splunk> .conf2017

Acute Care Patient Bedside Telemetry Monitor Datastream Processing, Visualization, and Querying with Splunk: A Tale in Carts

Leo Kobayashi MD FACEP | Associate Professor
Derek L. Merck PhD | Director

September 26, 2017 | Washington, DC

Forward-Looking Statements

During the course of this presentation, we may make forward-looking statements regarding future events or the expected performance of the company. We caution you that such statements reflect our current expectations and estimates based on factors currently known to us and that actual events or results could differ materially. For important factors that may cause actual results to differ from those contained in our forward-looking statements, please review our filings with the SEC.

The forward-looking statements made in this presentation are being made as of the time and date of its live presentation. If reviewed after its live presentation, this presentation may not contain current or accurate information. We do not assume any obligation to update any forward looking statements we may make. In addition, any information about our roadmap outlines our general product direction and is subject to change at any time without notice. It is for informational purposes only and shall not be incorporated into any contract or other commitment. Splunk undertakes no obligation either to develop the features or functionality described or to include any such feature or functionality in a future release.

splunk> .conf2017

Investigator Disclosures

- Funding Support:
  - Agency for Healthcare Research and Quality (AHRQ) R18
- In-kind Support:
  - Dept. of Diagnostic Imaging, Alpert Medical School of Brown University
  - Dept. of Emergency Medicine, Alpert Medical School of Brown University
  - Lifespan / Rhode Island Hospital
  - Splunk for Good, Splunk
- No financial conflicts of interest to disclose. Any opinions, findings and conclusions or recommendations expressed in this material are those of the speaker and do not necessarily reflect the views of their institutions, departments, centers or other funding sources / sponsors.

Framework

Parallel Simulated Systems / Clinical Environment Engineering

- Bedside clinical **informatics** systems research

- Setting
  - TESTPILOT
  - SimCode
  - CIRRUS
  - CREW
  - ASCENT AED
  - STORM
- Methods
  - ARGUS
  - Existing approaches
  - BIRDSS-I
- Results
  - PERSEUS
    - MeTeOR
- Next Steps
  - Machine learning
  - NAViGATOR

Cart #1: Setting

Pre-pre-Splunk

Setting

- RIH
  - “Can we use simulation to test a new ER before it opens?”

Transportable Enhanced Simulation Technologies for Pre-Implementation Limited Operations Testing (TESTPILOT) Program in new Emergency Departments

Leo Kobayashi MD, Marc J. Shapiro MD, Andrew Sucov MD, Robert Woolard MD, and Gregory Jay MD PhD
From the Department of Emergency Medicine, Brown Medical School, Providence RI

Transition of an active Emergency Department (ED) to a new physical plant presents tremendous challenges. Staff unfamiliarity with the new environment, emergence of systems incompatibilities, and discrepancies between expected and actual practice parameters create potentially hazardous conditions for patients. Efforts to mitigate unexpected problems are imperative to ensure effective healthcare delivery and patient safety during the transition period.

Actively employed in various settings, enhanced medical simulation (SIM) has become sufficiently sophisticated to assist evaluative and familiarization efforts for new clinical practice environments. With the “portabilization” of life-sized computerized manikins that exhibit real-time responses to participant interventions, SIM now permits analysis and performance of patient care activities *in situ*. Intended to realize complex events of high-risk and low-frequency, SIM may also enable assessment of actual patient care areas’ capacity for emergent resuscitative processes.

Patient monitor system placed too high

Controls for movable surgical lights obscured behind equipment cart

Limited tabletop surfaces

Unstable platform for airway equipment tray

Compressor unit

Laptop / Linkbox

Vital signs display

Portabilized medical simulation system

Operational issues identified through survey comments
(bold type indicates operational issues addressed prior to facility opening)

Resuscitative activity performance / Equipment availability and propriety
- Airway equipment tray easily knocked off pillar shelf (see Figure 2)
- Complicated airway management devices not readily available
- Controls for movable surgical lights obscured behind equipment carts
- Cricothyroidotomy kit location unclear
- Defibrillator connector cable difficult to locate
- Limited glove dispenser locations
- Patient monitor system placed too high
- Pediatric and large laryngoscope blades not found
- Small and large size endotracheal tubes not found
- Thoracostomy kit / tube location unclear
- Thoracotomy kit location unclear

Resuscitative space / Movement and flow of patient and staff members
- Equipment accessible with minimal movement
- Moving pillar system unstable for equipment trays and monitors
- Patient accessibility affected by monitor cords / intravenous lines
- Tabletop space and procedural table-stands limited and insufficient

Clinical staff preparedness
- New clinical environment orientation not completed by all clinical staff
- Supplemental orientation sessions necessary to train staff

Strengths of new clinical environment
- Movable pillar system with integrated resuscitation connectors / shelving
- New equipment (e.g., medical informatics computers with digital radiography capability, secured medication storage systems, patient monitors)
- Readily accessible equipment with clear line-of-sight arrangement
- Spacious work environment
- Teamwork behaviors and resourcefulness of staff members

Weaknesses of new clinical environment
- Delays in patient care processes due to staff unfamiliarity with environment
- Communications system (wireless broadcast) not yet implemented
- Tabletop space limited and insufficient for charting and procedures

TESTPILOT survey results

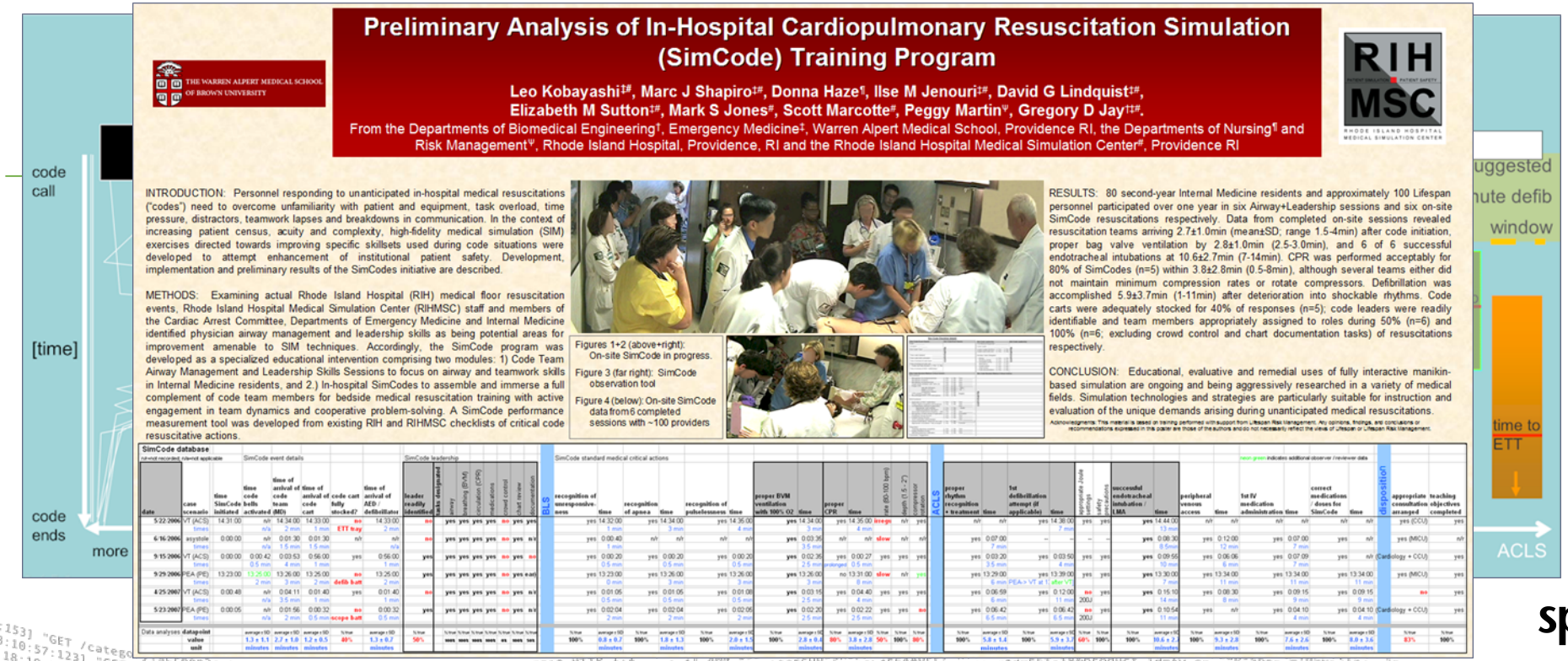
Survey question	1: Acute coronary syndrome / ventricular fibrillation (n=6)	2: Multi-trauma / complicated airway (n=7)	3: Septic shock / renal failure / hyperkalemia (n=3)	4: Pediatric clonidine overdose (n=5)	Overall (n=21)
	5-point Likert scale scores (1 = poor / disagree; 5 = excellent / agree) (mean score ± standard deviation)				
1 Ability to *perform* resuscitative actions (e.g. were intubation / intravenous access easily accomplished?)	4.8 ± 0.4	3.9 ± 0.9	4.7 ± 0.6	4.6 ± 0.5	**4.4 ± 0.7**
2 Ability to *find* resuscitative equipment and medications (e.g. were intubation / intravenous equipment / medications easily found?)	4.3 ± 0.8	3.6 ± 0.8	4.3 ± 0.6	4.4 ± 0.5	**4.1 ± 0.8**
3 *Appropriateness* of equipment for resuscitative actions (e.g. were intubation / intravenous equipment appropriate for cases?)	4.8 ± 0.4	4.1 ± 1.1	4.3 ± 0.6	4.8 ± 0.4	**4.5 ± 0.7**
4 Ability to properly *move* patient and equipment (e.g. was movement of the patient from triage / to CT scan suite easy?)	N/A - INSUFFICIENT RESPONSES FOR ANALYSIS	4.4 ± 0.8	4.5 ± 0.7	4.8 ± 0.4	**4.6 ± 0.6**
5 Ability to *communicate* with other providers (e.g. were telephones / intercom systems adequate?)	N/A - COMMUNICATIONS SYSTEMS NOT ACTIVE DURING STUDY				
6 Ability to utilize *computer systems* for patient care (e.g. were electronic medical records / Internet / lab systems available?)	N/A - INSUFFICIENT RESPONSES FOR ANALYSIS				
7 Availability of *physical space* (e.g. was physical space adequate for intubation / intravenous access?)	5.0 ± 0.0	4.7 ± 0.5	4.7 ± 0.6	4.8 ± 0.4	**4.8 ± 0.4**
8 Do you feel the *orientation session* adequately prepared you to take care of real patients in the new Emergency Department clinical environment?	4.6 ± 0.5	3.7 ± 1.1	4.5 ± 0.7	4.5 ± 0.6	**4.2 ± 0.9**
9 Do you feel the *simulation session* adequately prepared you to take care of real patients in the new Emergency Department clinical environment?	4.5 ± 0.5	4.3 ± 0.8	4.7 ± 0.6	4.6 ± 0.5	**4.5 ± 0.6**

Operational readiness testing and preliminary orientation to Rhode Island Hospital’s new ED have been arranged through a Transportable Enhanced Simulation Technologies for Pre-Implementation Limited Operations Testing (TESTPILOT) program. Designed by simulation experts and ED administrators, the program consists of cardiac arrest, multi-trauma, uroseptic shock, and pediatric toxicology SIM scenarios. Precisely scripted cases require assorted on-site interventions along the continuum of emergent patient care to elicit the dynamics of real-life ED activities and functions. Critical action checklists, surveys and debriefings have been designed to identify deficiencies and participant concerns requiring attention prior to opening day. Continuing the flight simulator analogy of SIM’s role in healthcare provider education, TESTPILOT may serve as a trouble-shooting “wind tunnel” for new clinical environments.

Setting

- RIH
  - "Can we use simulation to test a new ER before it opens?"
    - TESTPILOT
  - "Can we use simulation to see what happens during a hospital code?"
    - SimCode

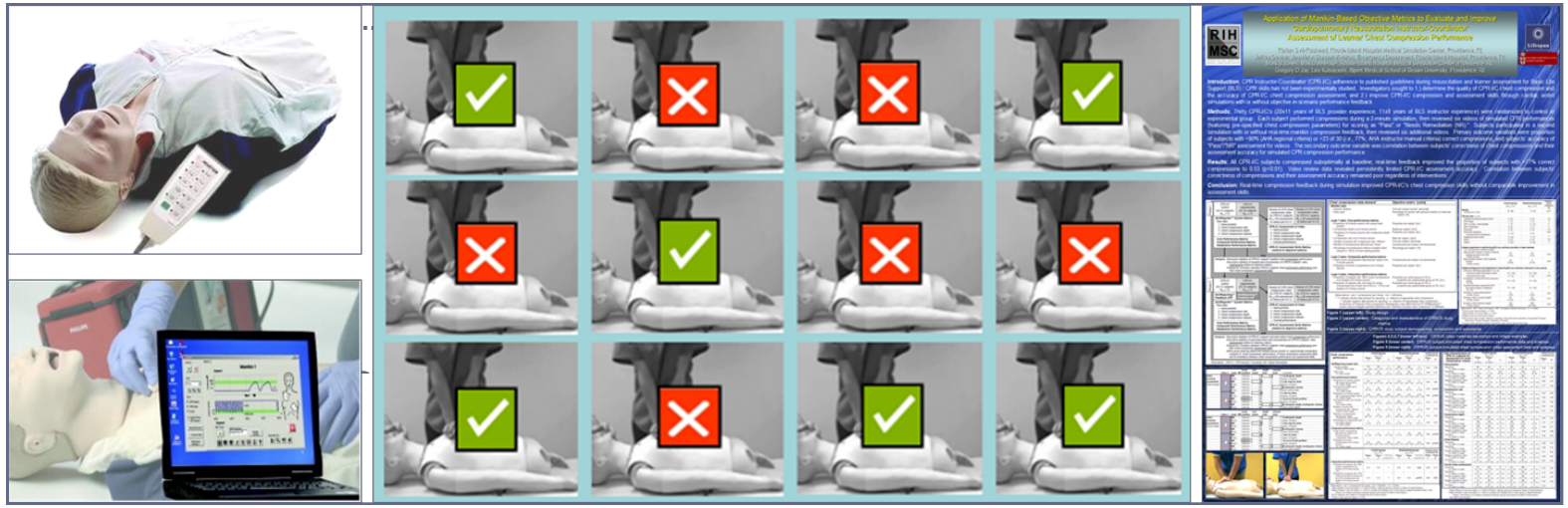
Yes.



splunk> .conf2017

Setting

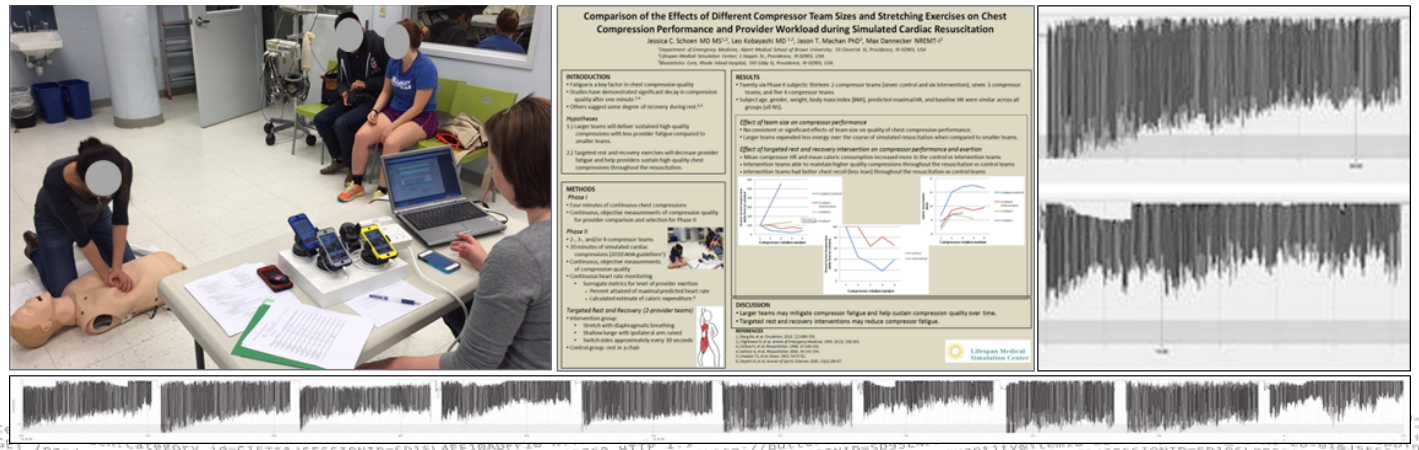
- RIH
  - “Can we use simulation to test a new ER before it opens?” Yes.
    - TESTPILOT
  - “Can we use simulation to see what happens during a hospital code?” Yes(!)
    - SimCode
  - “Why is CPR universally bad?”
    -



Setting

- RIH
  - "Can we use simulation to test a new ER before it opens?" — Yes.
    - TESTPILOT
  - "Can we use simulation to see what happens during a hospital code?" — Yes(!)
    - SimCode
  - "Why is CPR universally bad?"
    - "It could be the instructors?" — Maybe(!)

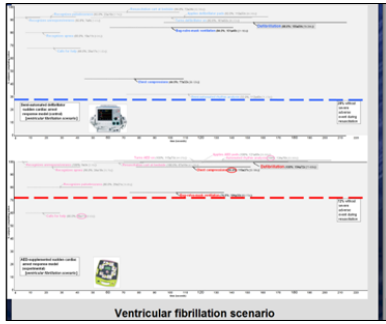
      CIRRUS
    - "Maybe we need more people to do CPR?"

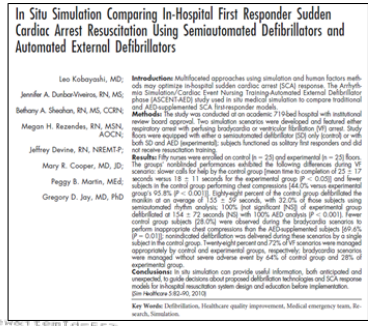


splunk> .conf2017

Setting

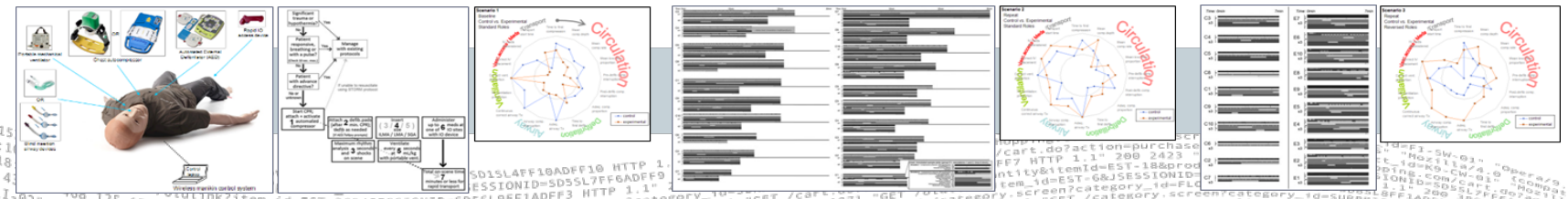
- RIH
  - "Can we use simulation to test a new ER before it opens?" — Yes.
    - TESTPILOT
  - "Can we use simulation to see what happens during a hospital code?" — Yes(!)
    - SimCode
  - "Why is CPR universally bad?"
    - "It could be the instructors?" — Maybe(!)
      CIRRUS
    - "Maybe we need more people to do CPR?" — Maybe.
      CREW
    - "What happens if you use AEDs?"

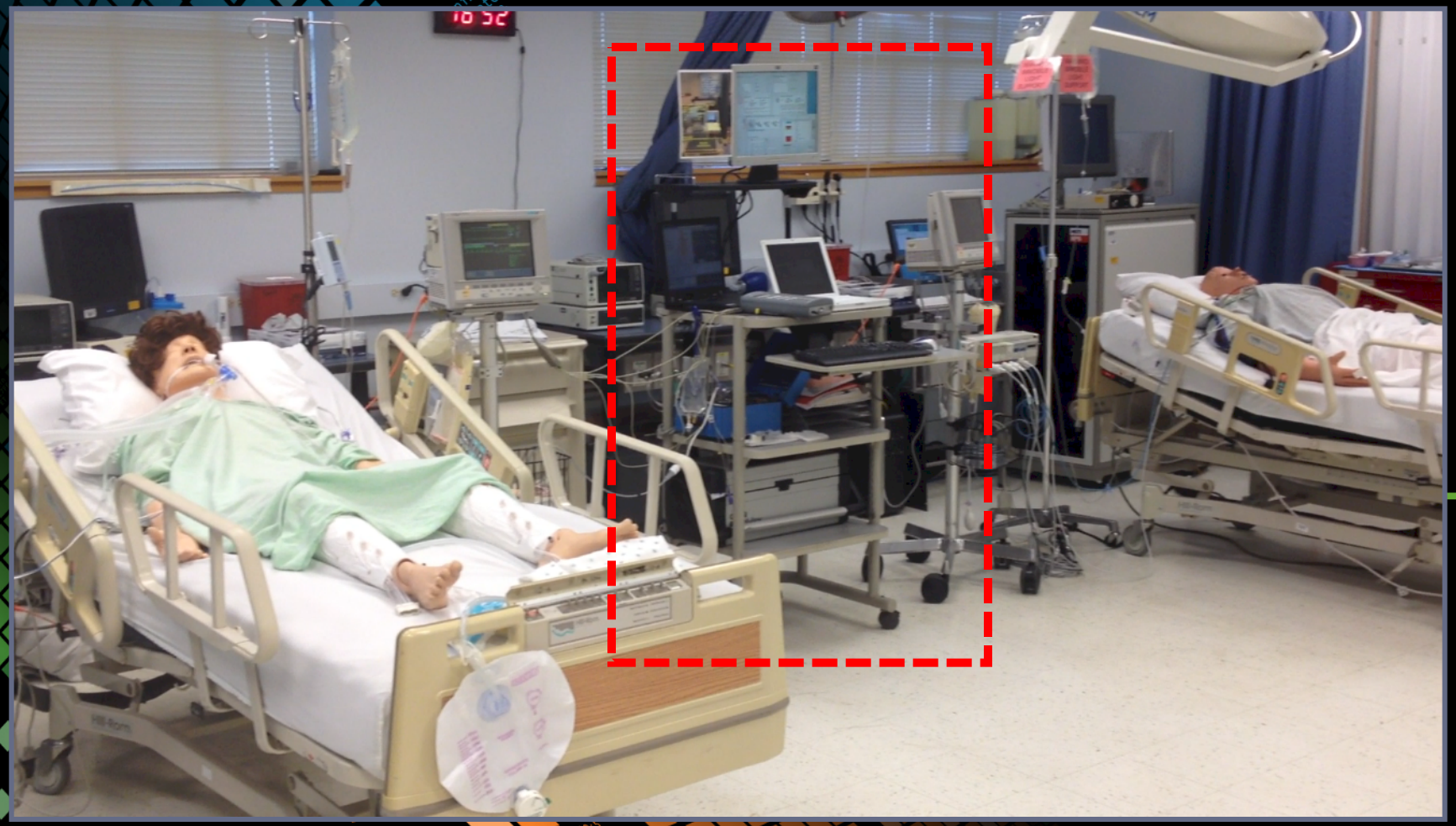



In Situ Simulation Comparing In-Hospital First Responder Sudden Cardiac Arrest Resuscitation Using Semiautomated Defibrillators and Automated External Defibrillators

Setting

- RIH
  - "Can we use simulation to test a new ER before it opens?" — Yes.
    - TESTPILOT
  - "Can we use simulation to see what happens during a hospital code?" — Yes(!)
    - SimCode
  - "Why is CPR universally bad?"
    - "It could be the instructors?" — Maybe(!)
      CIRRUS
    - "Maybe we need more people to do CPR?" — Maybe.
      CREW
    - "What happens if you use AEDs?" — Maybe.
      ASCENT AED
    - "Ok, forget the people, let's make machines do the work."



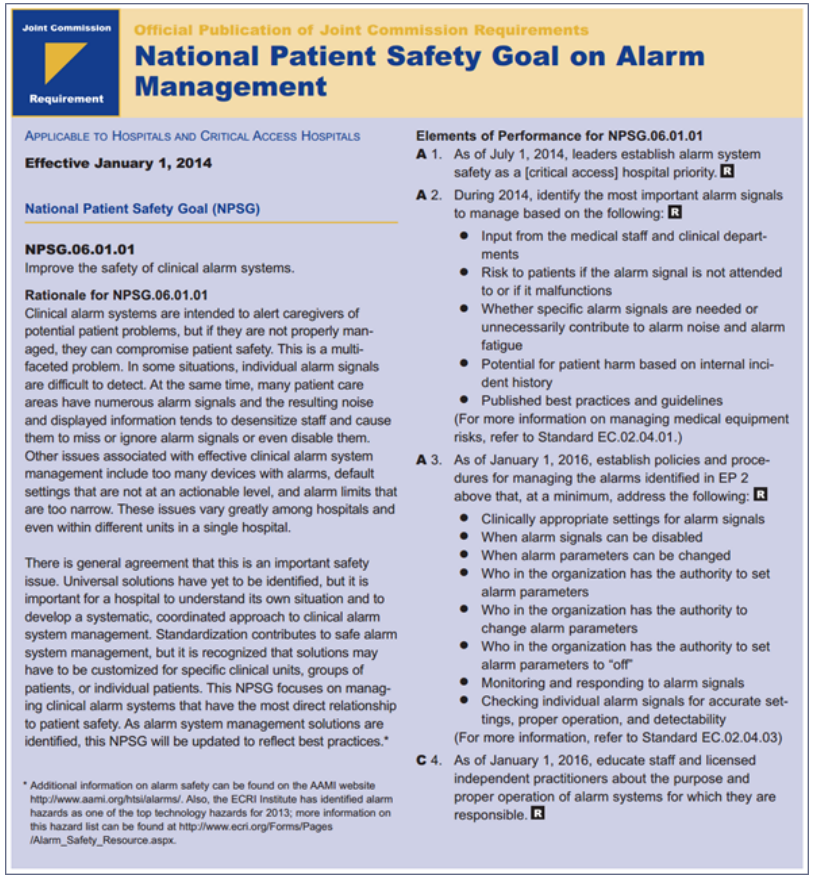


Cart #2: Methods

Pre-Splunk

Methods

- "Catching the problem earlier"
  - Common pathways to (medical) code blue
    - Primary cardiac arrhythmic arrest (VF / VTach; bradycardia)
    - Hypoperfusive / hypotensive arrest
    - Hypoxic / hypercarbic arrest
- Systems in place
  - Continuous patient monitoring with central telemetry system
  - Alarm parameters
  - Staff responsibilities
- Failures of systems in place
  - Failure to detect (accurately)
  - Failure to recognize (adequately)
  - Failure to respond (appropriately)



Joint Commission Requirement

Official Publication of Joint Commission Requirements

National Patient Safety Goal on Alarm Management

APPLICABLE TO HOSPITALS AND CRITICAL ACCESS HOSPITALS

Effective January 1, 2014

National Patient Safety Goal (NPSG)

NPSG.06.01.01
Improve the safety of clinical alarm systems.

Rationale for NPSG.06.01.01
Clinical alarm systems are intended to alert caregivers of potential patient problems, but if they are not properly managed, they can compromise patient safety. This is a multifaceted problem. In some situations, individual alarm signals are difficult to detect. At the same time, many patient care areas have numerous alarm signals and the resulting noise and displayed information tends to desensitize staff and cause them to miss or ignore alarm signals or even disable them. Other issues associated with effective clinical alarm system management include too many devices with alarms, default settings that are not at an actionable level, and alarm limits that are too narrow. These issues vary greatly among hospitals and even within different units in a single hospital.

There is general agreement that this is an important safety issue. Universal solutions have yet to be identified, but it is important for a hospital to understand its own situation and to develop a systematic, coordinated approach to clinical alarm system management. Standardization contributes to safe alarm system management, but it is recognized that solutions may have to be customized for specific clinical units, groups of patients, or individual patients. This NPSG focuses on managing clinical alarm systems that have the most direct relationship to patient safety. As alarm system management solutions are identified, this NPSG will be updated to reflect best practices.*

* Additional information on alarm safety can be found on the AAMI website http://www.aami.org/hts/alarms/. Also, the ECRI Institute has identified alarm hazards as one of the top technology hazards for 2013; more information on this hazard list can be found at http://www.ecri.org/Forms/Pages/Alarm_Safety_Resource.aspx.

Elements of Performance for NPSG.06.01.01

A 1. As of July 1, 2014, leaders establish alarm system safety as a [critical access] hospital priority. R

A 2. During 2014, identify the most important alarm signals to manage based on the following: R
- Input from the medical staff and clinical departments
- Risk to patients if the alarm signal is not attended to or if it malfunctions
- Whether specific alarm signals are needed or unnecessarily contribute to alarm noise and alarm fatigue
- Potential for patient harm based on internal incident history
- Published best practices and guidelines

(For more information on managing medical equipment risks, refer to Standard EC.02.04.01.)

A 3. As of January 1, 2016, establish policies and procedures for managing the alarms identified in EP 2 above that, at a minimum, address the following: R
- Clinically appropriate settings for alarm signals
- When alarm signals can be disabled
- When alarm parameters can be changed
- Who in the organization has the authority to set alarm parameters
- Who in the organization has the authority to change alarm parameters
- Who in the organization has the authority to set alarm parameters to "off"
- Monitoring and responding to alarm signals
- Checking individual alarm signals for accurate settings, proper operation, and detectability

(For more information, refer to Standard EC.02.04.03)

C 4. As of January 1, 2016, educate staff and licensed independent practitioners about the purpose and proper operation of alarm systems for which they are responsible. R

Methods

- Research + Development Program Aims / Phases

  - "To better **understand** the alarm fatigue resulting from existing bedside patient monitoring telemetry systems and create a non-proprietary mechanism to **augment** the analysis and delivery of critical information to clinical providers."
  - "To comparatively **evaluate** the performance and utility of existing and experimental patient monitoring telemetry systems with human factors engineering, simulation and patient tracer methods."
  - "To prepare and **disseminate** a non-proprietary medical technology interface toolbox for continued medical device and informatics research at the study institution and beyond."

Methods

- Research + Development (Phase 1; 2010-2012)
  - Existing systems
  - Intervention
  - Data access (middle layers)

Methods

- Existing Systems (RIH ED, 2010)
  - 100,000 adult census / year
  - Patient monitor telemetry system
    - *System as intended*
      - HP/Philips telemetry system
      - Monitored spaces:
        - 12 critical care
        - 45 urgent care
        - 7 observation unit
      - Central stations:
        - 1 in critical care (hallway)
        - 3 in urgent care
        - 1 in observation unit

Methods

- Existing Systems (RIH ED, 2010)
  - System in *operation*
    - 1 of 5 system PCs (A9-15) non-booting
    - All alarm speakers (actively) disconnected
    - No rhythm printers connected
    - Positioned at secluded non-clinical stations
    - Used by <50% of attending ED clinicians...

      ...yet anecdotal reports of “saves.

Methods

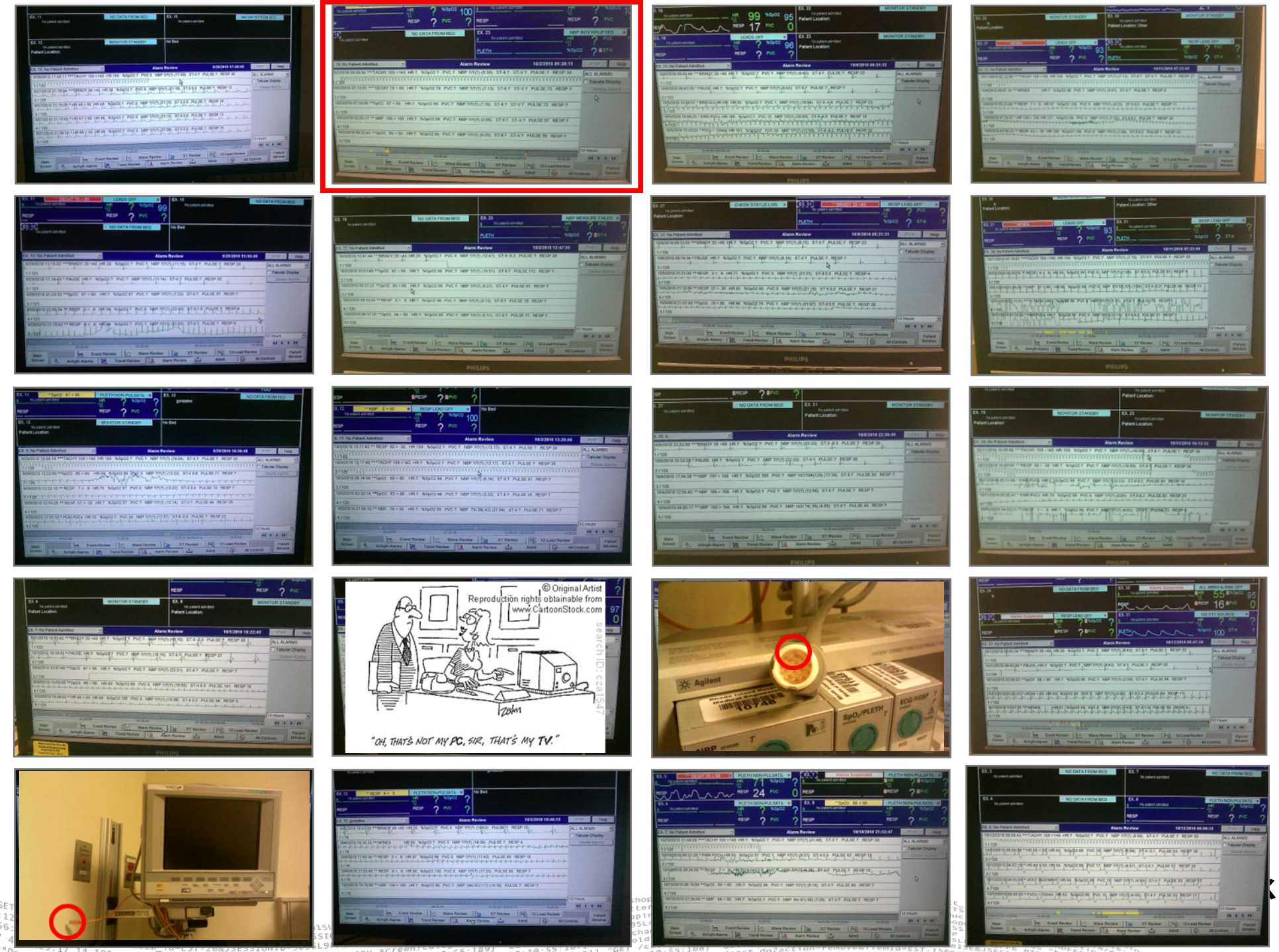
- Existing Systems (RIH ED, 2010)
  - Accessible Real-time clinical Guidance through Updated Signals [ARGUS]

Methods

- Existing Systems (RIH ED, 2010)
  - **1 of 10** VT runs (HR 150 x 3min)

    detected by providers
  - **0 of 10** S.Brady (HR 20 x 3 min)

    detected by providers



Methods

- Intervention
  - Improve relevance of telemetry system
    - Settings re-configuration, signal:noise
  - Improve “visibility” of telemetry system
    - Monitors moved to clinician / RN stations
  - Improve usability of telemetry system
    - Trackpad interface, routine maintenance
  - Reduce workplace footprint of system
    - Low volume alerts
    - User-specified printing
  - Increase userbase
    - User awareness + familiarity

Table 1: Experimental Multi-element Human Factors Engineering Intervention.

System feature	Specific deficiencies identified in baseline system implementation	Experimental intervention implemented	HFE conceptual basis / evidence for intervention
Accessibility / Usability			
Audibility	-Alarm speakers muted or non-functional	-Re-positioning of speakers to distributed telemetry display locations -Adjustment of alarm volumes for audible, less obtrusive notification	-Environment design -Equipment design + usability -Human-to-device interaction
General function	-System PC components in disrepair (disconnected, physically-distressed and/or non-booting PCs)	-Re-positioning and updating of system PC components in separate, secluded spaces -Coordination of institutional infrastructure for routine maintenance	-5S principles (sort, straighten, sweep, standardize, sustain) -Equipment usability
Input interface	-Traditional keyboard and mouse input devices suboptimal for limited workspace	-Placement of touchpad input devices at physician station telemetry displays and at nursing stations for intuitive interaction	-Equipment design + usability -Human-to-device interaction
Visibility	-Telemetry displays located in peripheral areas (*e.g.,* hallways, spaces for ED interpreting services)	-Re-positioning of central telemetry displays to physician stations -Installation of distributed telemetry large-screen displays at RN stations	-Environment design -Human-to-device interaction -Task design
Relevance / Utility			
Clinical relevance	-Poor signal:noise ratio, with excessive false alarms resulting in “alarm fatigue”	-Resetting of alarm parameters to reduce false alarms, *i.e.,* “Red” alarms only for: - asystole > 4 sec - bradycardia < 40 bpm - tachycardia > 130 bpm - [VF] or [VT > 100 bpm] “Yellow” alarms for: - NSVT - R-on-T PVC - SVT > 180 bpm - Ventricular rhythm > 14 PVCs Additional vital sign alarms: - SBP > 200 mmHg - SBP < 90 mmHg - SpO2 < 89% - Removal of all RR alarms (*e.g.,* apnea)	-ED administration and practice group input from MD and RN end-user Web surveys and small group discussions
General utility	-Low yield of system access for clinical providers	-System integration into RN charting workflow	-Operator selection -Task design
Userbase			
User awareness	-Widespread knowledge deficit of system presence, availability and features	-Announcement of study conduct and intervention at MD and RN meetings -Study simulation sessions	-Environment design -Operator selection
User familiarity	-Widespread knowledge deficit of system operation	-Group in-servicing and on-shift in-servicing of MD’s and RN’s	-Operator training

splunk> .conf2017

Methods

- Intervention

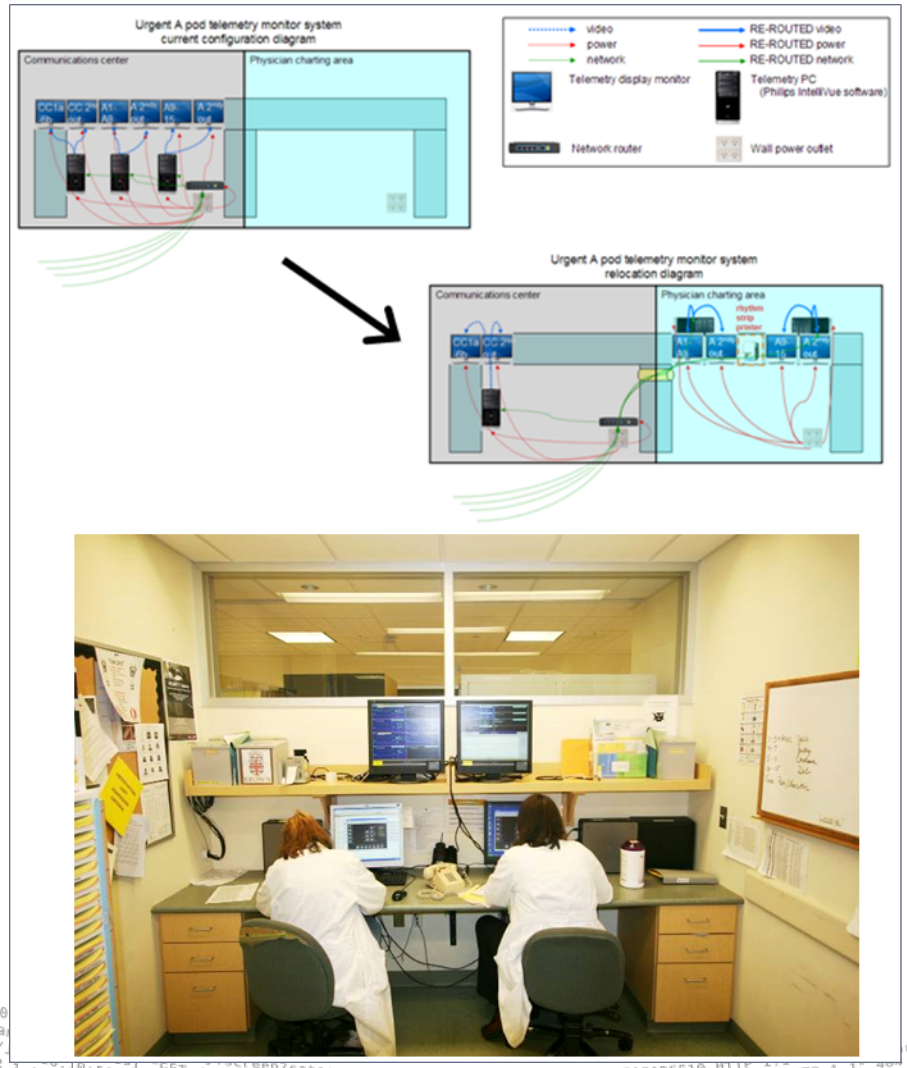
Previous default alarm / threshold settings:
- Low blood pressure: ≤90 mmHg
- High blood pressure: ≥160 mmHg
- Low heart rate: ≤50 bpm
- High heart rate: ≥120 bpm
- Low pulse oximetry: ≤90%
- Respiratory alarms: apnea alarm ON, bradypnea alarm ON, tachypnea alarm ON

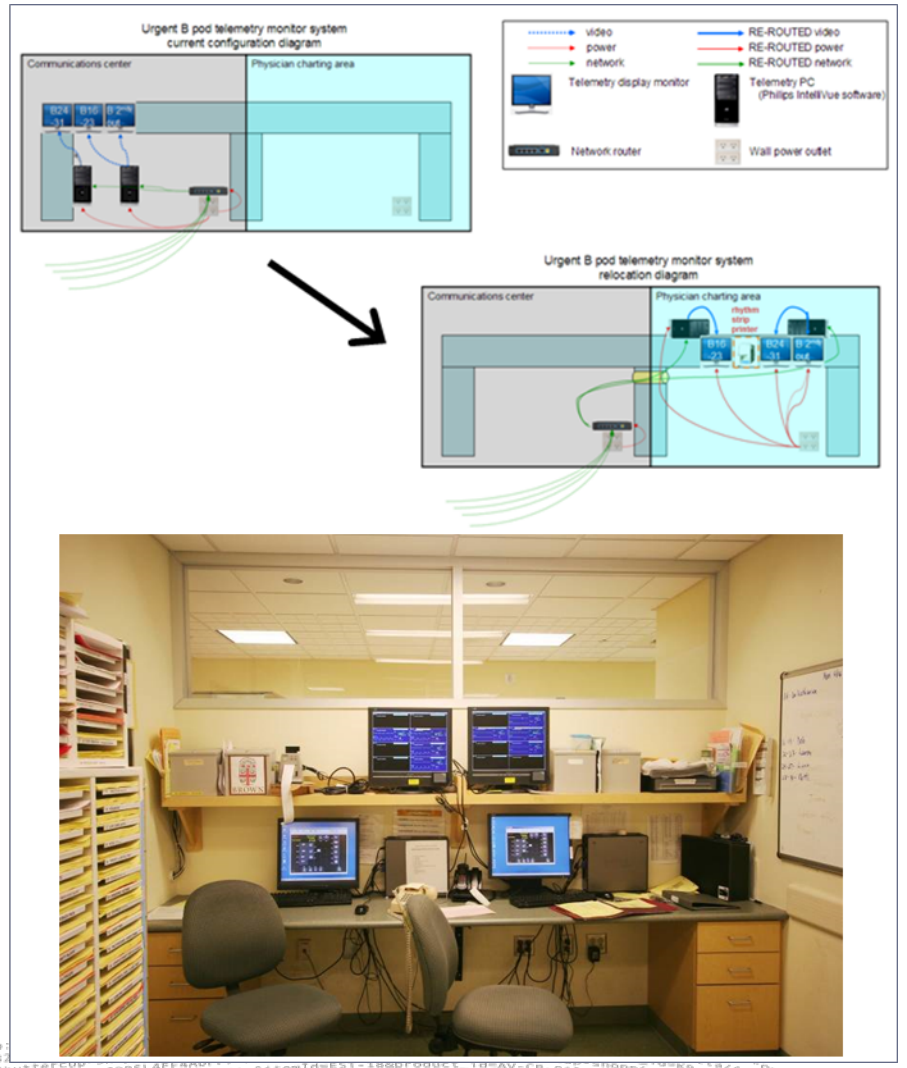
Revised default settings
- Low blood pressure: ≤90 mmHg (no change)
- **High blood pressure: ≥200 mmHg**
- **Low heart rate: ≤40 bpm**
- **High heart rate: ≥130 bpm**
- **Low pulse oximetry: ≤89%**
- **Respiratory rate: apnea alarm OFF, bradypnea alarm OFF, tachypnea alarm OFF**
  (based on the expectation that apneic patients will quickly develop other vital sign abnormalities / arrhythmias).

splunk> .conf2017

Methods

- Intervention

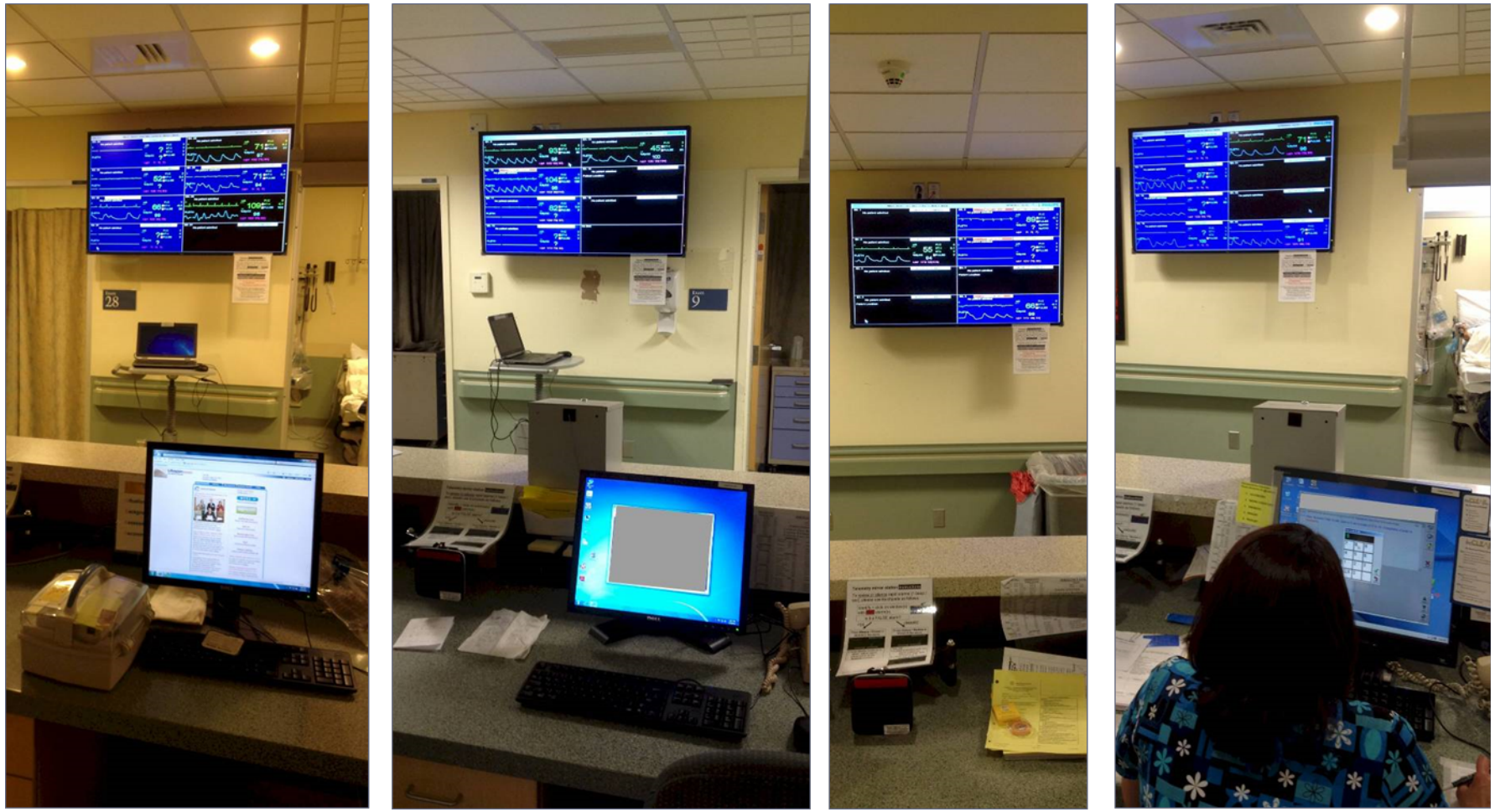




splunk> .conf2017

Methods

- Intervention



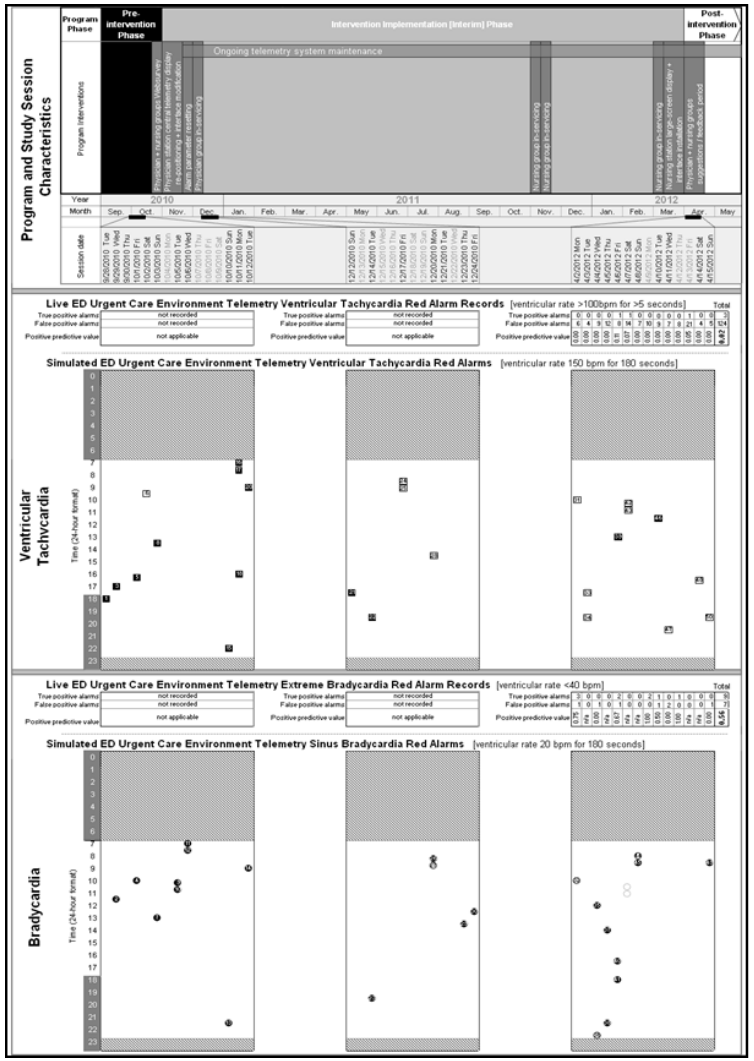
Methods

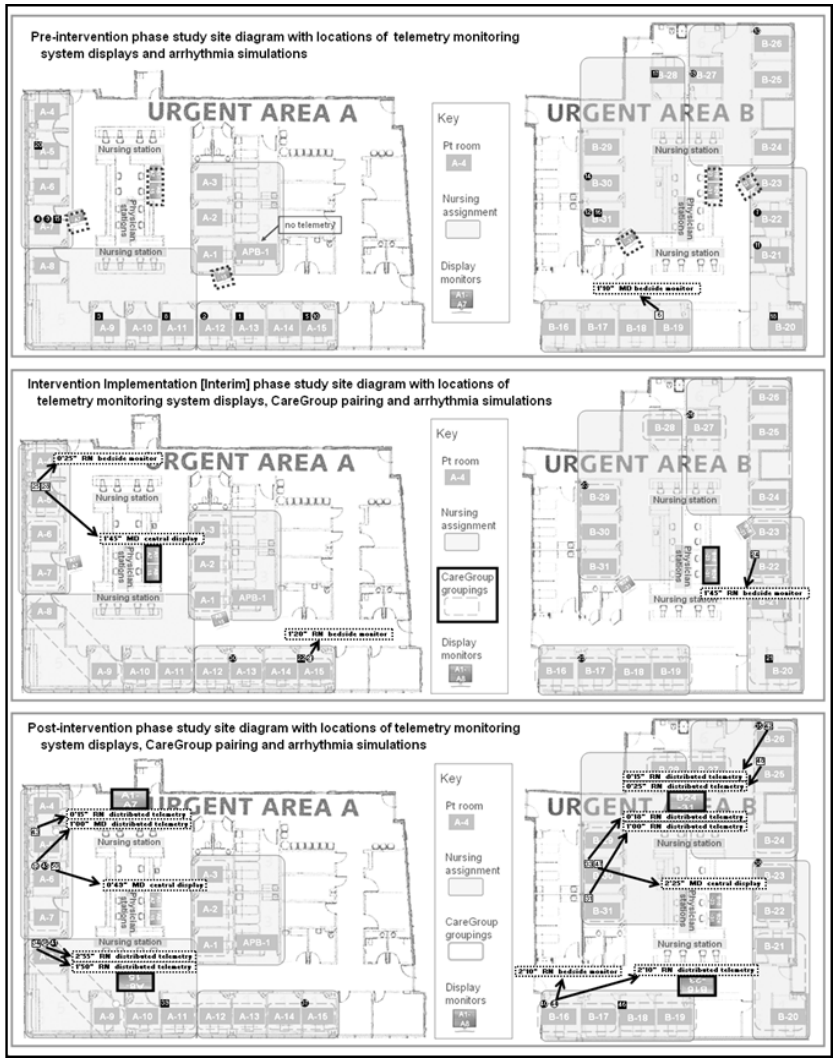
- Post-intervention (RIH ED, 2012)
  - **8 of 10** VT runs (HR 150 x 3min)

    detected by providers
  - **3 of 10** S.Brady (HR 20 x 3 min)

    detected by providers

Methods





splunk> .conf2017

Methods

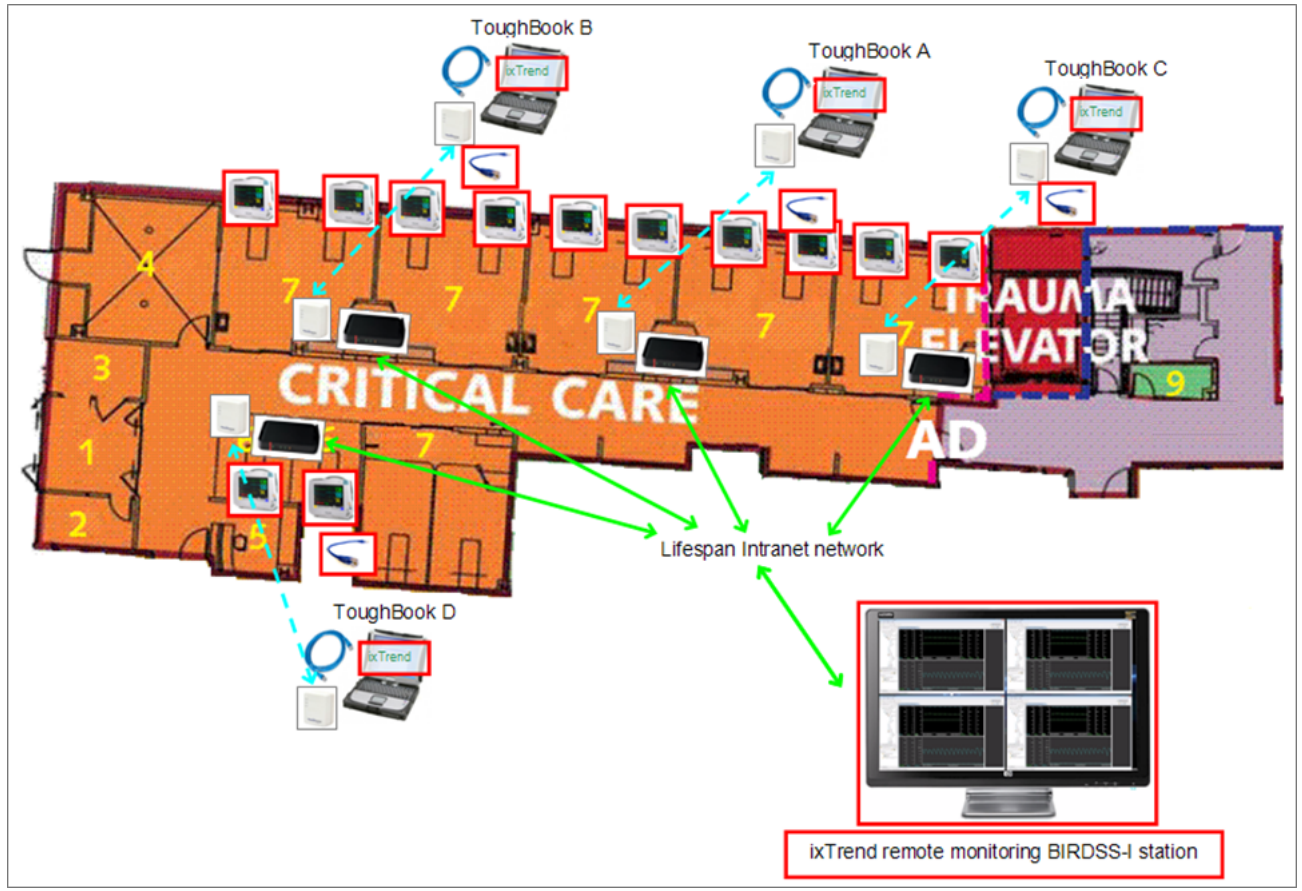
- ARGUS...
  - Live environment, 2 week alarm sample dataset review
  - VTach alarm PPV **0.02** (3 of 124)
  - SBrady alarm PPV **0.56** (9 of 16)
- **...PERSEUS (Push Electronic Relay for Smart Alarms for End User Situational Awareness) !**

Methods

- Data access (middle layers)
  - Existing systems
    - [Philips Research Data Export (RDE) $ 20k]
    - BedMaster
    - ixTrend 3k euros
    - Capsule
    - MediCollector $ 1.5k
    - OpenICE

Methods

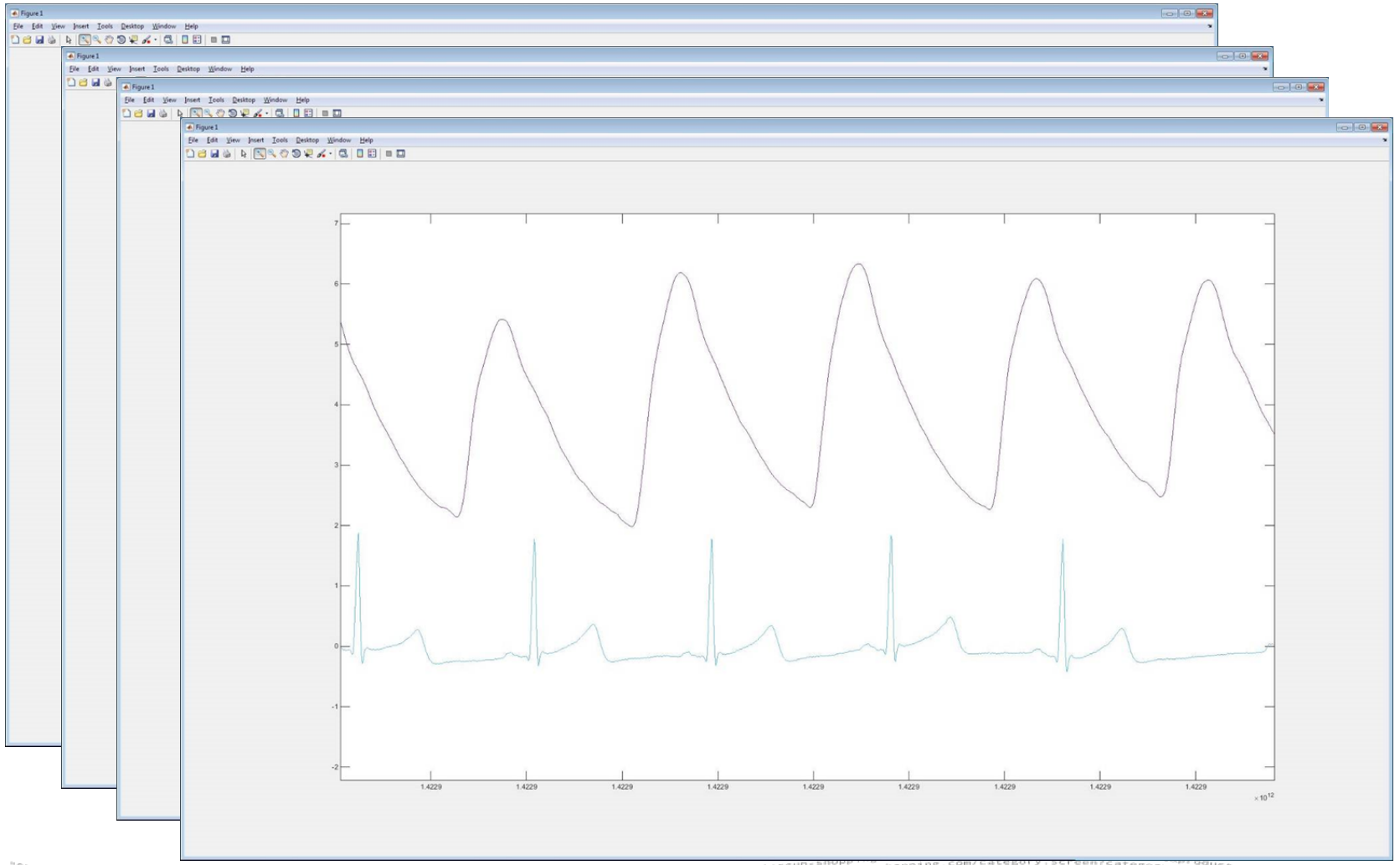
- Data access (middle layers)
  - BIRDSS-I

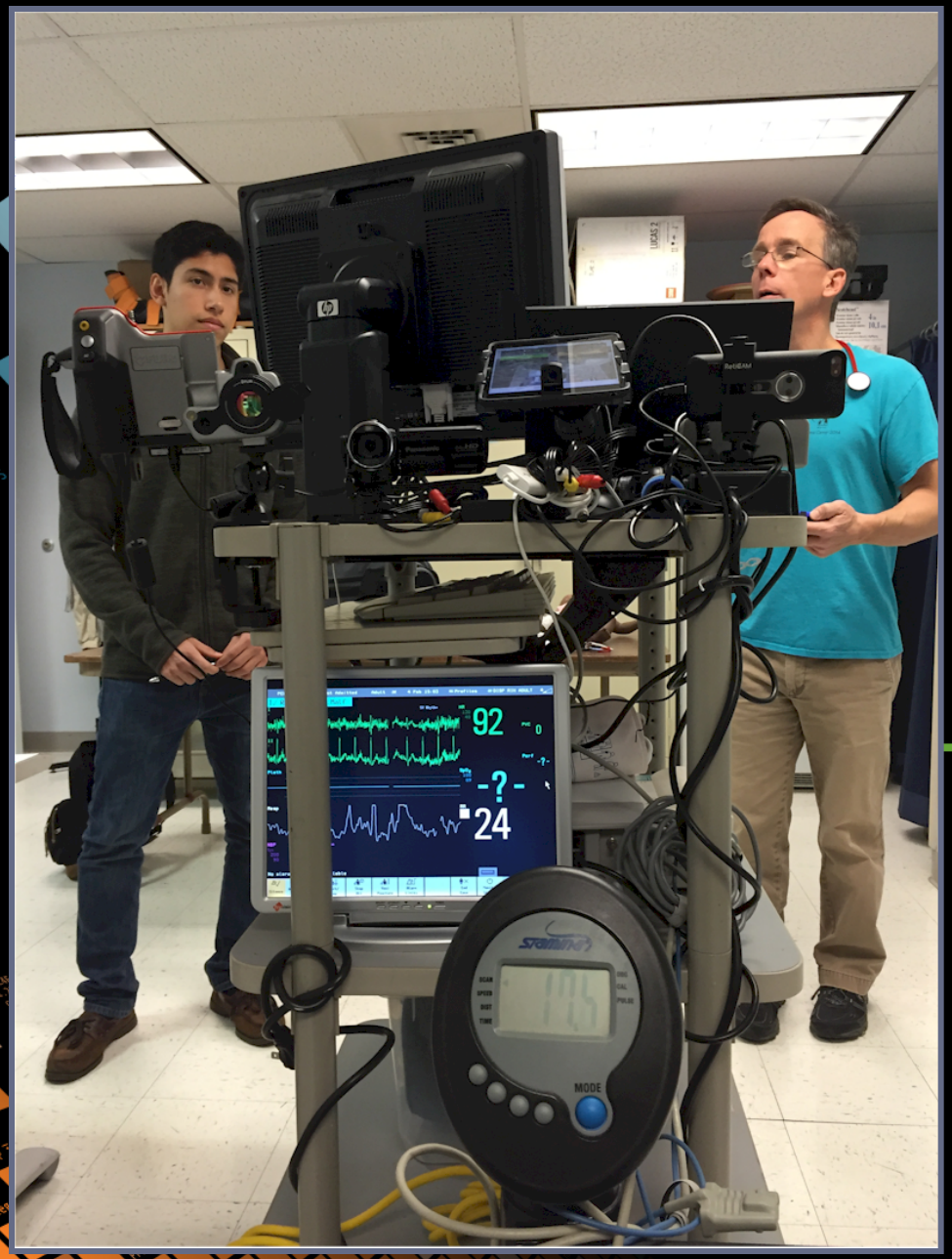


splunk> .conf2017

Methods

- Data access (middle layers)





Cart #3: Results

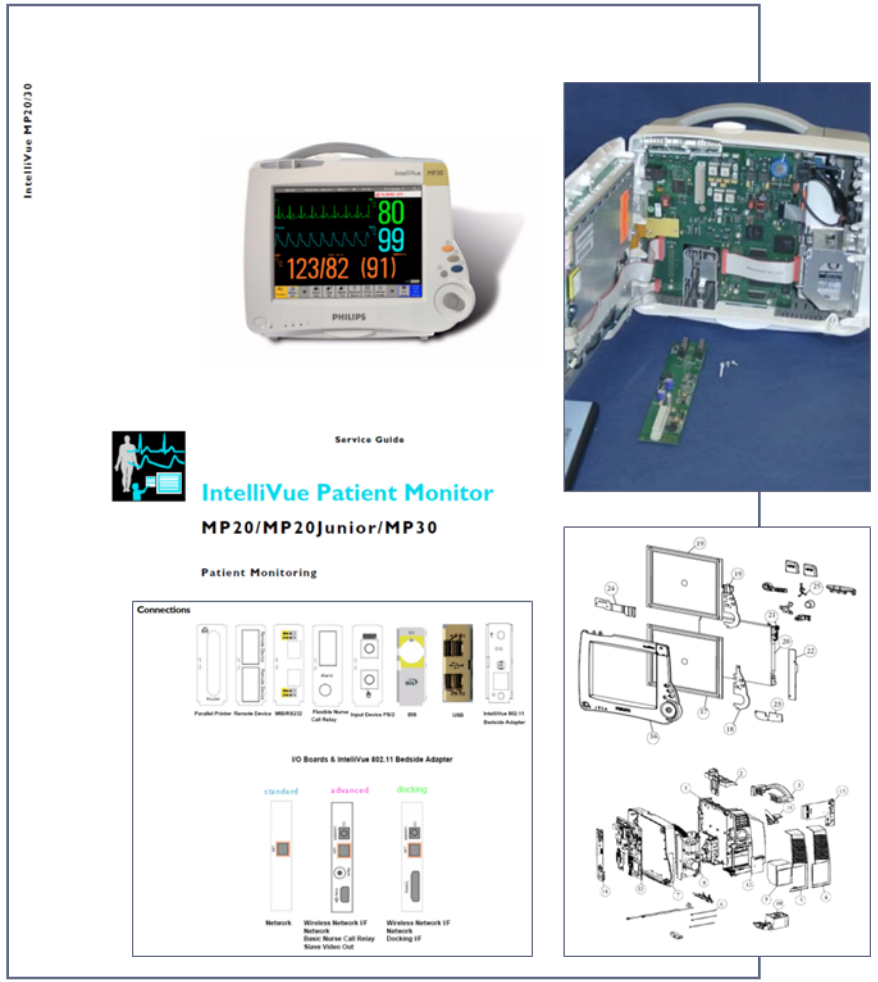
Splunk!

Results

- Research + Development (Phase 2; 2012-2017)
  - Data acquisition (lower layers)
  - Data analytics

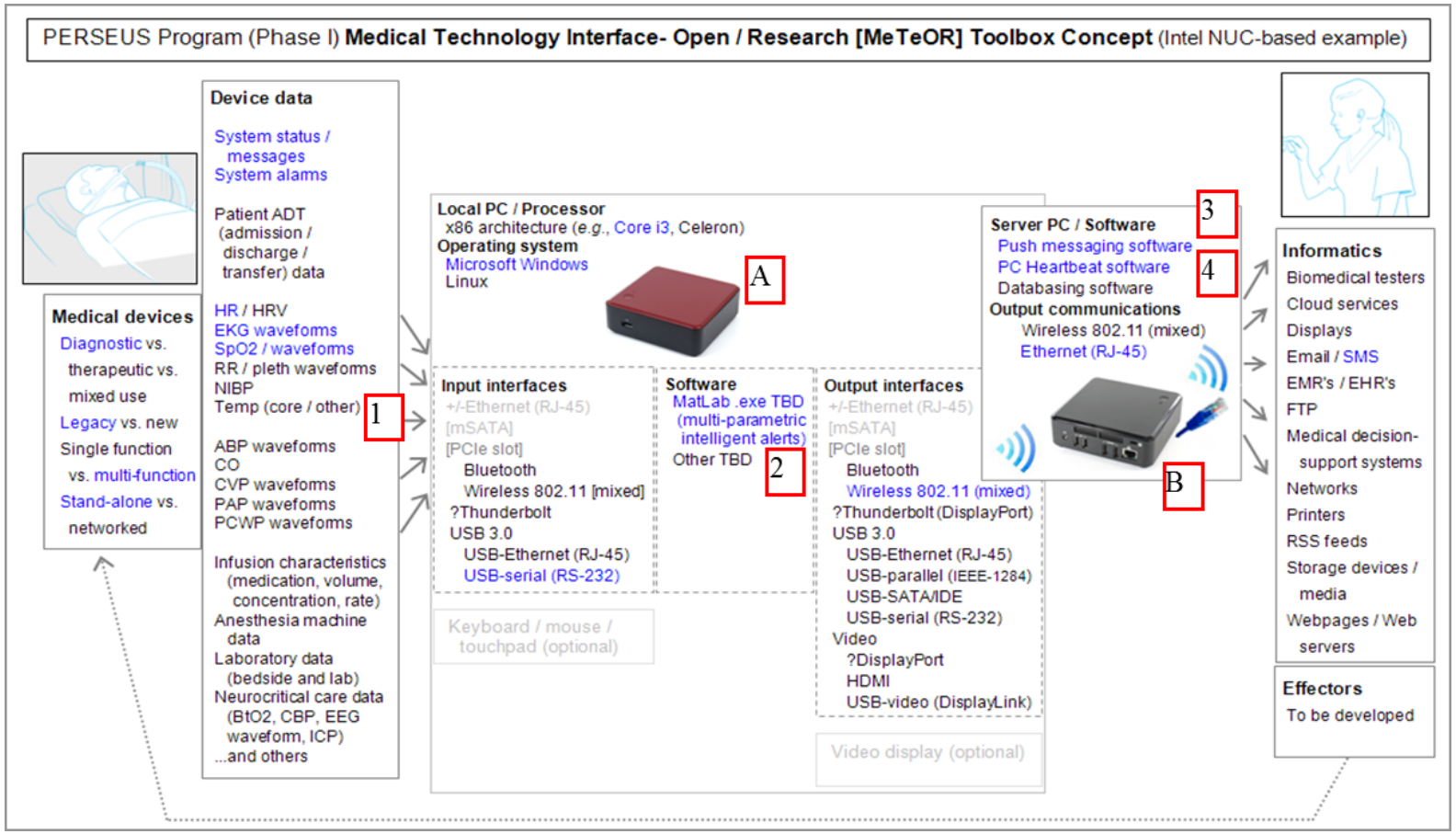
Results

- Data acquisition (lower layers)



Results

- Data acquisition (lower layers)
  - MeTeOR

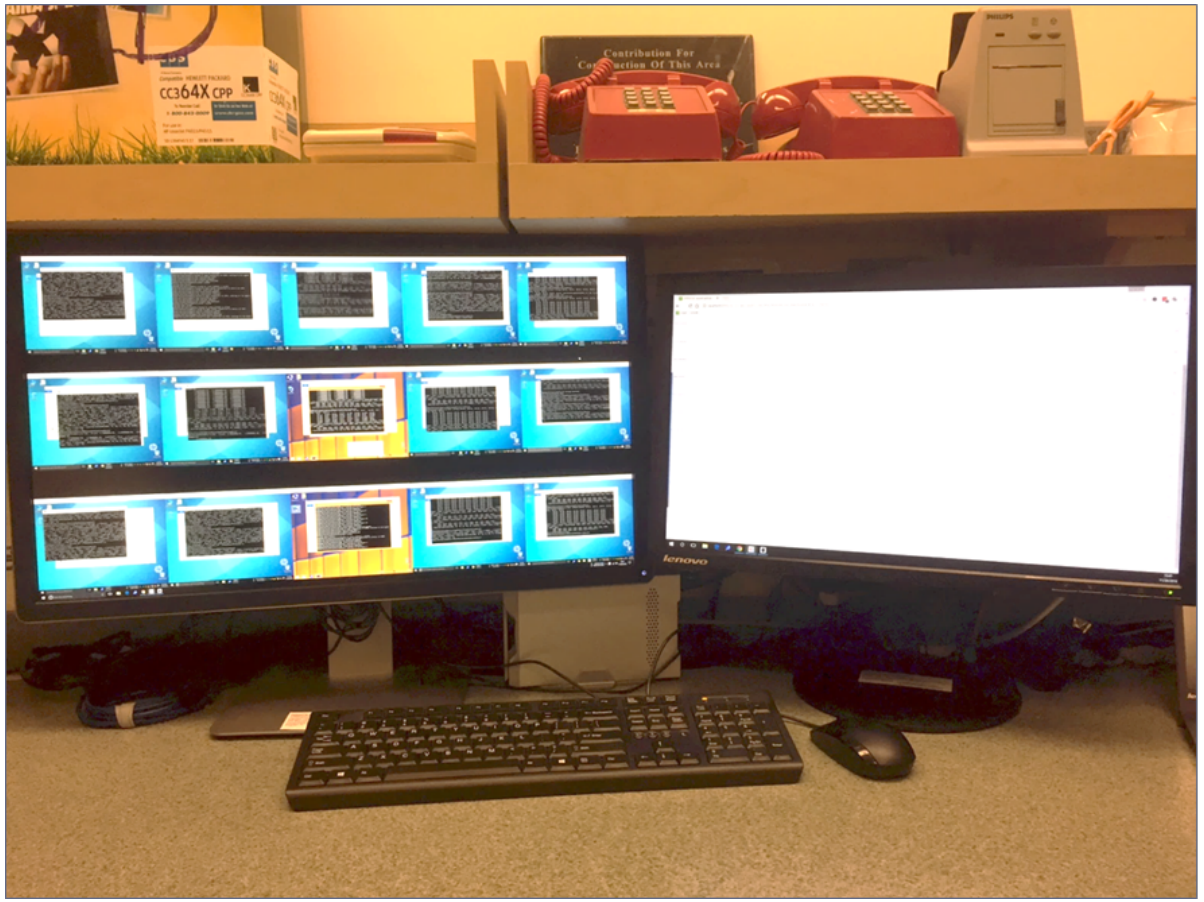


Results

- Data acquisition (lower layers)
  - MeTeOR

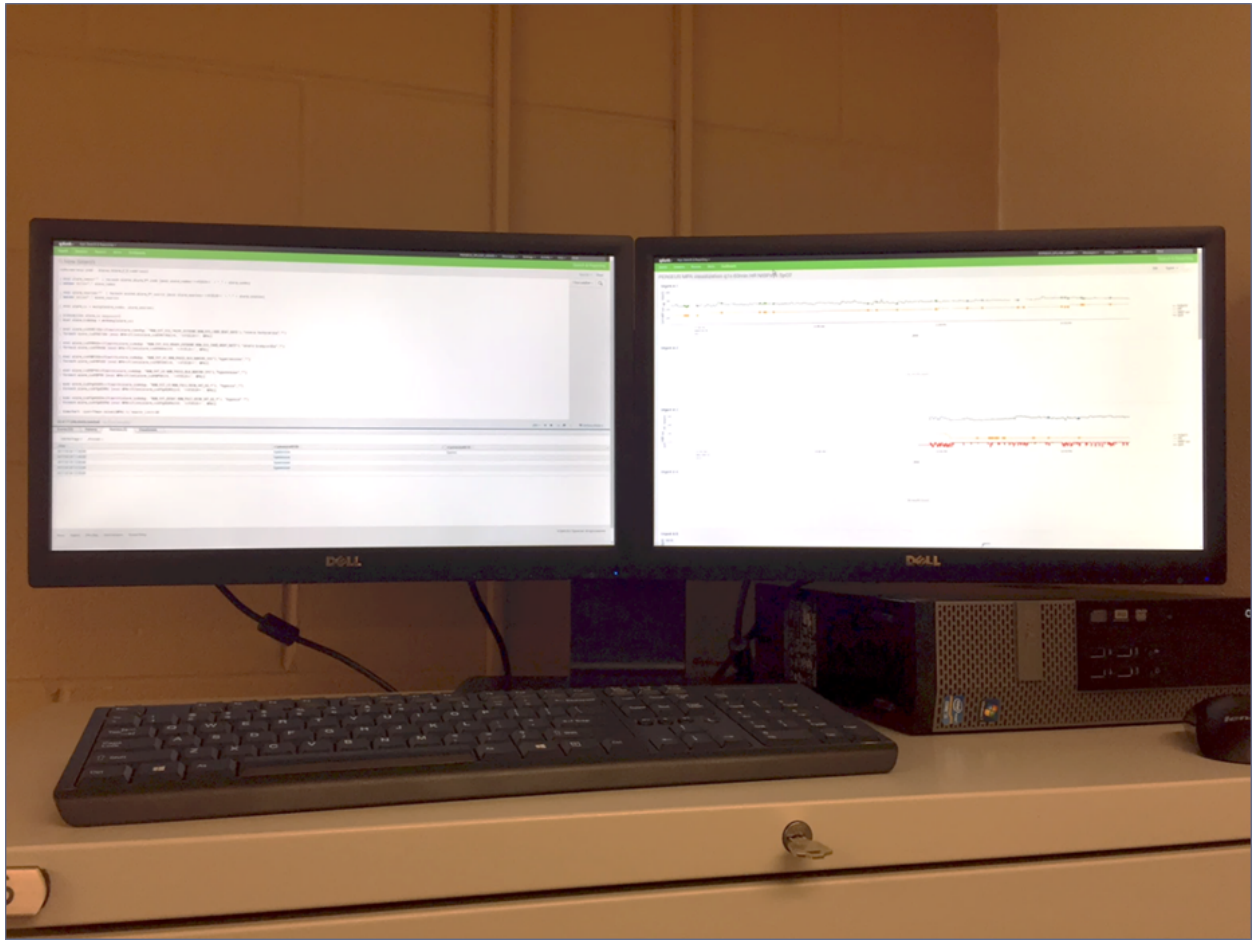
Results

- Data acquisition (lower layers)
  - MeTeOR



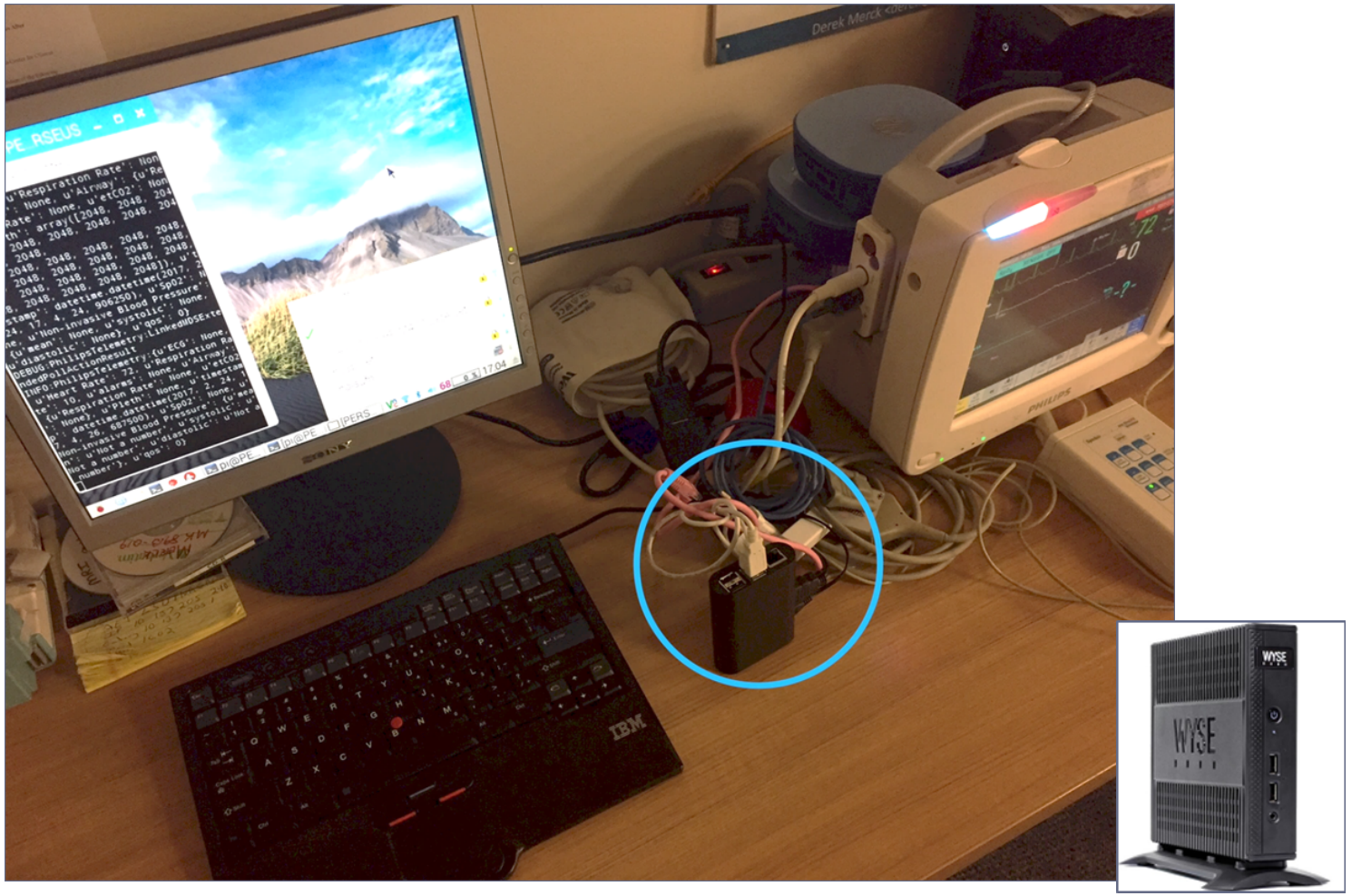
Results

- Data acquisition (lower layers)
  - MeTeOR



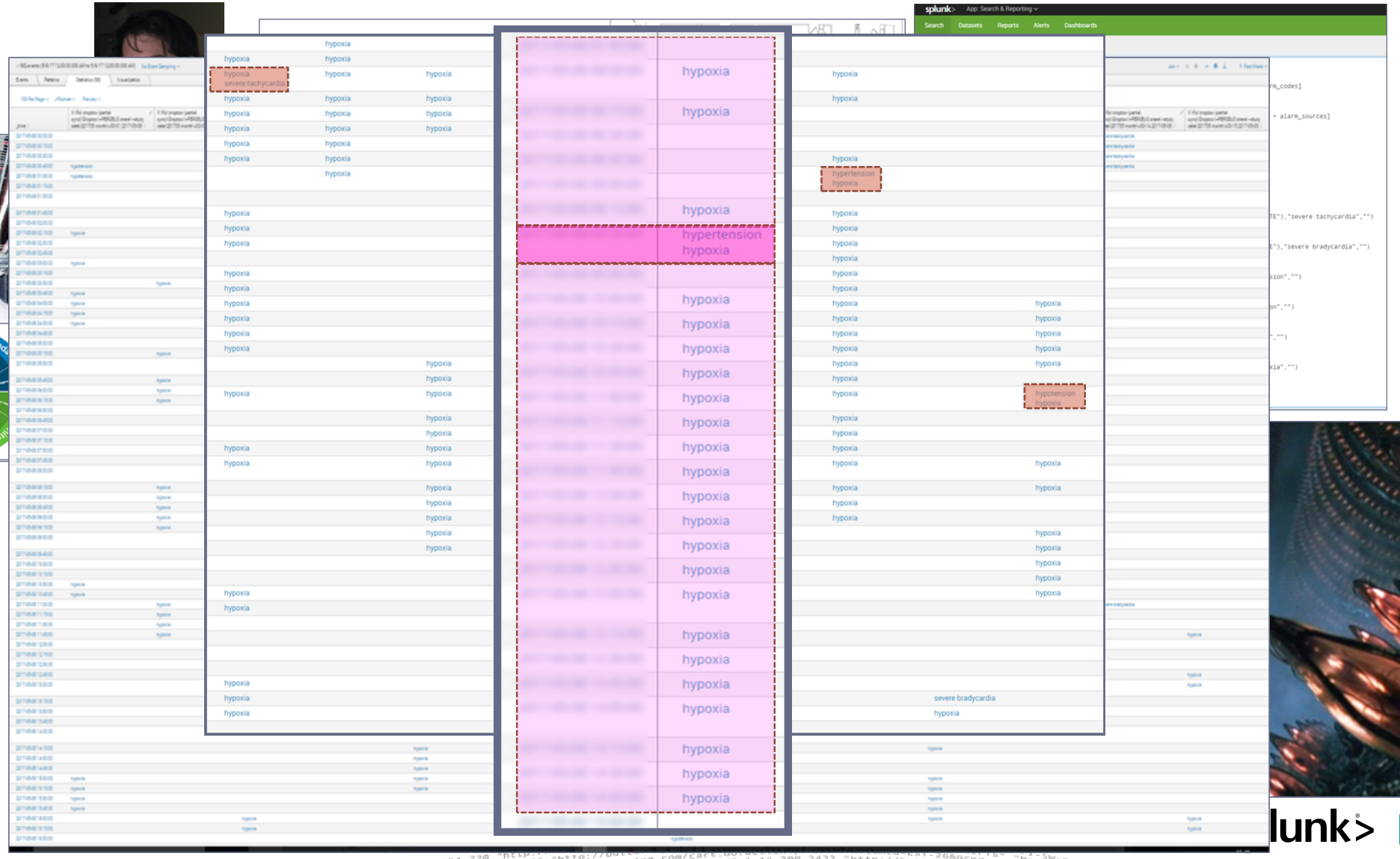
Results

- Data acquisition (lower layers)
  - MeTeOR



Results

- "Just" data
  - Dev-ops



splunk> .conf2017

Results

- Data acquisition (lower layers)
  - Splunk

```
index=<index>  source=<source>  Pleth{}!=null
| eval Pleth0=mvindex('Pleth{}',0)
| where Pleth0!=2047
| eval counters=mvrange(0,32)
| eval fields=mvzip('Pleth{}',counters)
| mvexpand fields
| rex field=fields "(?<Pleth>.),(?<counter>.)"
| eval _time=_time + counter/128
| chart first(Pleth) by _time
```

```
-EKG
index=<index>  source=<source>  ECG{}!=null
| eval ecg0=mvindex('ECG{}',0)
| where ecg0>-40
| eval counters=mvrange(0,64)
| eval fields=mvzip('ECG{}',counters)
| mvexpand fields
| rex field=fields "(?<ecg>.),(?<counter>.)"
| eval _time=_time + counter/256
| chart first(ecg) by _time
```

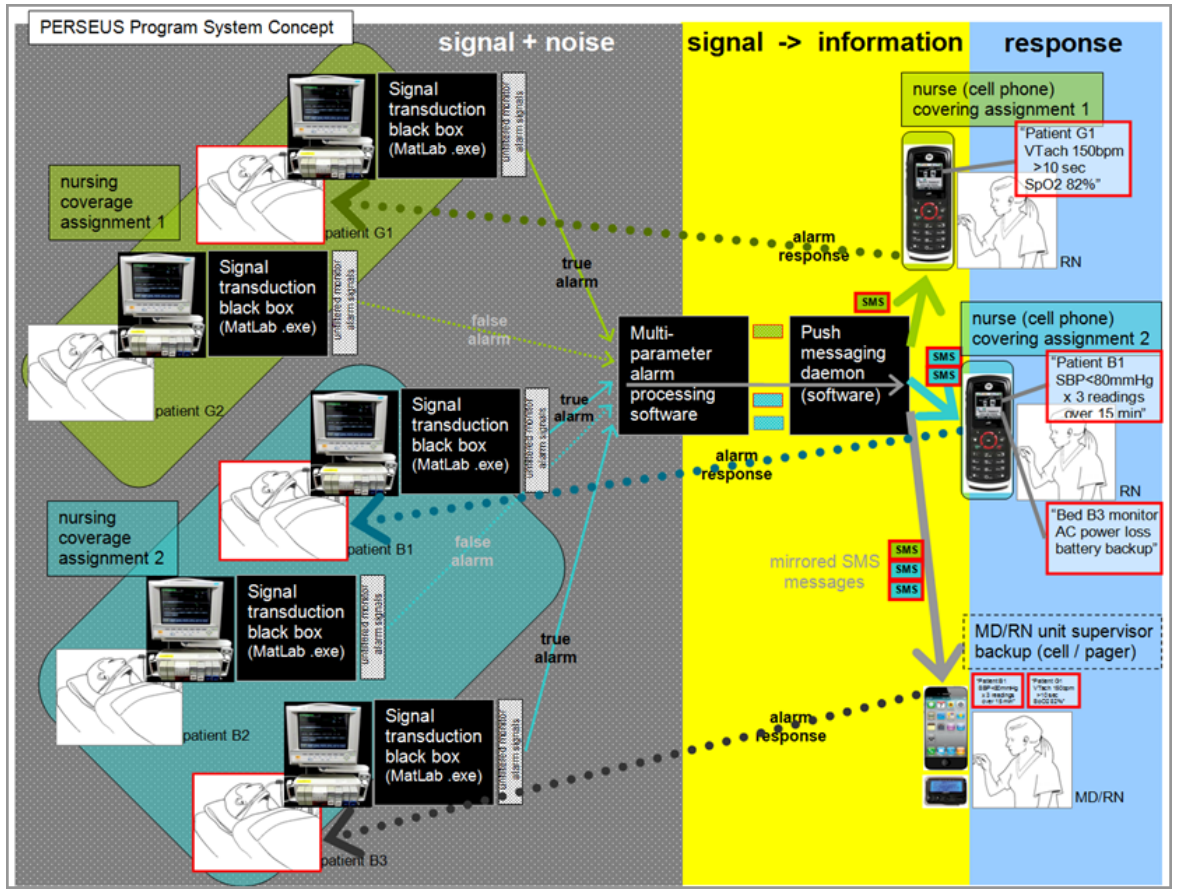
```
index=perseus-json  alarms.Alarm_P_0.code!=null
| eval alarm_codes="" | foreach alarms.Alarm_P*.code [eval alarm_codes='<<FIELD>>' + "," + alarm_codes]
| makemv delim="," alarm_codes
| eval alarm_sources="" | foreach alarms.Alarm_P*.source [eval alarm_sources='<<FIELD>>' + "," + alarm_sources]
| makemv delim="," alarm_sources
| eval alarm_cs = mvzip(alarm_codes, alarm_sources)
| rex field=source ".\d{8}.(?<source_machine>.).\d{4}-\d\d-\d\d"
| eval alarm_csS = mvzip(alarm_cs, source_machine)
| transaction alarm_csS maxpause=5
| eval alarm_csdedup = mvdedup(alarm_csS)
| eval alarm_csdfHR130e=if(match(alarm_csdedup, "NOM_EVT_ECG_TACHY_EXTREME,NOM_ECG_CARD_BEAT_RATE"),"severe tachycardia","")
| foreach alarm_csdfHR130e [eval MPA=if(len(alarm_csdfHR130e)>0, '<<FIELD>>', MPA)]
| eval alarm_csdfHR40e=if(match(alarm_csdedup, "NOM_EVT_ECG_BRADY_EXTREME,NOM_ECG_CARD_BEAT_RATE"),"severe bradycardia","")
| foreach alarm_csdfHR40e [eval MPA=if(len(alarm_csdfHR40e)>0, '<<FIELD>>', MPA)]
| eval alarm_csdfBP200=if(match(alarm_csdedup, "NOM_EVT_HI,NOM_PRESS_BLD_NONINV_SYS"),"hypertension","")
| foreach alarm_csdfBP200 [eval MPA=if(len(alarm_csdfBP200)>0, '<<FIELD>>', MPA)]
| eval alarm_csdfBP90=if(match(alarm_csdedup, "NOM_EVT_LO,NOM_PRESS_BLD_NONINV_SYS"),"hypotension","")
| foreach alarm_csdfBP90 [eval MPA=if(len(alarm_csdfBP90)>0, '<<FIELD>>', MPA)]
| eval alarm_csdfSpO289l=if(match(alarm_csdedup, "NOM_EVT_LO,NOM_PULS_OXIM_SAT_O2_*"), "hypoxia","")
| foreach alarm_csdfSpO289l [eval MPA=if(len(alarm_csdfSpO289l)>0, '<<FIELD>>', MPA)]
| eval alarm_csdfSpO289d=if(match(alarm_csdedup, "NOM_EVT_DESAT,NOM_PULS_OXIM_SAT_O2_*"), "hypoxia","")
| foreach alarm_csdfSpO289d [eval MPA=if(len(alarm_csdfSpO289d)>0, '<<FIELD>>', MPA)]
| timechart  span=15min values(MPA) by source_machine limit=15  (edited)
```

  - ELK stack (Elastic Search, Logstash, Kibana) open source

splunk> .conf2017

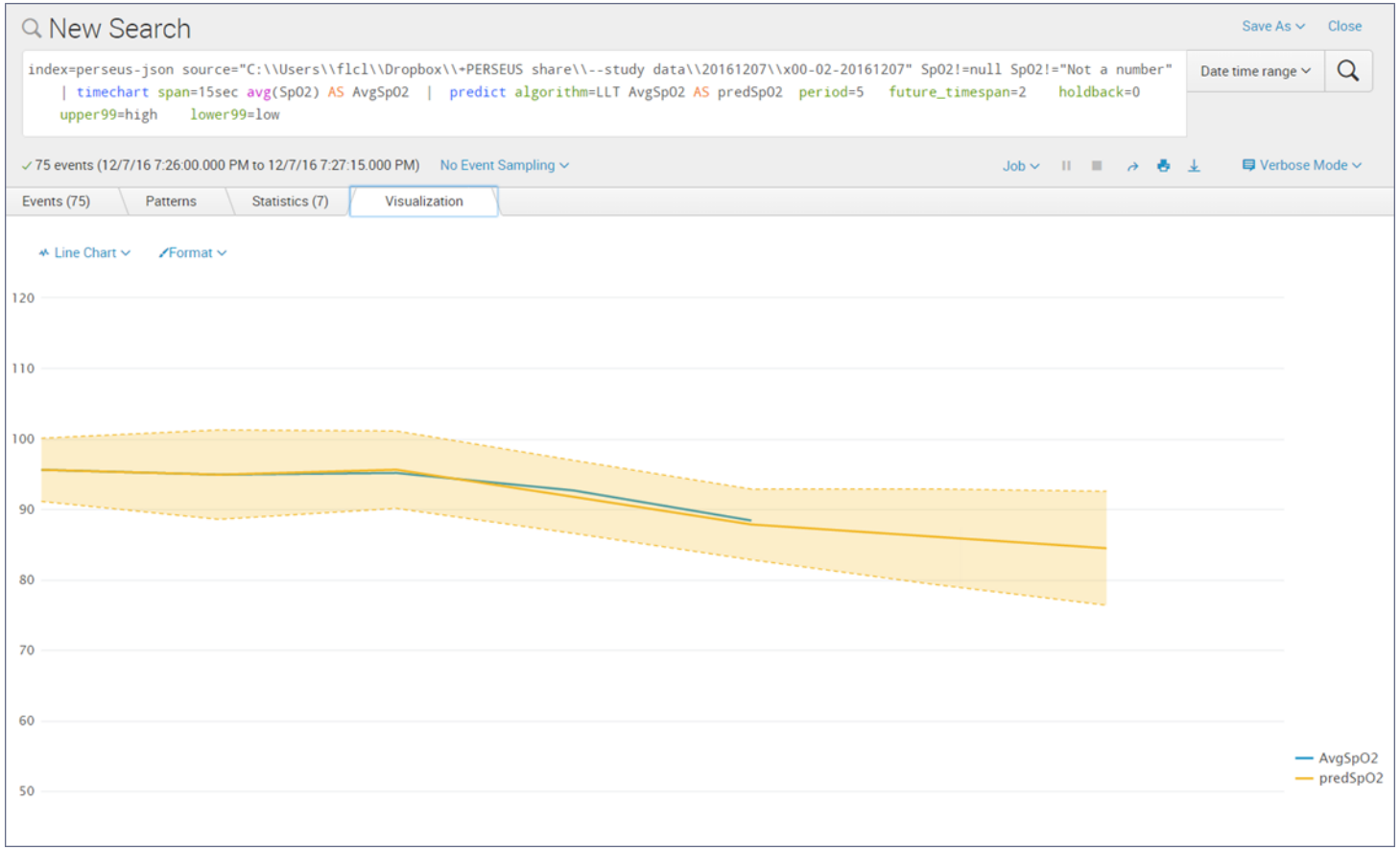
Results

- Data analytics
  - Bedside clinical informatics applications



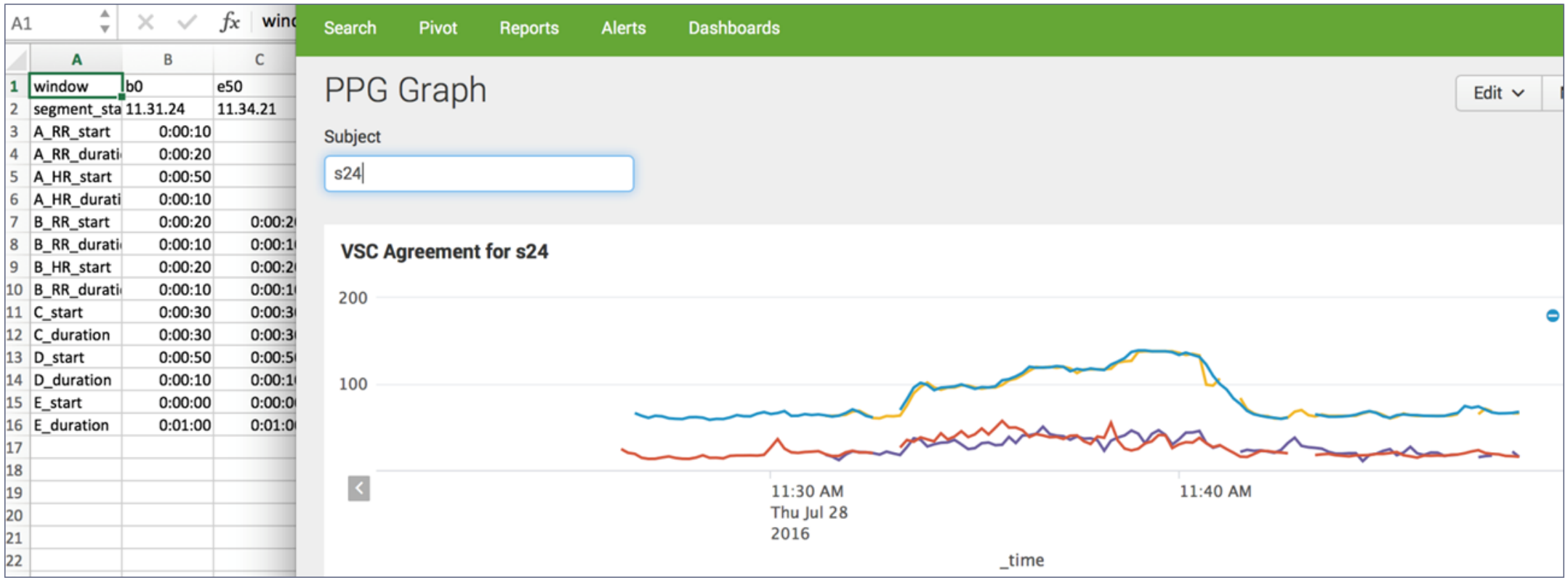
Results

- Data analytics
  - Predictive functions



Results

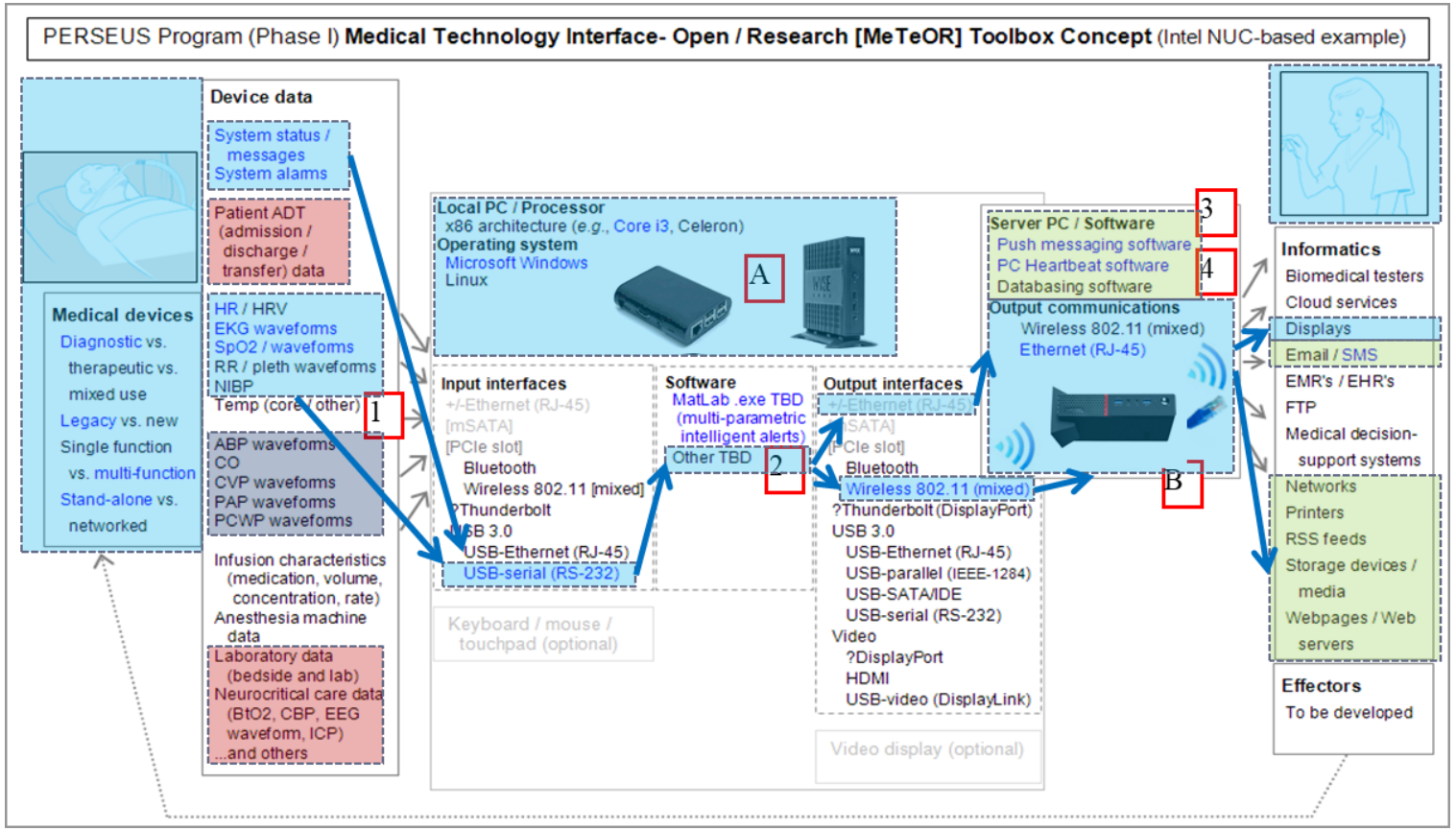
- Data analytics
  - Associated applications

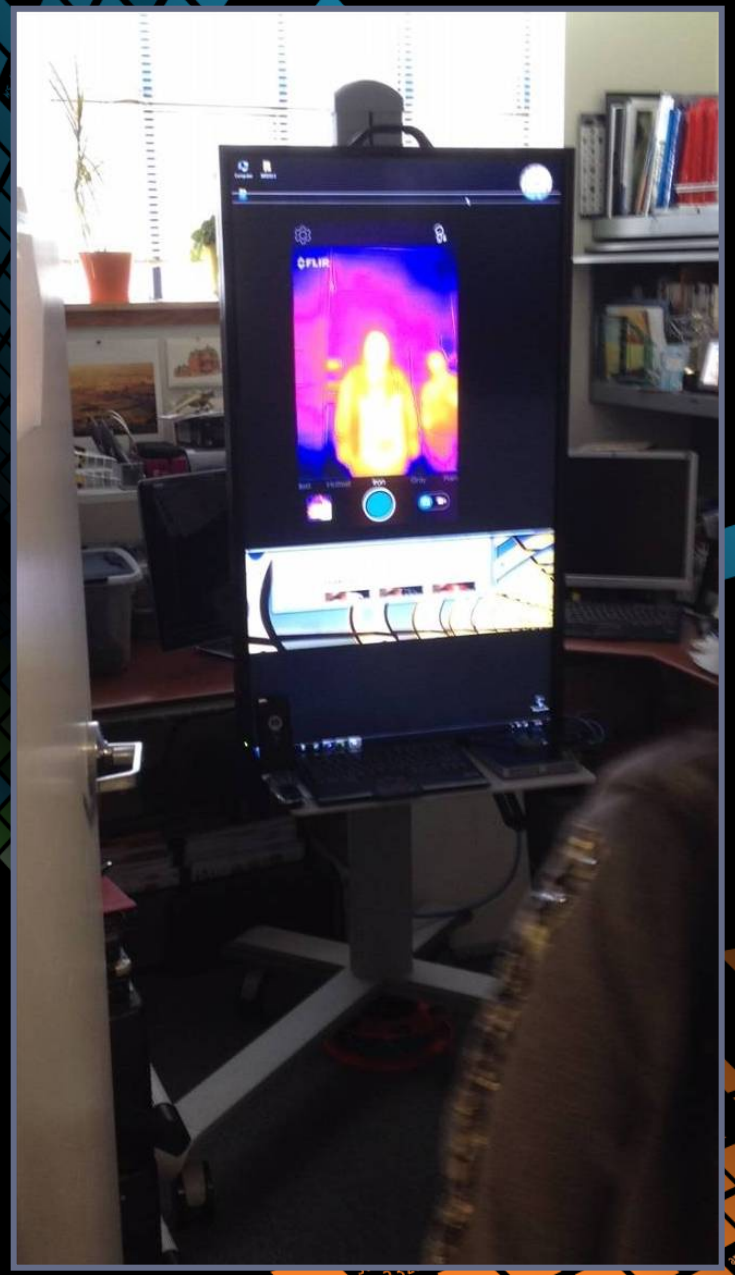


Results

- Data acquisition
- Data analytics

(5.2017 update)





Cart #4+: Next Steps

More Splunk!

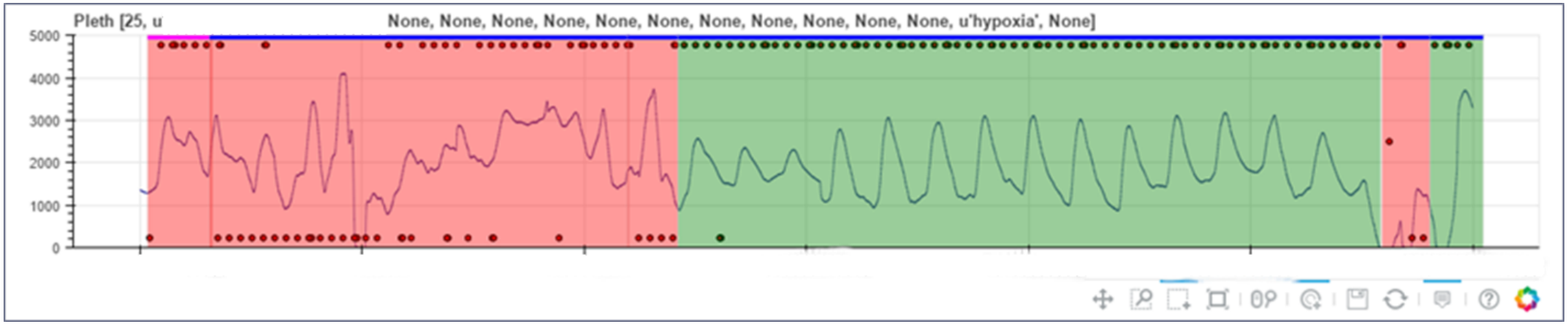
Next Steps

- Research + Development (Phase 3; 2017+)
  - Experimental applications
  - Dissemination

splunk> .conf2017

Next Steps

- Experimental Applications
  - Real-time / Near-real-time data processing
    - QoS



Next Steps

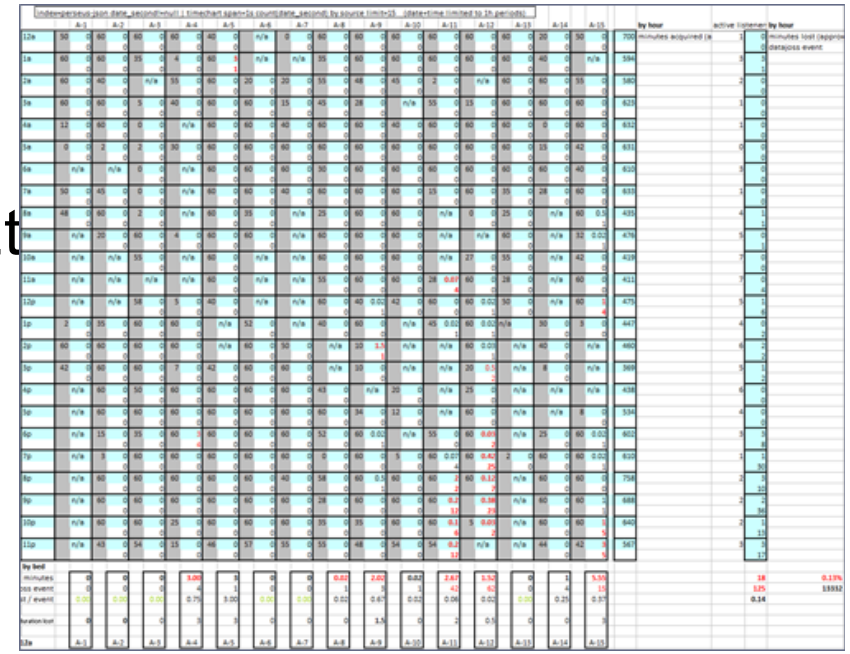
- Experimental Applications
  - Physiologic datastream acquisition
    - NAViGATOR program
      - Non-contact vitals
    - Temperature
    - Heart rate / pulse
    - Respiratory rate
    - Pulse oximetry
    - Co-oximetry / CO
    - Hemoglobin
    - Perfusion

Next Steps

- Experimental Applications
  - Delivering more than an Amazon package

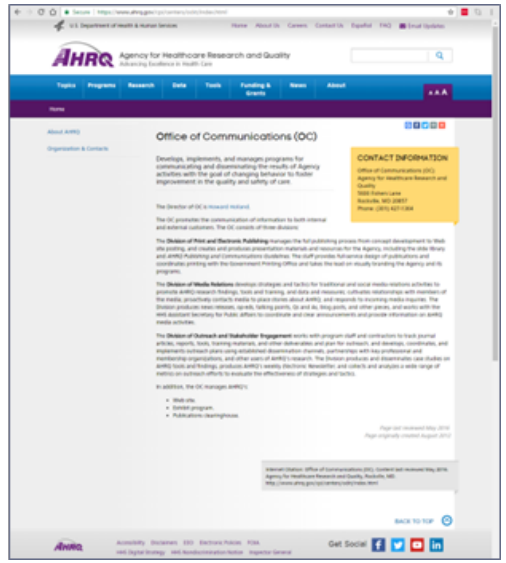
Next Steps

- Dissemination
  - Open-source hardware and software **toolkit**
    - Research use (**not** for clinical or commercial use; EULA)
    - Waveforms: EKG (<3 leads)
      SpO2/pleth
      invasive (CVP, Aline, ICP)
    - Numerics: vital signs (HR, RR, BP, SpO2, Et
    - Alarms
    - ~99.83% data acquisition (15 beds)



Next Steps

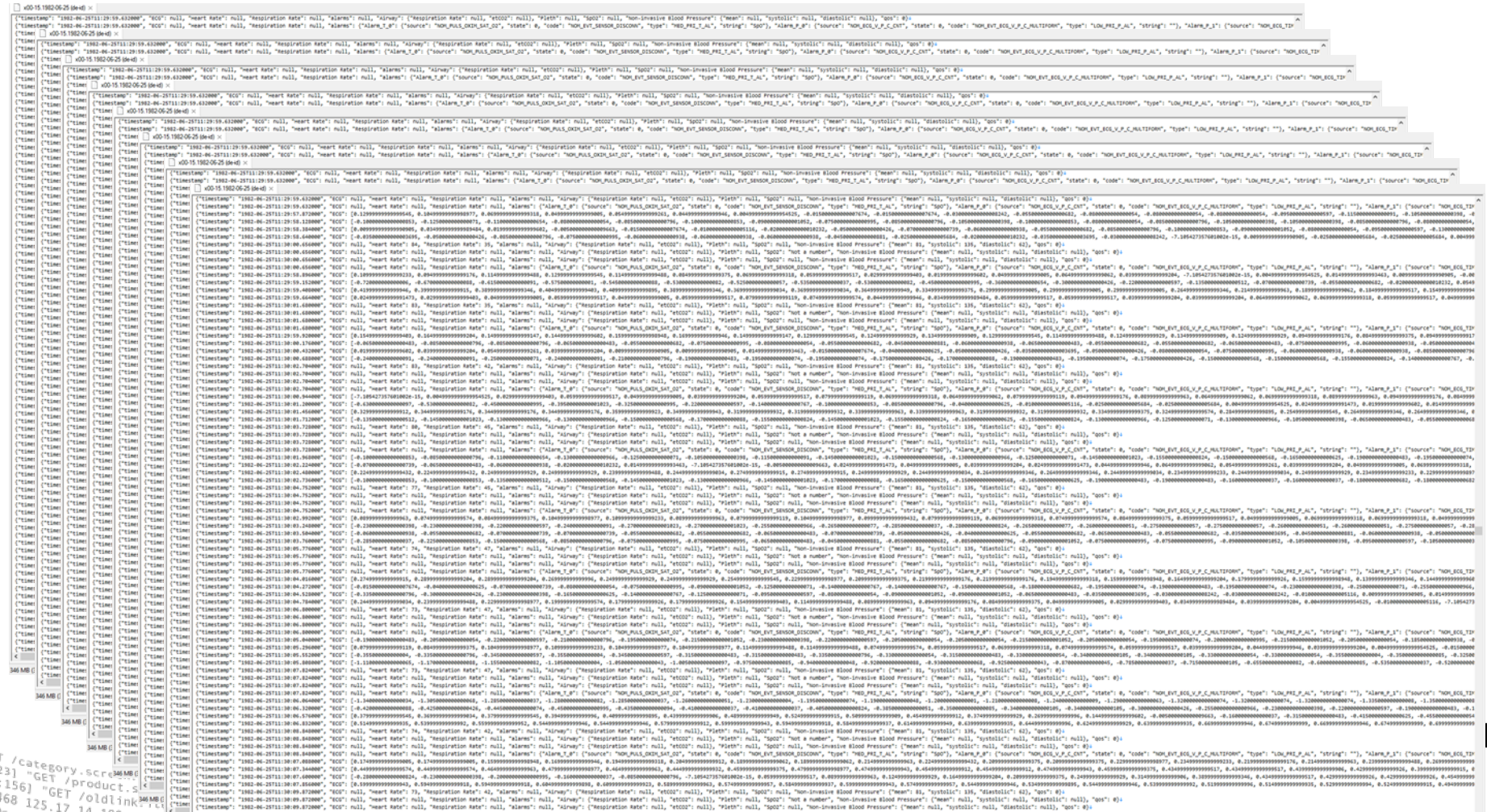
- Dissemination
  - Open-source hardware and software **toolkit**
    - Distribution
    - Python-> Windows, Mac, Linux/Raspbian
    - GitHub repository -> AHRQ OCKT



splunk> .conf2017

Next Steps

- Dissemination
  - De-identified **datasets** (24/7/365 * 15 bedside monitors)



Next Steps

- Dissemination
  - De-identified, *annotated* **datasets**
    - ATOMICS (Annotation of Telemetry signals for Medically Important and Clinically Significant events) database
    - 15 beds, 50% monitoring -> approx. 100 “red alarms” / day

PERSEUS data annotation code + Nostromo SpeedPad n52 key-mapping

EKG waveform

interpretability	yes	1	row1-1
	no	0	row1-2
	no data	<null>	row1-3
connection	connect	C	row2-1
	connect (new pt)	CN	row2-2
	connect?	C?	row2-3
	disconnect	D	row2-4
	disconnect?	D?	row2-5
change	clinical significance (improvement)	Δ+	row3-1
	clinical significance (deterioration)	Δ-	row3-2
	no clinical significance	Δ0	row3-3
	indeterminate clinical significance	Δ?	row3-4
annotation error		err	manual enrty

SpO2 waveform - QoS

interpretability	yes	1	row1-1
	no	0	row1-2
	no data	<null>	row1-3
connection	connect	C	row2-1
	connect (new pt)	CN	row2-2
	connect?	C?	row2-3
	disconnect	D	row2-4
	disconnect?	D?	row2-5
QoS analysis (meta)	correct	Q+	row1-5
	incorrect	Q-	thumb button
	indeterminate	Q?	cursor+ button
annotation error		err	manual enrty

splunk> .conf2017

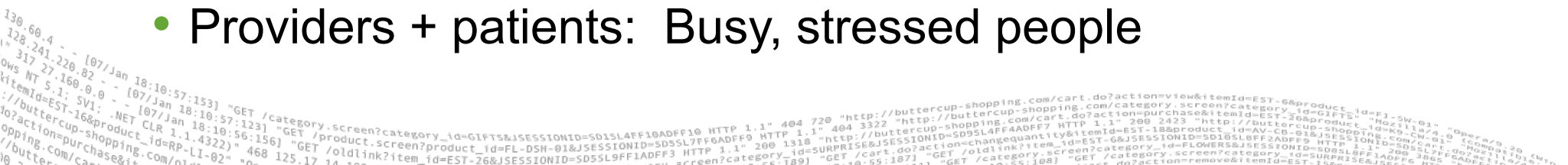
Next Steps

- Dissemination
  - Open code for real-time / near-real-time data acquisition
    - Open-source alternative to commercial systems for *research purposes
  - Open code for real-time / near-real-time data processing
    - QoS
  - Open datasets for playback
    - Critical event replication (*e.g.,* M+M)

      - Accurate, precise, high-resolution physiologic datastreams
    - Device testing
  - Open datasets for un-/structured machine learning
    - ED-focused datasets a la PhysioNET (MIT-BIH ; MIMIC-I/II/III)

Take Home Points/Lessons Learned

- ***Bedside*** clinical informatics on live (ED) patient datastreams
  - Automated monitoring for signals detection
  - Automated analyses for algorithm development
- Bedside ***implementation*** into clinical workflow is the challenge
  - Device and datastream access in open, safe, meaningful manner:
    - De-identified populational datasets for open sharing (web repositories)
    - Patient-specific datasets with clinical correlates for approved on-site research
  - Device and datastream intervention:
    - Real-time / near-real-time processing at the bedside
    - Integration into existing infrastructure and systems
- Compute / outcomes in ***challenging context***
  - EDs: Busy, stressful, restricted, noisy, malodorous environments
  - Providers + patients: Busy, stressed people



Research Teams + Co-investigators

- Rhode Island Hospital Medical Simulation Center
  -> Lifespan Medical Simulation Center
  - Sim core team
    - F.Overly, L.Brown, J.Callahan, J.Taveira, G.Jay
    - D.Werner, M.Jones, J.Devine, S.Marcotte, M.Dannecker, A.Sousa
    - Physician and Nurse Clinical + Simulation Educators
  - Program- / Project-specific Teams
    - TESTPILOT: M.Shapiro, R.Boss, J.Dunbar, R.Sciamacco
    - SimCode: D.Lindquist, I.Jenouri, K.Dushay, D.Haze, J.Foggle, D.Tammaro
    - CIRRUS: R.Al-Rasheed
    - CREW: J.Schoen
    - STORM: B.Choi, N.Asselin, C.Pettit

splunk> .conf2017

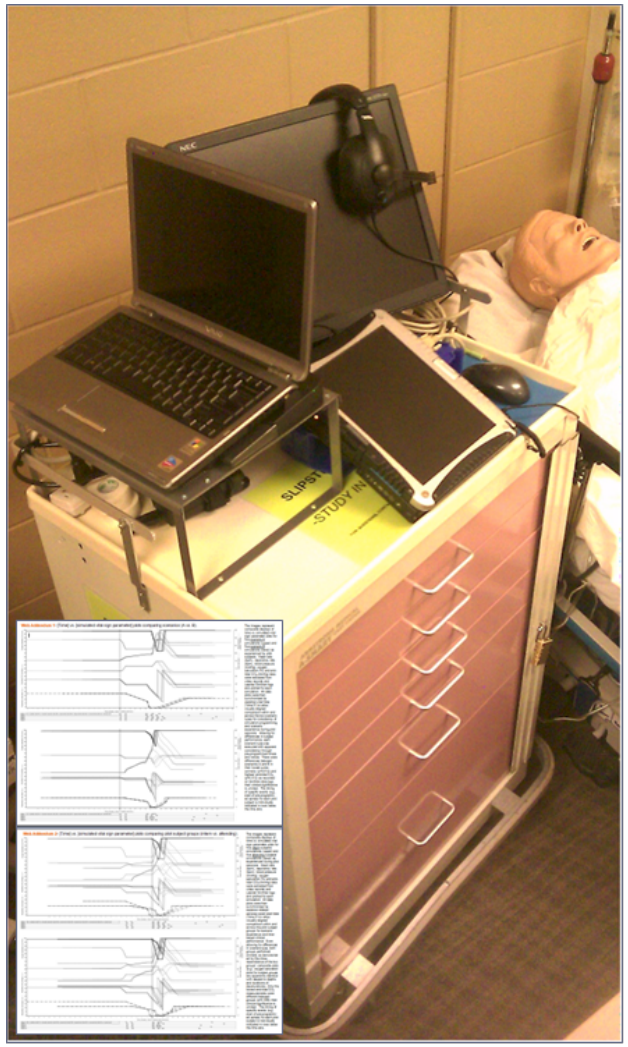
Research Teams + Co-investigators

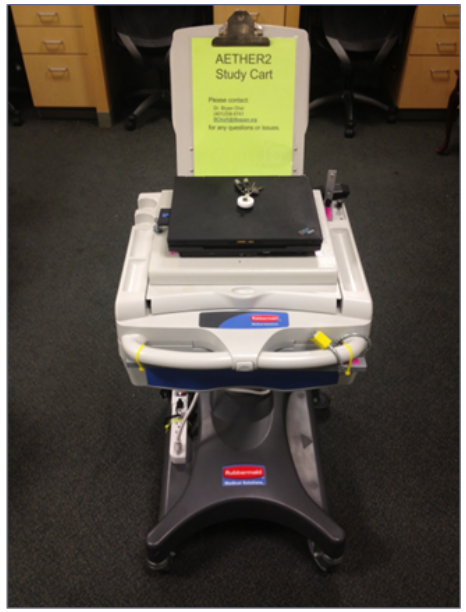
- ARGUS / PERSEUS Program
  - Rhode Island Hospital / Lifespan
    - Rhode Island Hospital Emergency Department
    - S.Chen, M.Luke, I.Gueye, R.Parchuri + team (RIH Biomedical Engineering)
    - Lifespan Information + Network Services
  - Brown University
    - D.Merck (3DLab), A.Oyalowo + U.Agrawal (RIH NeuroLOGIC Lab)
  - Case Western Reserve University
  - Red Forest Consulting (J.Gosbee)
  - University of California San Francisco
    - X.Hu + team (Department of Nursing)
- Splunk for Good, Splunk

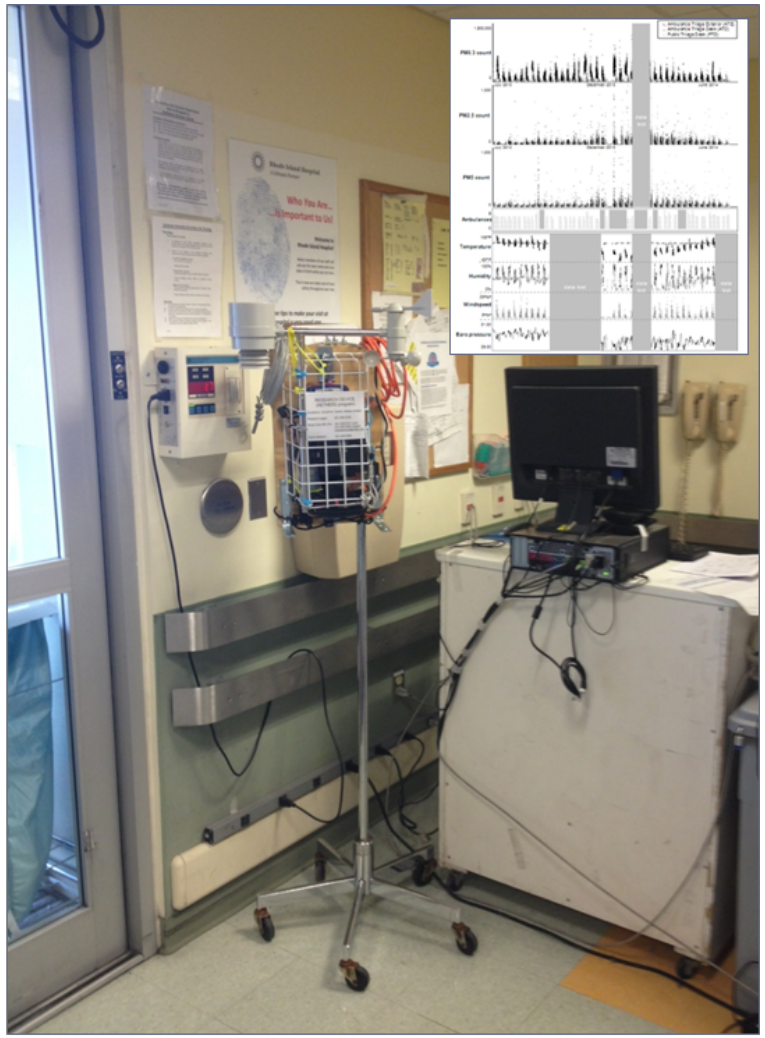
Research Teams + Co-investigators

- NAViGATOR Program
  - Brown University
    - G.Capraro, L.Mercurio (Pedi EM)
    - C.Etebari, K.Luchette
  - Philips Healthcare Research, Philips

Other Notable Carts







RHODE ISLAND HOSPITAL

MEDICAL SIMULATION CENTER

LIFESPAN MEDICAL SIMULATION CENTER

Q&A

splunk> .conf2017

Thank You

Don't forget to rate this session in the .conf2017 mobile app