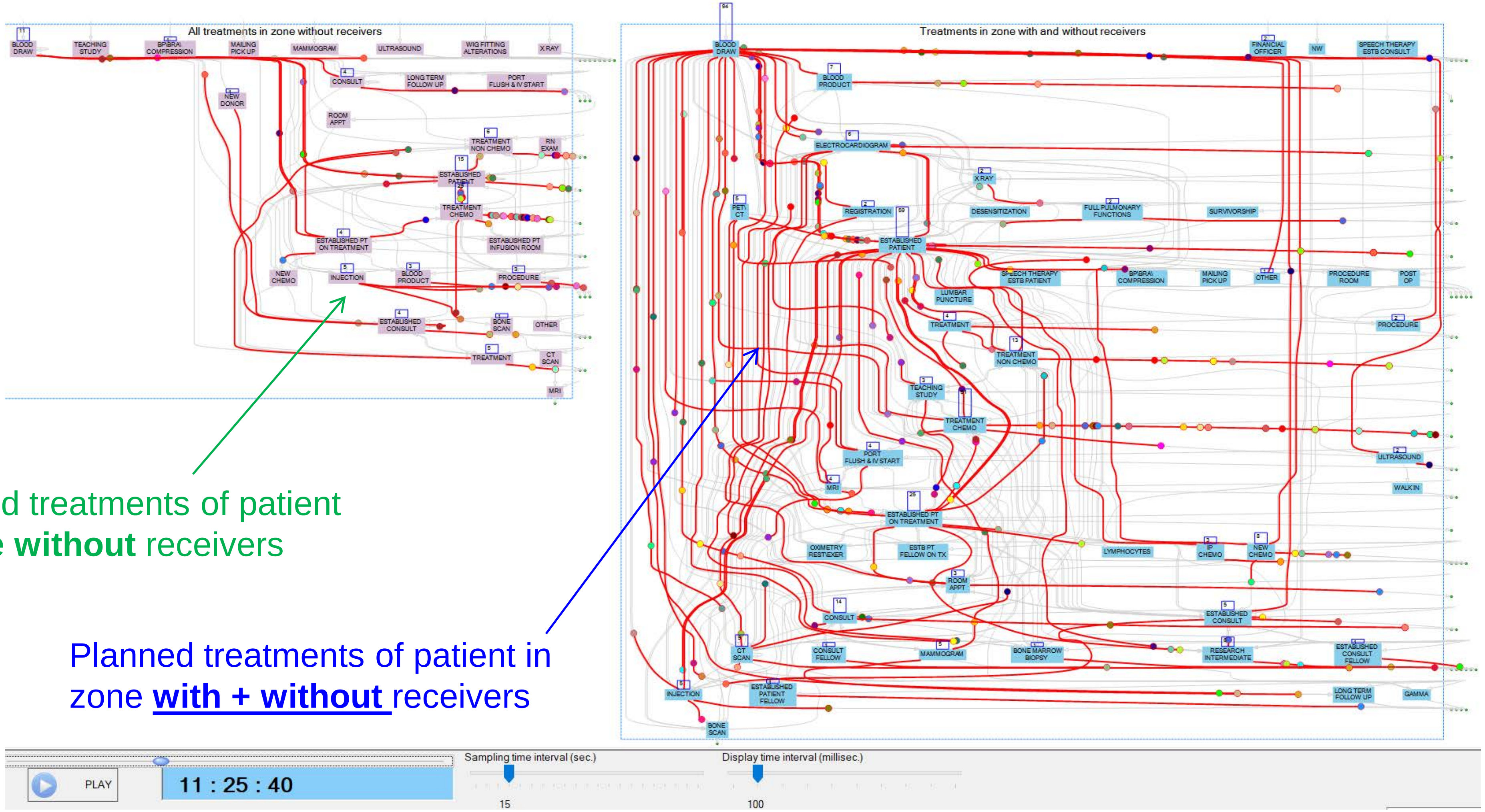
Service Engineering of …





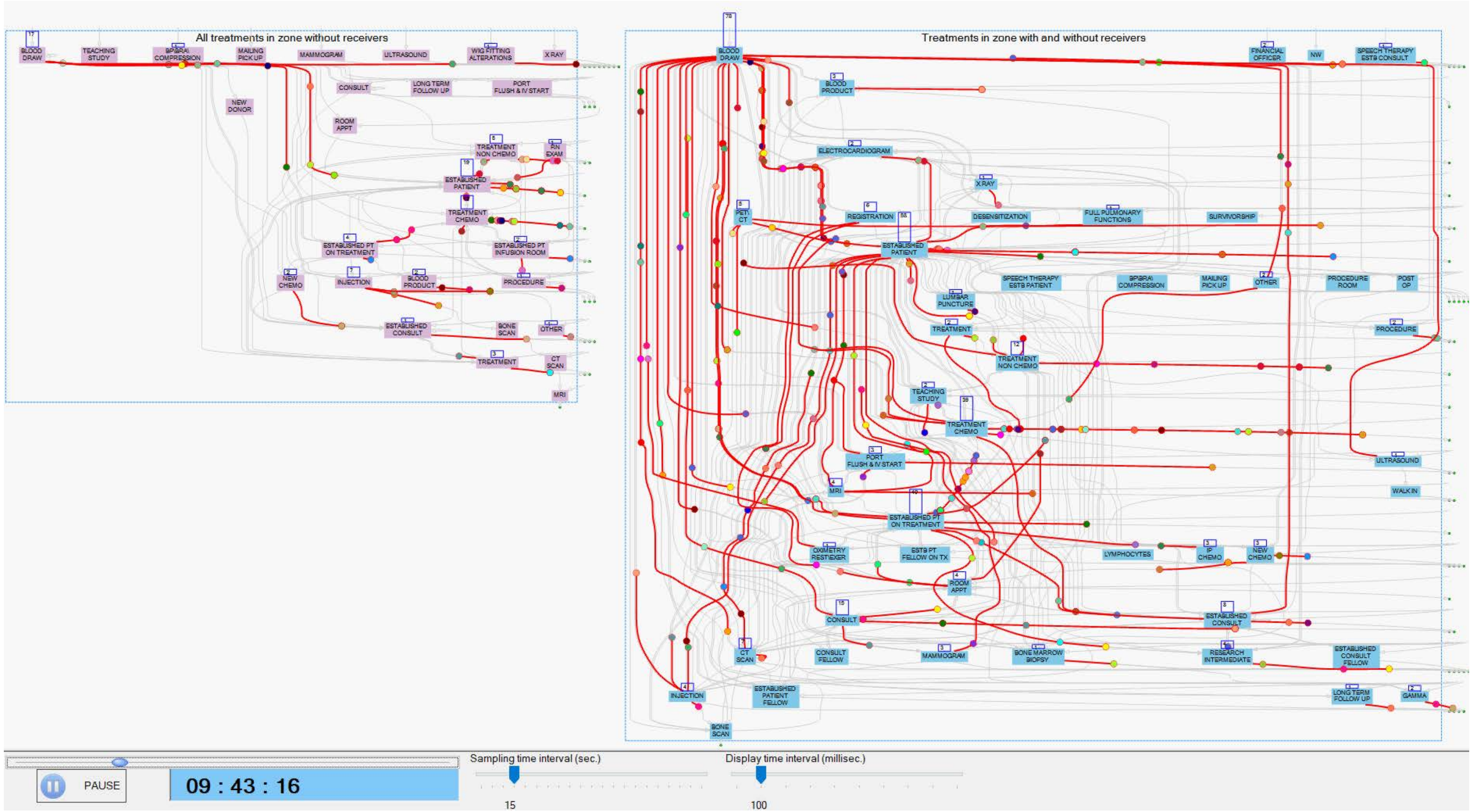
BLOOD DRAW
BLOOD PRODUCT
DESENSITIZATION
ELECTROCARDIOGRAM
TREATMENT NON CHEMO
PET\CT
POST OP
CONSULT
ESTABLISHED PATIENT
CONSULT FELLOW
ULTRASOUND
MRI
ESTABLISHED CONSULT FELLOW
BONE MARROW BIOPSY
ESTABLISHED PT ON TREATMENT
X RAY
LYMPHOCYTES
NEW CHEMO
FULL PULMONARY FUNCTIONS
SPEECH THERAPY ESTB CONSULT
INJECTION
ROOM APPT
BMT CONSULT
TREATMENT CHEMO
BRONCHODILATOR THERAPY
RN EXAM
TREATMENT
ESTABLISHED PT INFUSION ROOM
ESTABLISHED CONSULT
SPEECH THERAPY ESTB PATIENT
PORT FLUSH & IV START
PROCEDURE
MAMMOGRAM
REGISTRATION
GAMMA
CT SCAN
RVG
PROCEDURE ROOM
LONG TERM FOLLOW UP
SPIROMETRY
TEACHING\STUDY
NEW DONOR
BONE SCAN
ESTABLISHED PATIENT FELLOW
OXIMETRY REST\EXER
ESTB PT FELLOW ON TX
RESEARCH INTERMEDIATE
PAUSE
07 : 24 : 36
Sampling time interval (sec.)
30
Display time interval (millisec.)
100

Processes in zones with and without receivers (Appointments)



Planned treatments of patient in zone **without** receivers

Planned treatments of patient in zone **with + without** receivers



All treatments in zone without receivers
Treatments in zone with and without receivers
BLOOD DRAW
TEACHING STUDY
MAILING PICK UP
MAMMOGRAM
ULTRASOUND
X RAY
CONSULT
LONG TERM FOLLOW UP
NEW DONOR
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IP CHEMO
CONSULT FELLOW
BONE MARROW BIOPSY
RESEARCH INTERMEDIATE
ESTABLISHED CONSULT FELLOW
ESTABLISHED PATIENT FELLOW
GAMMA
PAUSE
09 : 43 : 16
Sampling time interval (sec.)
15
Display time interval (millisec.)
100

Anatomy of Waiting (in Queue for a Phone Service)

What is "Waiting"?

<u>Expected</u> to wait 5 minutes

<u>Required</u> to wait 10

<u>Felt</u> like waited 20

<u>Actually</u> waited 7 minutes, and then <u>Abandoned</u>

… etc

Anatomy of Waiting (in Healthcare Queues, e.g. for Specialist)

Common "Waiting": <u>must</u> wait 2 weeks for effect of medicine/treatment, then <u>be seen</u> within 2 days by a specialist; <u>expected</u> to wait a total of 14+1=15 days, <u>required</u> by system to wait 1 week after MRI (3 weeks total) for Specialist A, <u>felt</u> like waited 1 month, <u>actually</u> waited 18 days and abandoned queue to see Specialist B immediately, …

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Conceptual Model?

Time that customer	**must**	**wait**	**clinical**		**(a,b)** (a=0, b=∞ are ok)
	expects	**to wait**			experience, character
	willing	**to wait**	**Patience**	τ	combo
	required	**to wait**	**Offered-Wait**	**V**	system status + priority
	actually	**waited**	**min$\{\tau, V\}$**		
Time that customer	**perceived**	**waiting**			psychological

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What can RTLS measure? "operational" waiting

Time that customer	**must**	**wait**	**clinical**		**(a,b)** (a=0, b=∞ are ok)
	expects	**to wait**			experience, character
	willing*	**to wait**	**Patience**	**τ**	combo
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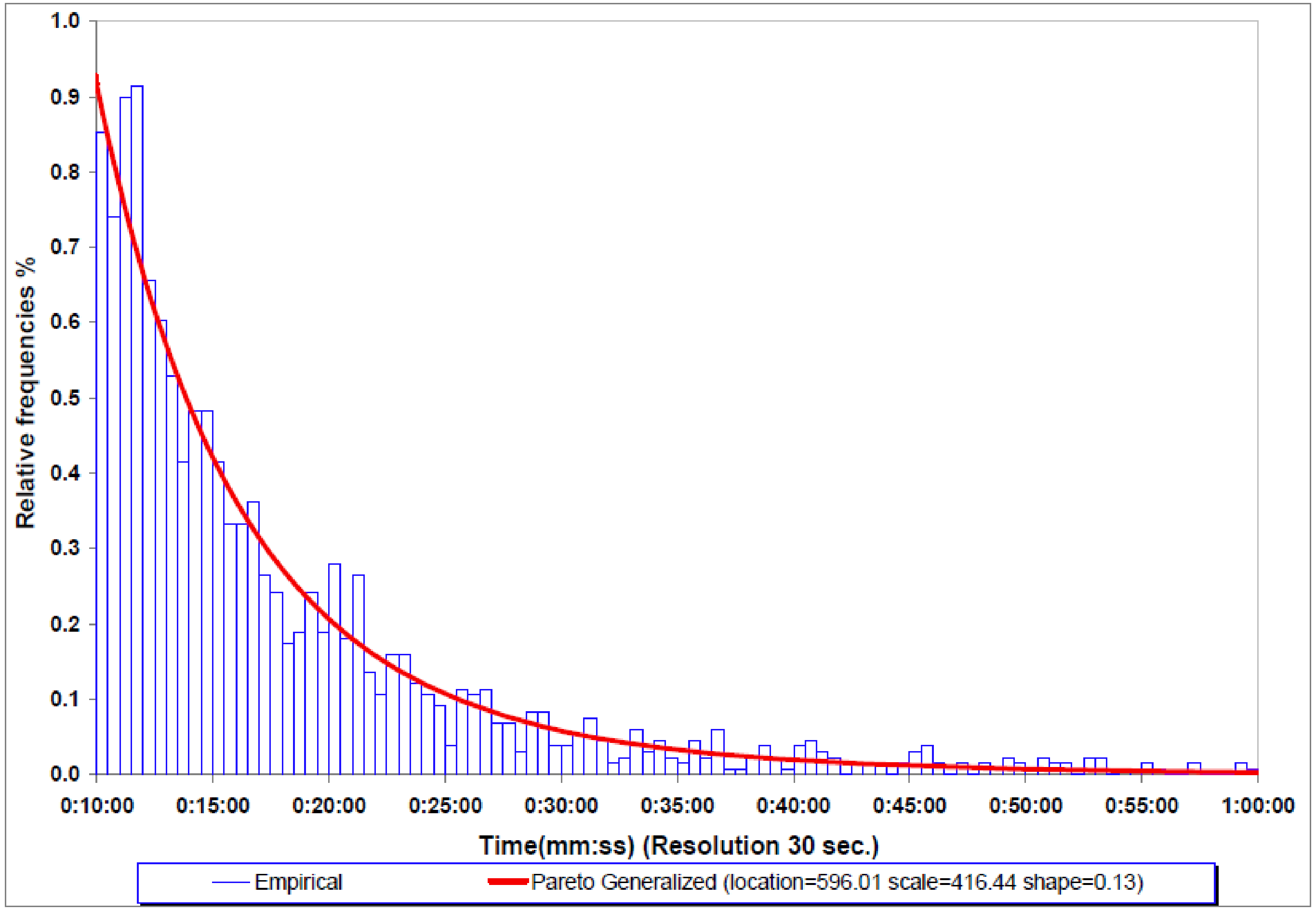
Time that customer	**perceived**	**waiting**			psychological

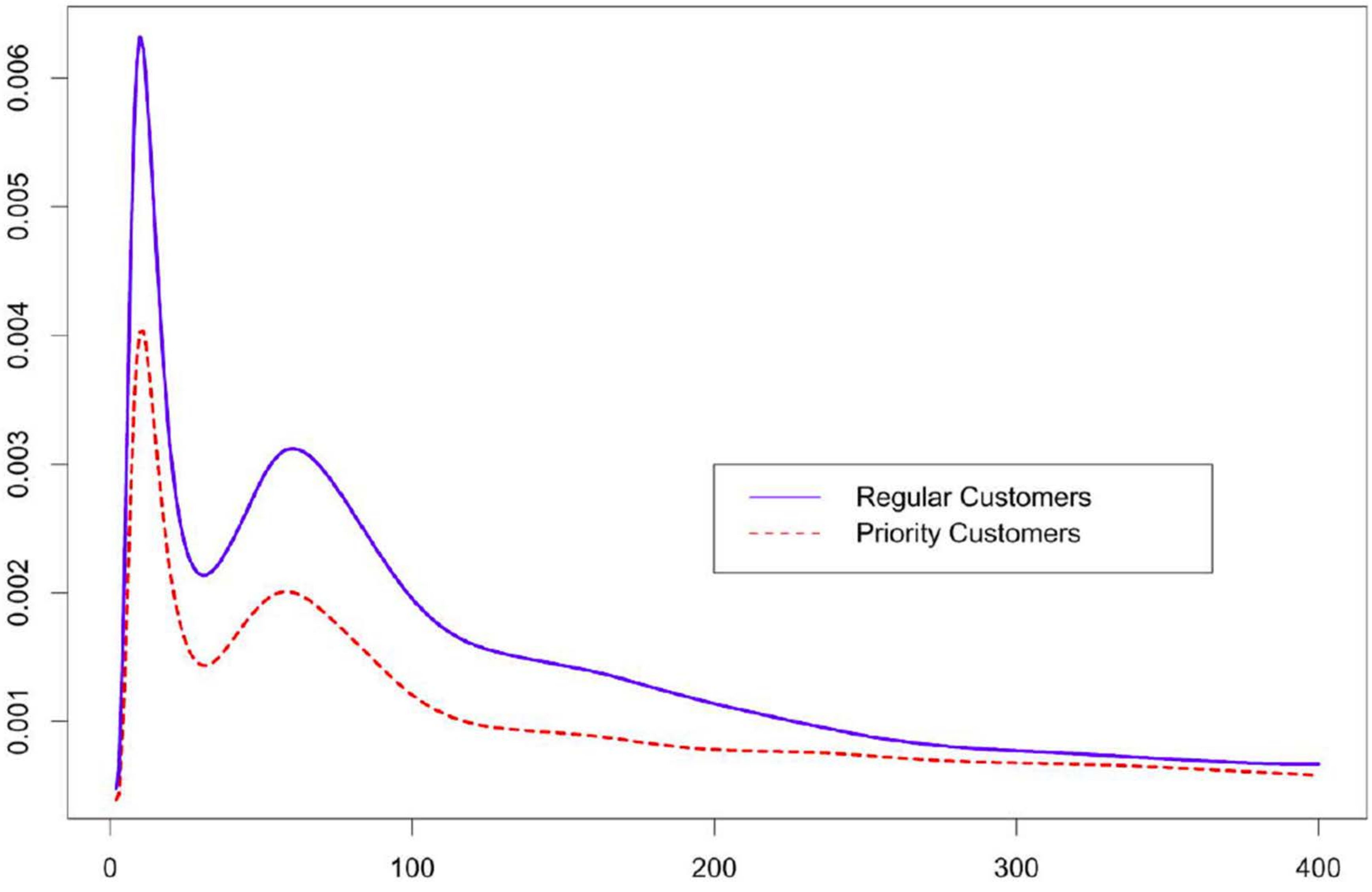
Primitives: (Im)Patience

Israeli Bank: Uncensored 13,000 Customers, 24/11/2008

Patience $\geq 10min$: Why Pareto Tail?

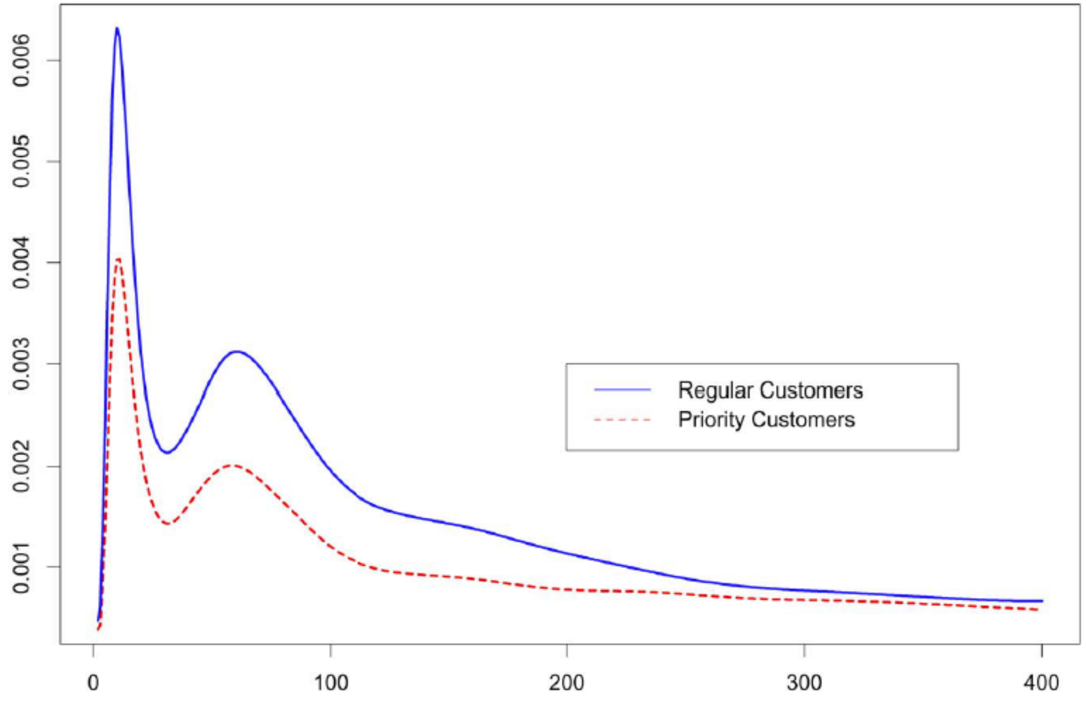


(Palm 1943-53) Hazard-rate :Patience on the Phone



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

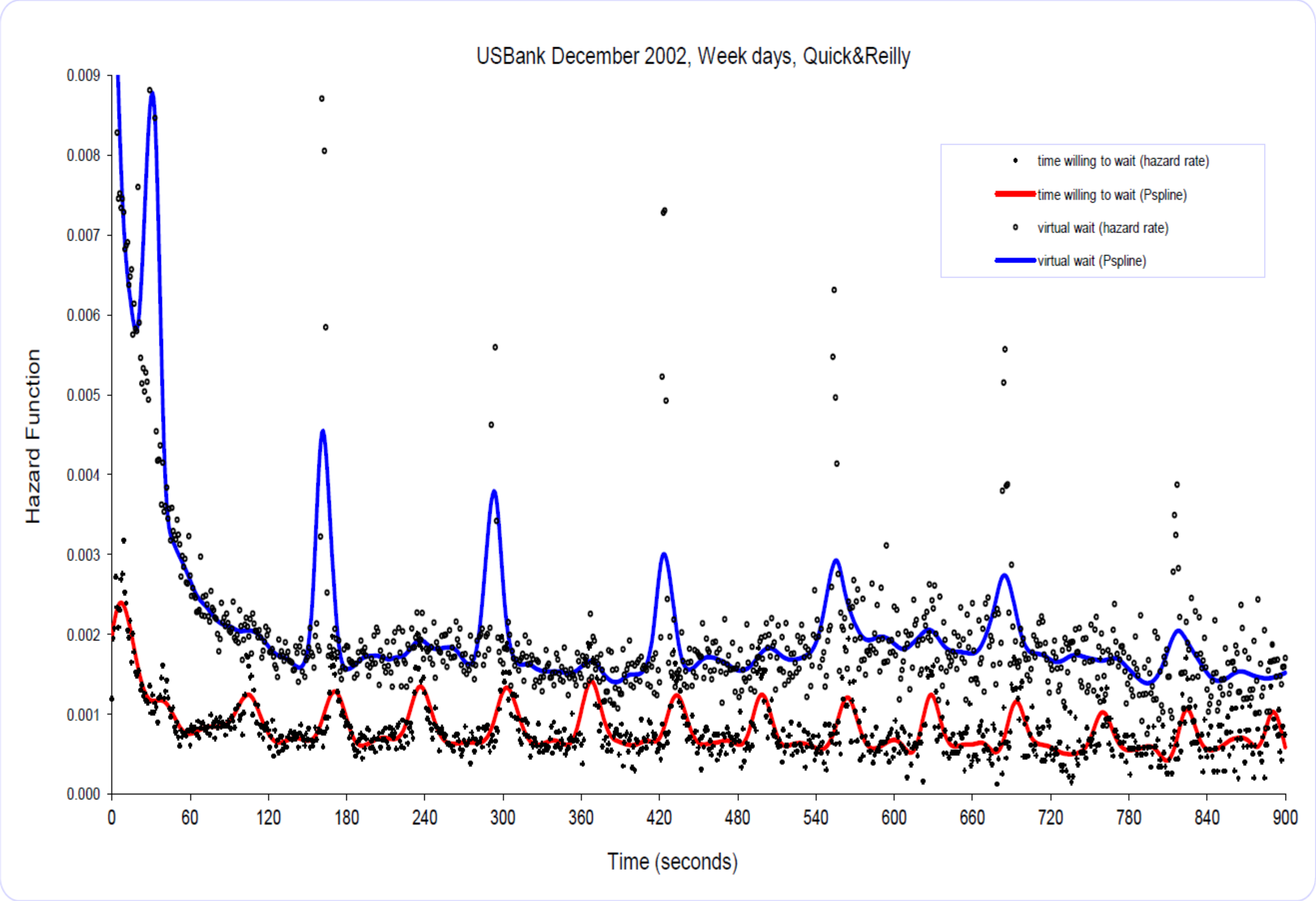
Hazard Rate of (Im)Patience Distribution $\propto$ Irritation
Regular over VIP Customers – Israeli Bank



- **VIP** Customers are **more Patient** (Needy)
- **Peaks** of abandonment at times of **Announcements**
- Challenges: **Un-Censoring, Dependence (vs. KP), Smoothing**
  - requires **Call-by-Call Data**

Psychology (Time Willing to Wait) + Protocols (Required)

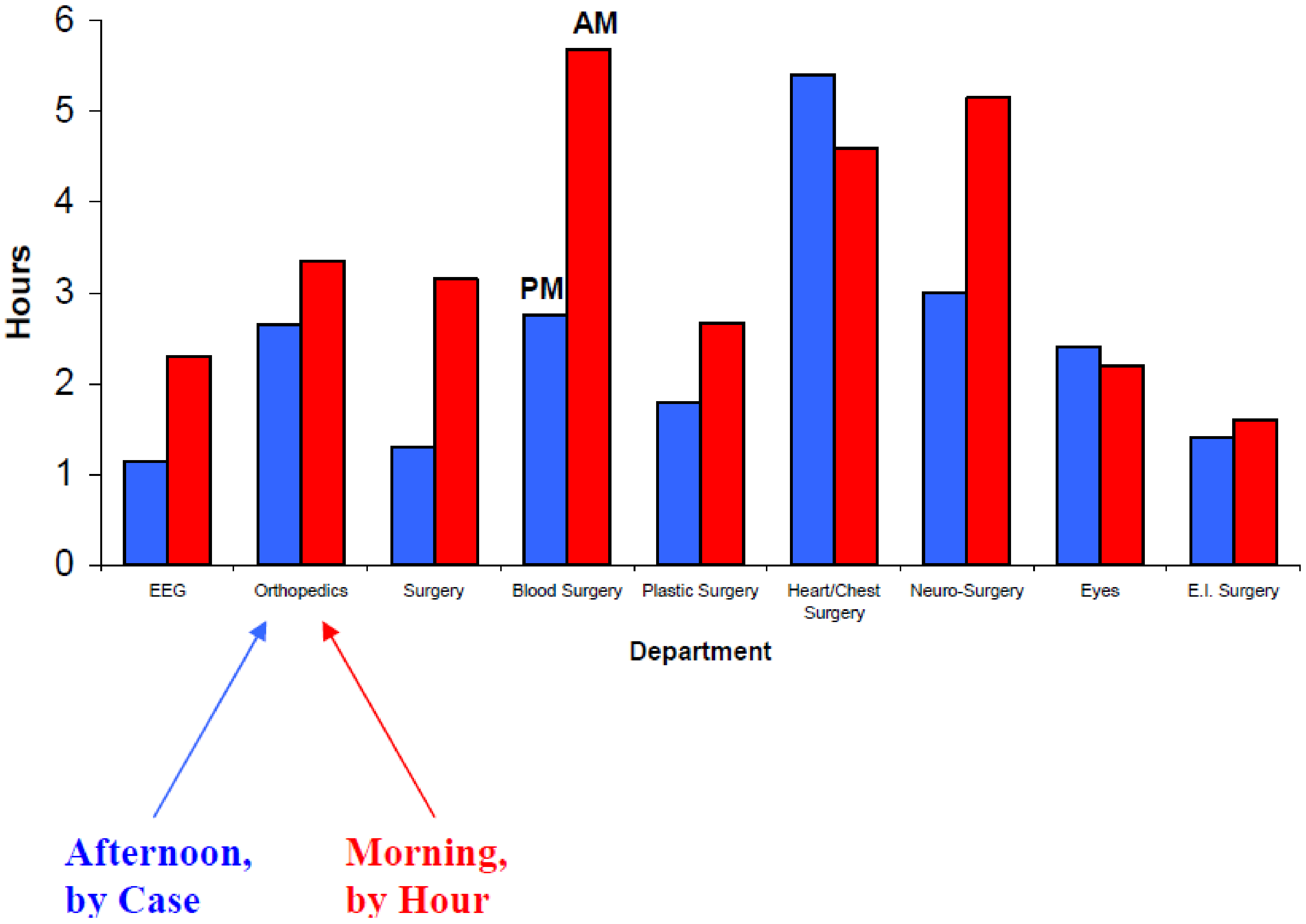
Patient Customers, Announcements, Priority Upgrades



Incentives

Interesting Averages: The Human Factor, or Even "Doctors" Can Manage

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



Outline

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- Limitations, relative to needs

- Examples, that hint at some future apps: Research, Practice

- **Concluding speculations / comments**

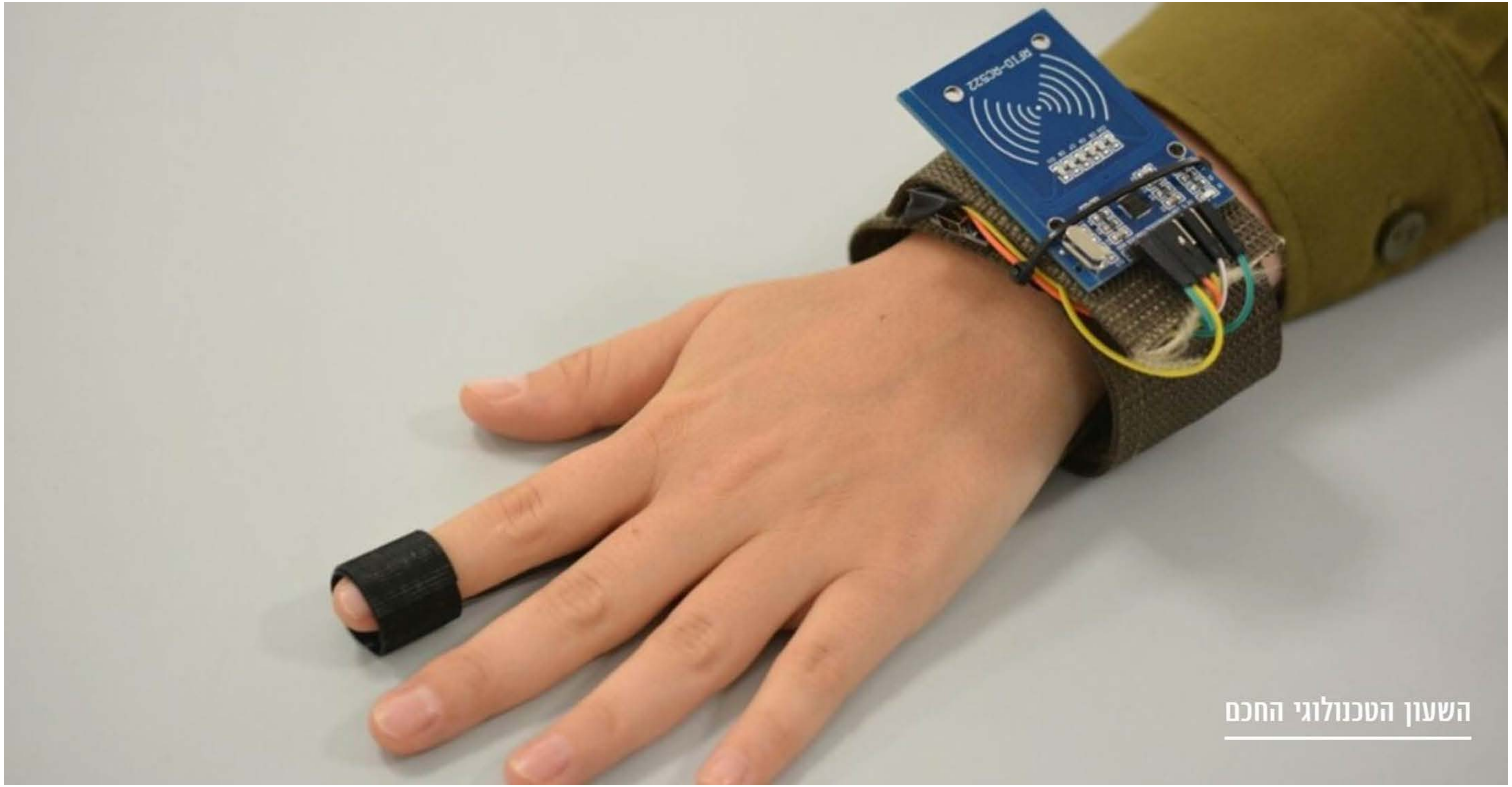
(How) Will RTLS transform healthcare delivery (research) ?

- Healthcare delivery must and is due to undergo transformational changes
- "RTLS+**DFCI**" is a prerequisite for such a transformation

Around the corner:

- RTLS**+**, via wearable personalized sensors (active smartphones): Operational, physical and physiologic tracking.
- This will empower people, both healthy or not (e.g. chronic), to routinely conduct self-monitoring and self-care (e.g. full cycle of care).
- Data-based research-partnerships require Infrastructure (funding).
- Will empower researchers and organizations to develop and adopt novel models of delivery, world-wide (e.g. China).

Physiological Dimension: BioMarkers
MCE Smart Watch (Israeli Army)



Research Infrastructure: Data Science for Processing Networks (NSF Proposal 5/7/29)

Itai Gurvich (PI), w/ Paul Feigin & AM (Technion)

Shane Henderson, David Shmoys (Cornell ORIE)

Thorsten Joachims, Deborah Estrin (Cornell CS)

Curtis Cole, Fei Wang (Cornell Weill)

David Chokshi (NYU and NYC Health)

Establish **SEENYC = Data Lab** at Cornell-Tech / Jacobs, which will become a blue-print for

= Online platform for data-based science of processing/healthcare nets

Research: Infrastructure for Data Science (NSF Proposal 5/7/29, Itai Gurvich PI)

Hospitals, courts and public transportation are **service networks of central societal importance**. Due to technological advances and public awareness, processes in such networks create (or could create) **vast amounts of operational data, at unprecedented resolution and quality**. Yet harnessing this data **for publishable, reproducible and scalable research** is an acknowledged and yet-to-be overcome **challenge**.

What we offer here is a **blueprint for data-science labs**, … : specifically, bringing together **multiple scientific disciplines** to the study of processing networks, which will support their **design, planning, control, prediction and improvement** along dimensions such as operational efficiency, quality of outcomes, and fairness of access.

… develop **infrastructure – physical (a data lab), human (a research team) and scientific (scholarly knowledge)** – to advance **data-science for processing networks in general, and healthcare systems in particular**.

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… propose **blueprint for data-science labs**, …

Following the model of Technion SEELab and it partnership with DFCI

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Following the model of Technion SEELab and it partnership with DFCI

Research challenge: Why has the DFCI+Technion partnership model been successful (personal, organizational & both)

Some Observations on "Academia-Industry Partnerships" (not MSR or the Original-Bell-Labs)

- Intriguingly: RTLS successful at a **leading research** hospital?
- Intriguingly: **Physicians** at DFCI initiative (as opposed to managers)?
- **Conjectures?**

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- Intriguingly: **Physicians** at DFCI initiative (as opposed to managers)?
- **Conjectures?**

Observations: Partnership has succeeded with the “Strong”, who appreciate Research/Evidence-Based-Management, and it is based on DATA

(Theory/Academia/Technion) & (Practice/Industry/(Banks, Hospitals, Judges,…)

Data “creates” SYMMETRIC Partnerships, caters to goals of both partners (e.g. IP)

The Technion SEE Center / Laboratory

Data-Based Service Science / Engineering