



**Duke Institute for
Health Innovation**

Promoting transformative innovation in health and healthcare

Creating an Ecosystem for Integrating Machine Learning into Clinical Care

The DIHI Experience



August 2019



Duke Institute for Health Innovation

Pythia: A Surgical Use-Case

Sepsis Watch – Build to Show Value

Sepsis Watch – Build to Integrate

Sepsis Watch – From Models to Bedside

Recap



Duke Institute for Health Innovation



Duke Institute for Health Innovation

Founded in 2012... now a 10-person team in 2019

Our Mission: **Catalyze innovation at Duke**

Promote **transformative innovation in health and healthcare** through high-impact research, leadership development and workforce training and the cultivation of a community of entrepreneurship

Our Approach: **Innovation by design**

Understand **user workflow**, desired **outcomes** and **problems (needs)** and then collaboratively develop concepts and prototypes, and **iterate through** to finalize **solution**



Sourcing Innovations: Structured & Opportunistic

RFA Innovation Pilots

DIHI RFA approach

“Top-down + Bottom-Up” approach to sourcing innovations

- Duke Health leadership carefully develops mission-aligned **strategic themes** for innovation pilots
- Front-line faculty and staff propose “**problems**” aligned themes and **novel solutions**
- **Systematic review** and **due diligence**: Assessments on team, feasibility, resource needs, impact and value to patients
- **8-12 innovation pilots** chosen and funded each year; Duration: **12-15 months**
- DIHI members embedded within project innovation teams to rapidly catalyze the innovations
- **Pivots as needed** to support rapid evolution to create value
- **Metrics**: clinical utility, economic utility, cultural impact, IP and academic outputs

Structured

6 Years Catalyzing Innovations

55+ Innovation Pilots

250+ Proposals

Innovation Jam

DIHI Innovation Jam

A Health focused **Shark Tank** at Duke

- Solicits and identifies high-potential healthcare and health innovations ready for commercialization
- **Duke Leadership as Sharks:**
 - DUHS leaders, Department Chairs, Deans of School of Medicine, Nursing, Engineering, OLV, I&E, MedBlue, Center and Institute Directors
- Innovation proposals from students, faculty, trainees and staff across campus
- **Funding** to support entrepreneurship / **formation of company** and also **develop the product/service** etc.
- Inventors offer portion of their share of Duke internal returns for investment from the sharks
- Internal syndicated investment agreements documented through MOUs.

Unstructured

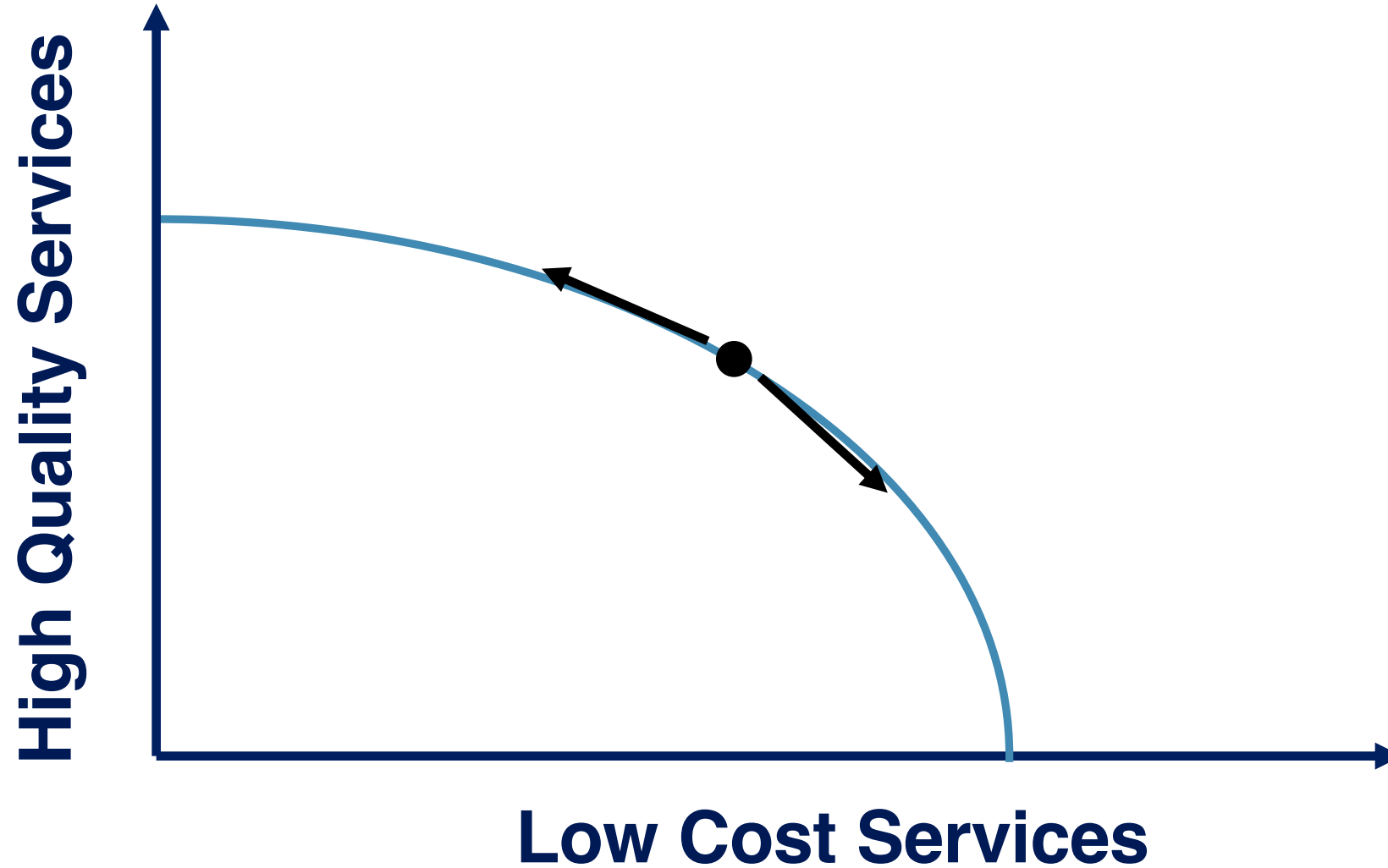
3 Years of Jamming

24+ Pitches

6 Companies Incubated

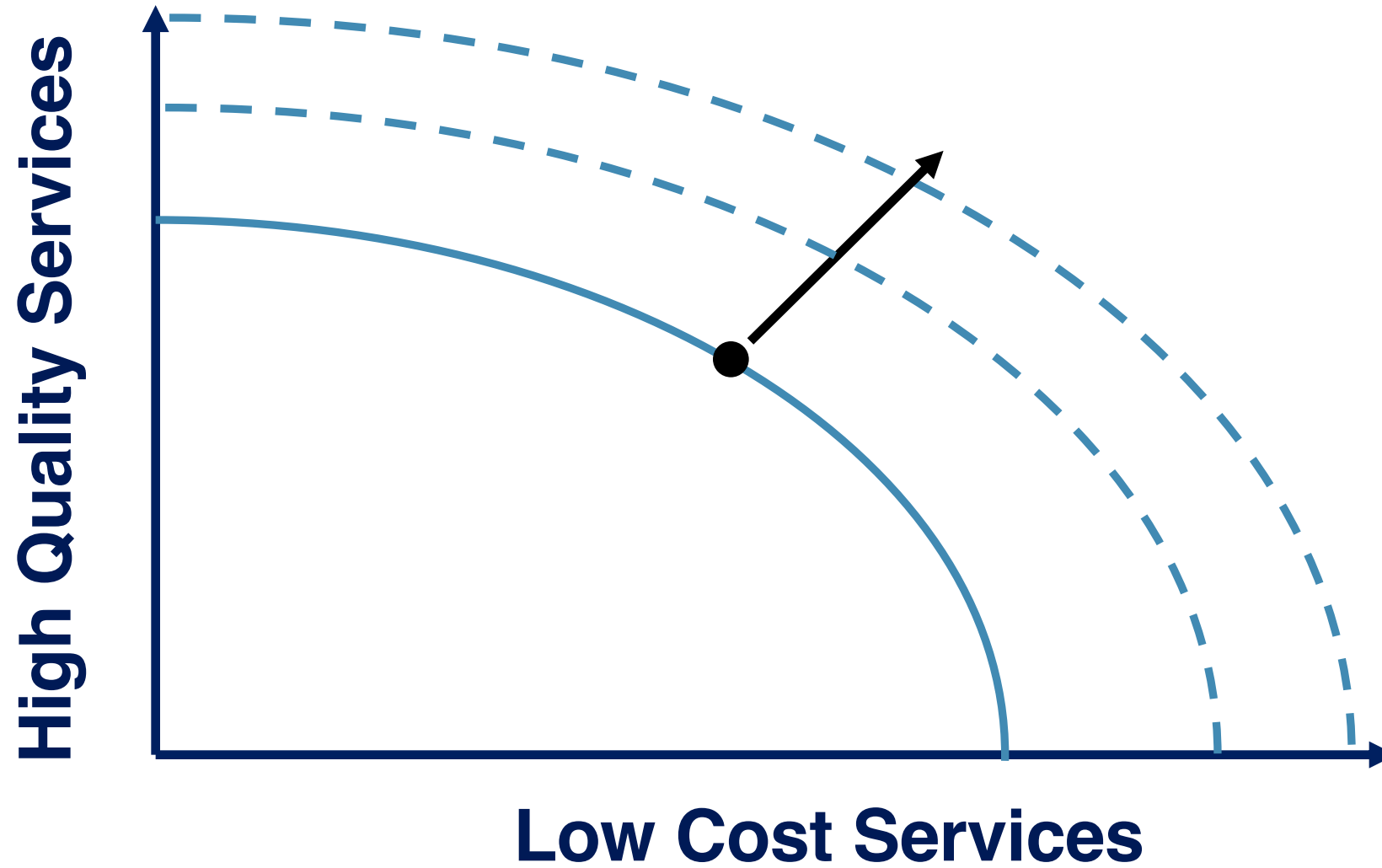


Health Care Possibility Frontier



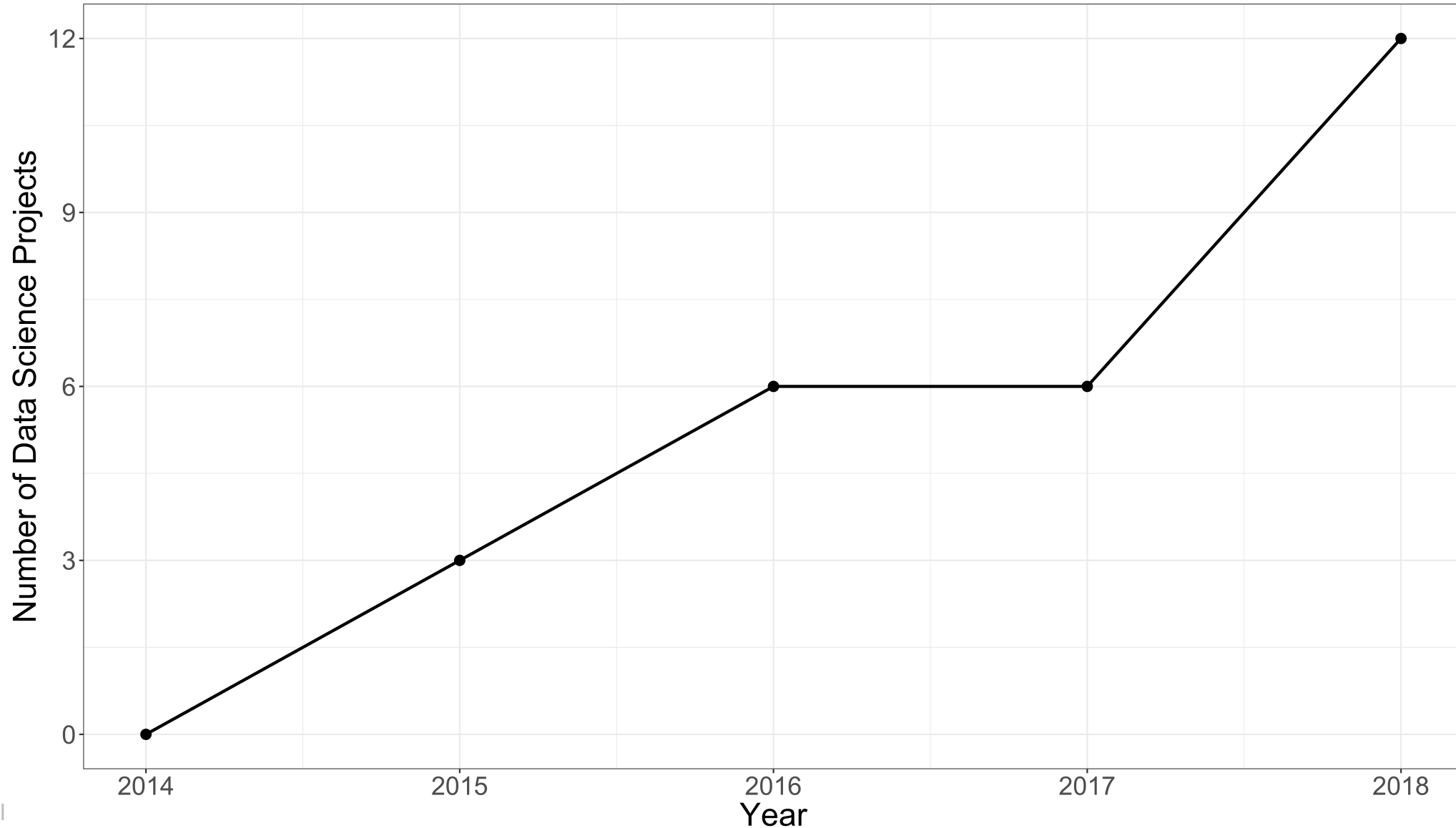


Health Care Possibility Frontier



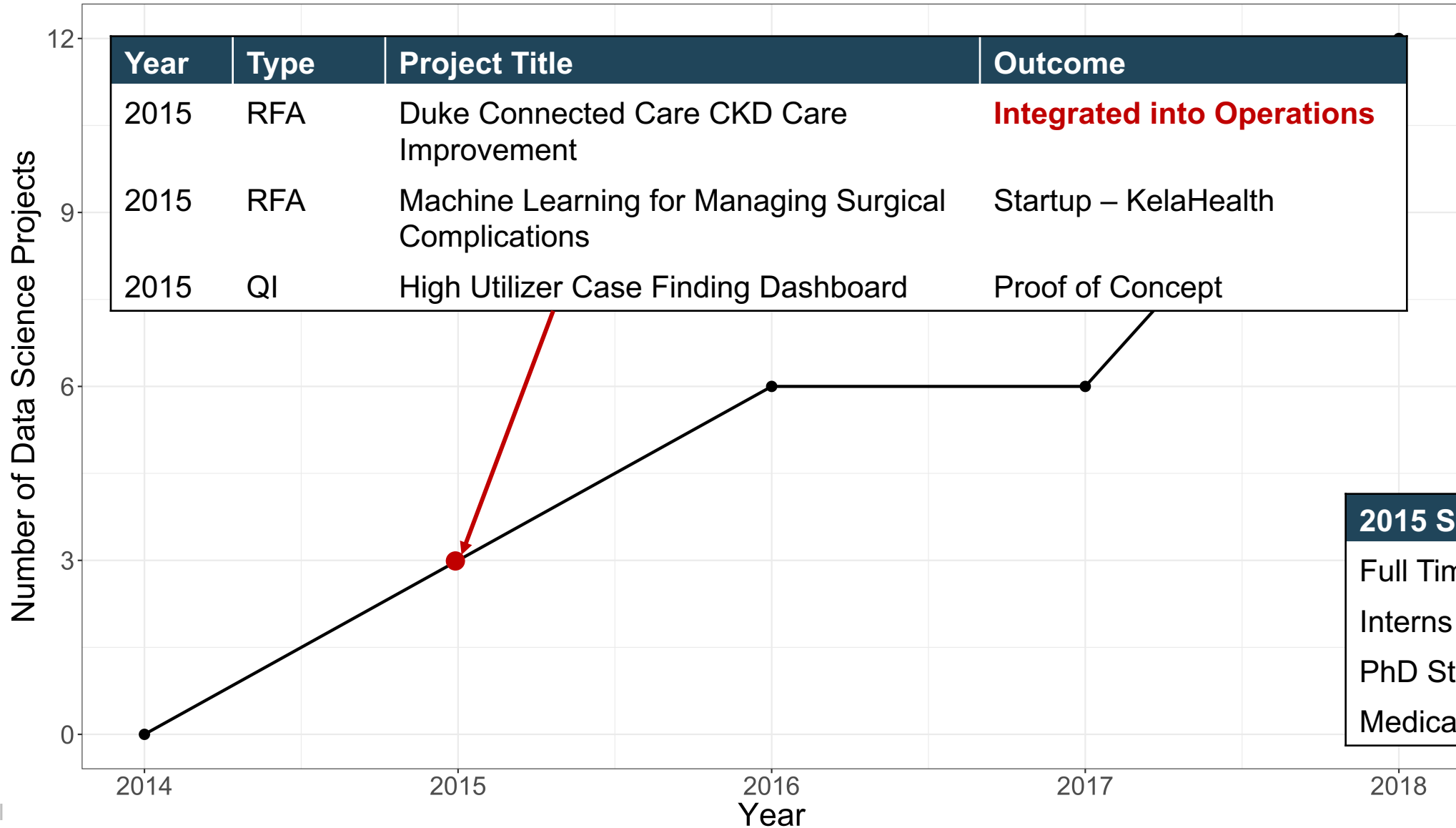


Growth of Data Science Capabilities





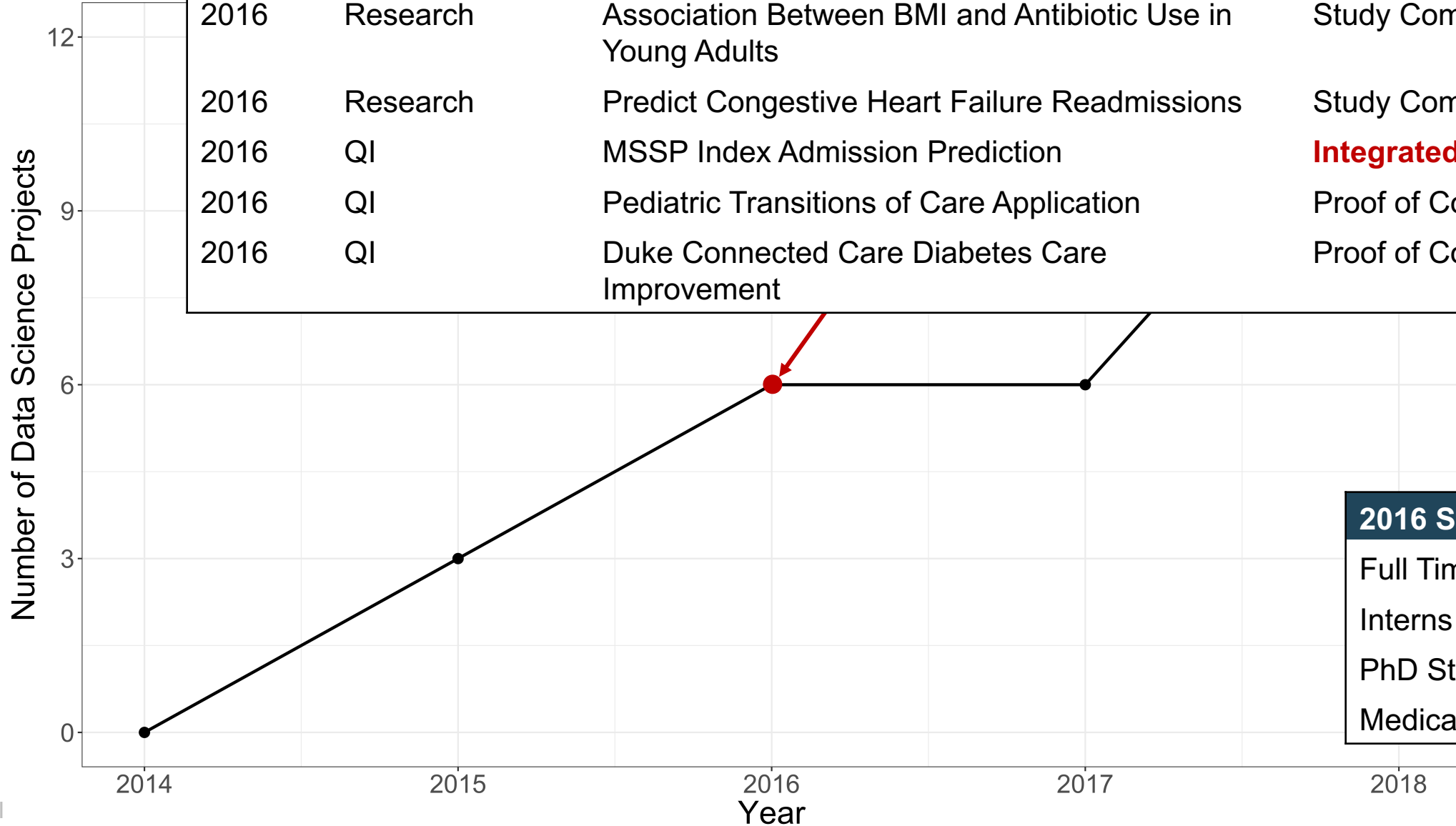
Growth of Data Science Capabilities



2015 Staffing	
Full Time	1
Interns	4
PhD Students	2
Medical Students	-



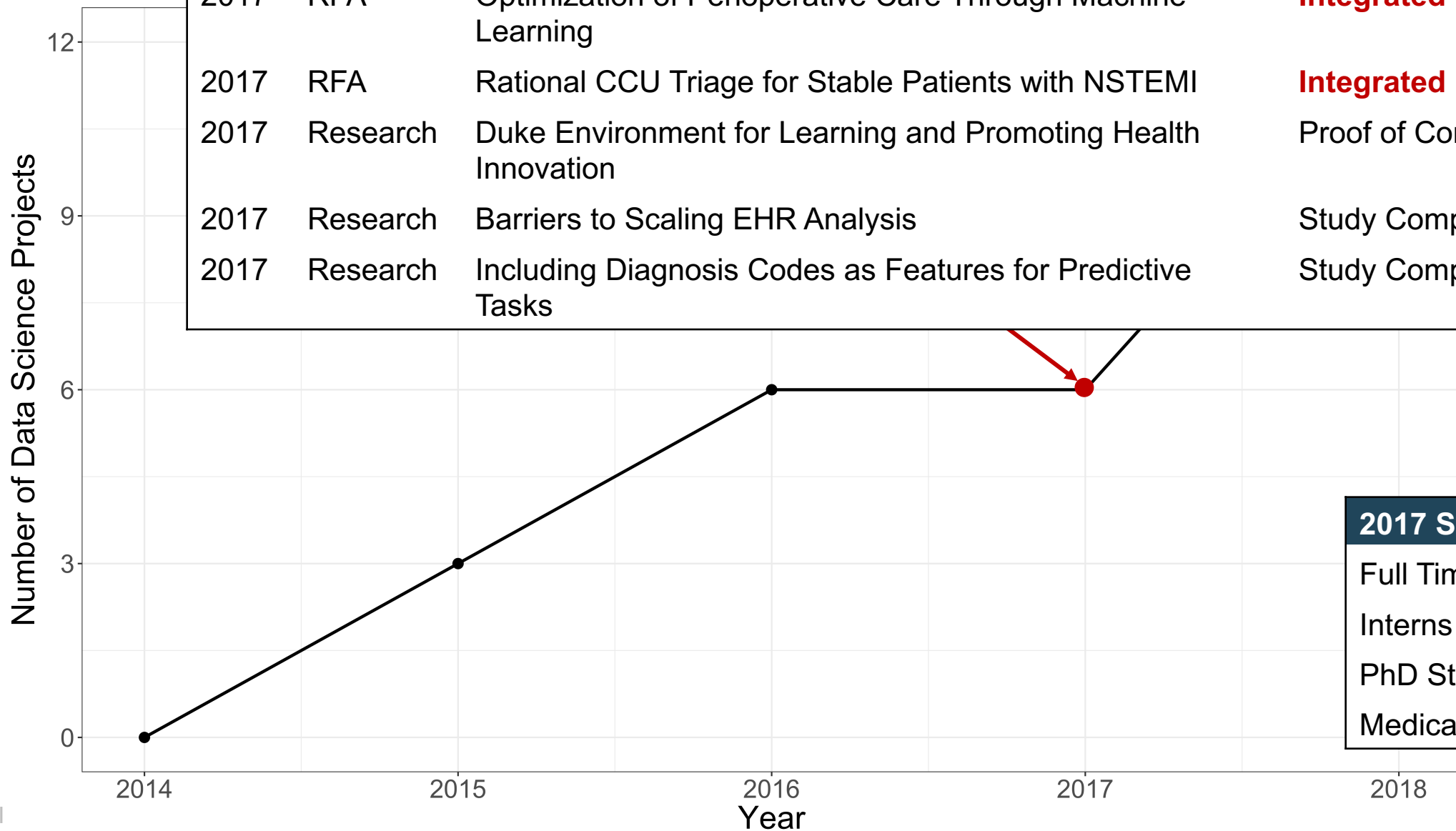
Growth



Year	Type	Project Title	Outcome
2016	RFA	Development of a Duke Specific Sepsis Early Warning Score	Integrated into Operations Commercial License
2016	Research	Association Between BMI and Antibiotic Use in Young Adults	Study Complete
2016	Research	Predict Congestive Heart Failure Readmissions	Study Complete
2016	QI	MSSP Index Admission Prediction	Integrated into Operations
2016	QI	Pediatric Transitions of Care Application	Proof of Concept
2016	QI	Duke Connected Care Diabetes Care Improvement	Proof of Concept

2016 Staffing	
Full Time	2
Interns	2
PhD Students	2
Medical Students	4

Growth



Year	Type	Project Title	Outcome
2017	RFA	Pallialytics: Analytics to Inform a Palliative Care Population Health Program	Integrated Into Operations
2017	RFA	Optimization of Perioperative Care Through Machine Learning	Integrated Into Operations
2017	RFA	Rational CCU Triage for Stable Patients with NSTEMI	Integrated Into Operations
2017	Research	Duke Environment for Learning and Promoting Health Innovation	Proof of Concept
2017	Research	Barriers to Scaling EHR Analysis	Study Complete
2017	Research	Including Diagnosis Codes as Features for Predictive Tasks	Study Complete

2017 Staffing	
Full Time	3
Interns	2
PhD Students	2
Medical Students	5



Year	Type	Project Title	Outcome
2018	RFA	High Value Analyte Ordering	Integrated Into Operations
2018	RFA	Automated Transthoracic Echocardiogram Interpretation	Project Ongoing
2018	RFA	Cardiogenic Shock Management Program	Project Ongoing
2018	RFA	Inpatient Hyperglycemia Prediction and Management	Project Ongoing
2018	Research	Surgical Open Data Science and Learning Health Platform	Study Complete
2018	Research	Colorectal Cancer Prediction from CBCs	Study Complete
2018	Research	Diagnosis Grouping Predictor Comparison	Study Complete
2018	Research	Data Quality Assessment Framework	Study Complete
2018	Research	All-Cause Readmission Prediction	Study Complete
2018	Research	Federated AI: Assessing Model Generalizability	Study Complete
2018	QI	Inpatient Mortality Prediction and Dashboard	Integrated Into Operations
2018	QI	30-Day Mortality Prediction and Dashboard	Integrated Into Operations



2018 Staffing	
Full Time	4
Interns	2
PhD Students	1
Medical Students	5





Four Months Into 2019...

Year	Type	Project Title	Outcome
2019	RFA	Adult Inpatient Decompensation Prediction	Project Ongoing
2019	RFA	Pediatric Inpatient Decompensation Prediction	Project Ongoing
2019	RFA	Adult Cardiothoracic Intensive Care Bound-Back Prediction	Project Ongoing
2019	RFA	Emergency Department Triage Prediction	Project Ongoing
2019	RFA	Duke Patient Message Virtual Assistant	Project Ongoing
2019	RFA Update	Model Update - Duke Specific Sepsis Prediction	Project Ongoing
2019	Research	Real-Time Prediction Model Evaluation Framework	Project Ongoing
2019	Research	Unstructured Note Text Pipeline	Project Ongoing
2019	RFA	Adult Inpatient Decompensation Prediction	Project Ongoing
2019	RFA	Pediatric Inpatient Decompensation Prediction	Project Ongoing
2019	RFA	Adult Cardiothoracic Intensive Care Bound-Back Prediction	Project Ongoing
2019	RFA	Emergency Department Triage Prediction	Project Ongoing



Guiding Principles for Growth

Build to show value

Build to integrate

Build to scale

Build Responsibly

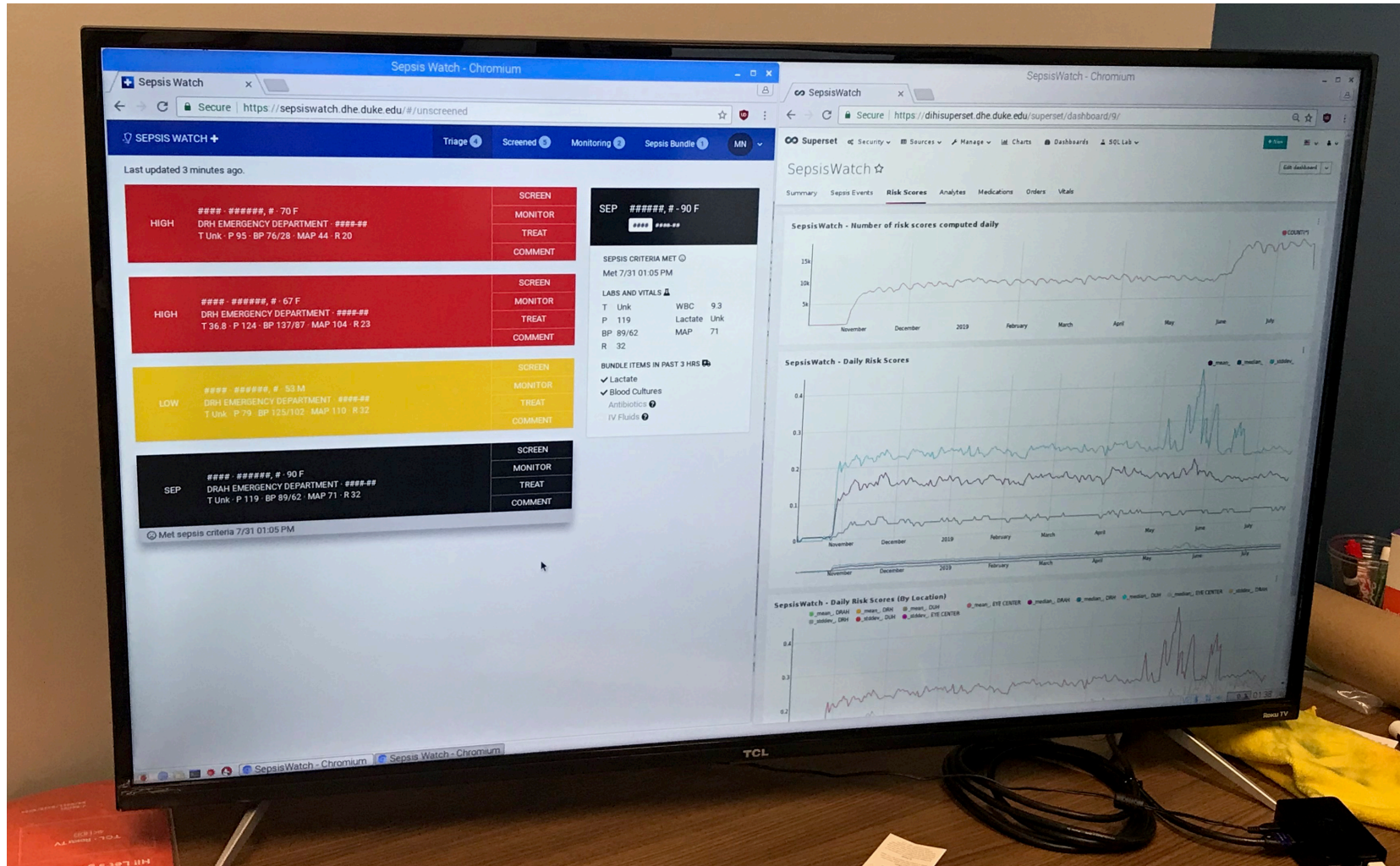


Build Responsibly

- Partner with outside organizations to evaluate
 - Data & Society, Duke's Social Sciences Research Institute
- Retrospective, external model evaluations
- “Silent Mode” periods before go-live
- Continuous post-implementation model monitoring
- Undergo peer-review to disseminate
- Rigorous data quality assessment
- Model threshold selection tools
- “Model Fact” sheet for standard reporting for clinical end users
- Stakeholder feedback loops to continue iterating
- Pre-register clinical trials



Build Responsibly – Model Monitoring





Build Responsibly – “Model Fact” Sheet

Model Facts
Model name: Deep Sepsis Version: 1.0
Summary This model uses EHR input data collected from a patient’s current encounter at the hospital to estimate the probability that the patient will meet sepsis criteria within the next 4 hours. It was developed in 2016-2019 by the Duke Institute for Health Innovation. The model was licensed to Cohere Med in July 2019.
Mechanism <ul style="list-style-type: none"> ▪ OutcomeSepsis within the next 4 hours. See (1) for sepsis criteria ▪ Output0% - 100% probability of sepsis occurring in the next 4 hours ▪ Patient populationall adult patients >18 y.o. presenting to DUH ED and admitted ▪ Time of prediction every hour of a patient’s encounter ▪ Input data source.....Epic data in extracted from Clarity ▪ Input data typedemographics, analytes, vitals, medication administrations ▪ Training data location and time-periodDUH, 10/2014 – 12/2015 ▪ Model type..... Recurrent Neural Network
Validation and performance <ul style="list-style-type: none"> • Retrospective: 20% random held out set from 10/2014 – 12/2015, AUROC 0.882 • Temporal: 6-month temporal validation set of ED visits at DUH between 03/2018 – 08/2018, AUROC 0.943 • Prospective: TBD • External: TBD

Uses and directions <ul style="list-style-type: none"> ▪ General use: This model is intended to be used to by clinicians to identify patients for further assessment for sepsis. The model is not a diagnostic for sepsis and is not meant to guide or drive clinical care. This model is intended to complement other pieces of patient information related to sepsis as well as a physical evaluation to determine the need for sepsis treatment. ▪ Examples of appropriate decisions to support: Identification of high-risk patients for further evaluation to determine appropriateness of treatment for sepsis. ▪ Before using this model: Test the model prospectively on local data and confirm generalizability of model to the local setting and that model is effectively integrated into production system. ▪ Effectiveness evaluation: Evaluated in an emergency department to assist identification of high-risk patients for further evaluation in an emergency department. The rapid response team, nurse-driven workflow was effective at improving sepsis treatment bundle compliance. ▪ Safety evaluation: TBD
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Warnings <ul style="list-style-type: none"> ▪ General warnings: This model was not trained or evaluated on patients receiving care in the ICU. Do not use this model in the ICU setting without further evaluation. This model was trained to identify the first episode of sepsis during an inpatient encounter. During long inpatient stays with multiple sepsis episodes, model accuracy needs to be further evaluated. The model is not interpretable and does not provide rationale for high risk scores. Clinical end users are expected to place model output in context with other clinical information to make final determination of diagnosis. ▪ Examples of inappropriate decisions to support: Implementation in the ICU or throughout inpatient encounters without further evaluation. Use of model as a diagnostic to guide clinical diagnosis and treatment for sepsis. ▪ Discontinue use if: Clinical staff raise concerns about how the model is being used or model performance deteriorates due to data shifts or population changes.
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Other information: <ul style="list-style-type: none"> ▪ Publications: 1) pre-print: https://www.biorxiv.org/content/10.1101/648907v1 ▪ Related models: 1) qSOFA: Seymour, C. W., Liu, V. X., Iwashyna, T. J., Brunkhorst, F. M., Rea, T. D., Scherag, A., et al. (2016). Assessment of Clinical Criteria for Sepsis: For the Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3). <i>Jama</i>, 315(8), 762–774. http://doi.org/10.1001/jama.2016.0288
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Pythia: A Surgical Use-Case of Building Value, Integration, and Scalability

Kristin Corey



DIHI's Guiding Principles

Build to show value

Build to show value

- Work on the right problem
- Bring together the right team
- Engage the right leaders
- Optimize to learn
- Generate short term wins

Build to integrate

Build to integrate

- Design solutions with front line staff
- Establish governance
- Identify champions to drive adoption
- Collaborate to train and educate

Build to scale

Build to scale

- Developing project infrastructure to help serve other projects

Build to show value

Build to integrate

Build to scale

50 million

30%





Build to show value

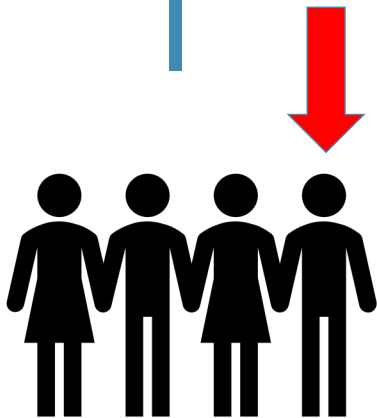
Build to integrate

Build to scale

Working with the right team



Perioperative Journey





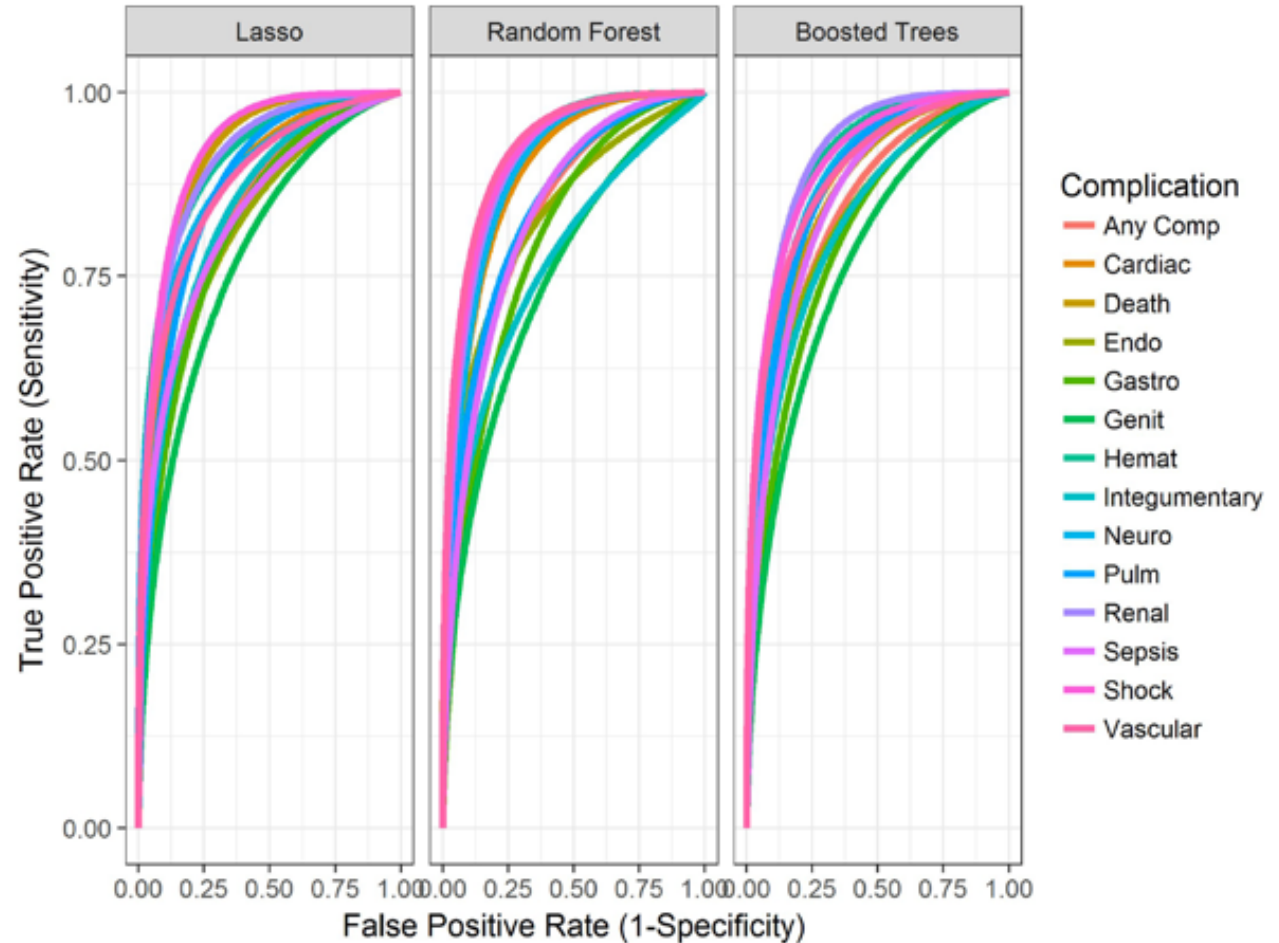
Post-Operative Complication Risk Prediction Models



RESEARCH ARTICLE

Development and validation of machine learning models to identify high-risk surgical patients using automatically curated electronic health record data (Pythia): A retrospective, single-site study

Kristin M. Corey^{1,2,3,4}, Sehj Kashyap^{1,2}, Elizabeth Lorenzi^{2,3}, Sandhya A. Lagoo-Deenadayalan², Katherine Heller², Krista Whalen¹, Suresh Balu², Mitchell T. Hefflin⁴, Shelley R. McDonald⁴, Madhav Swaminathan², Mark Sendak¹



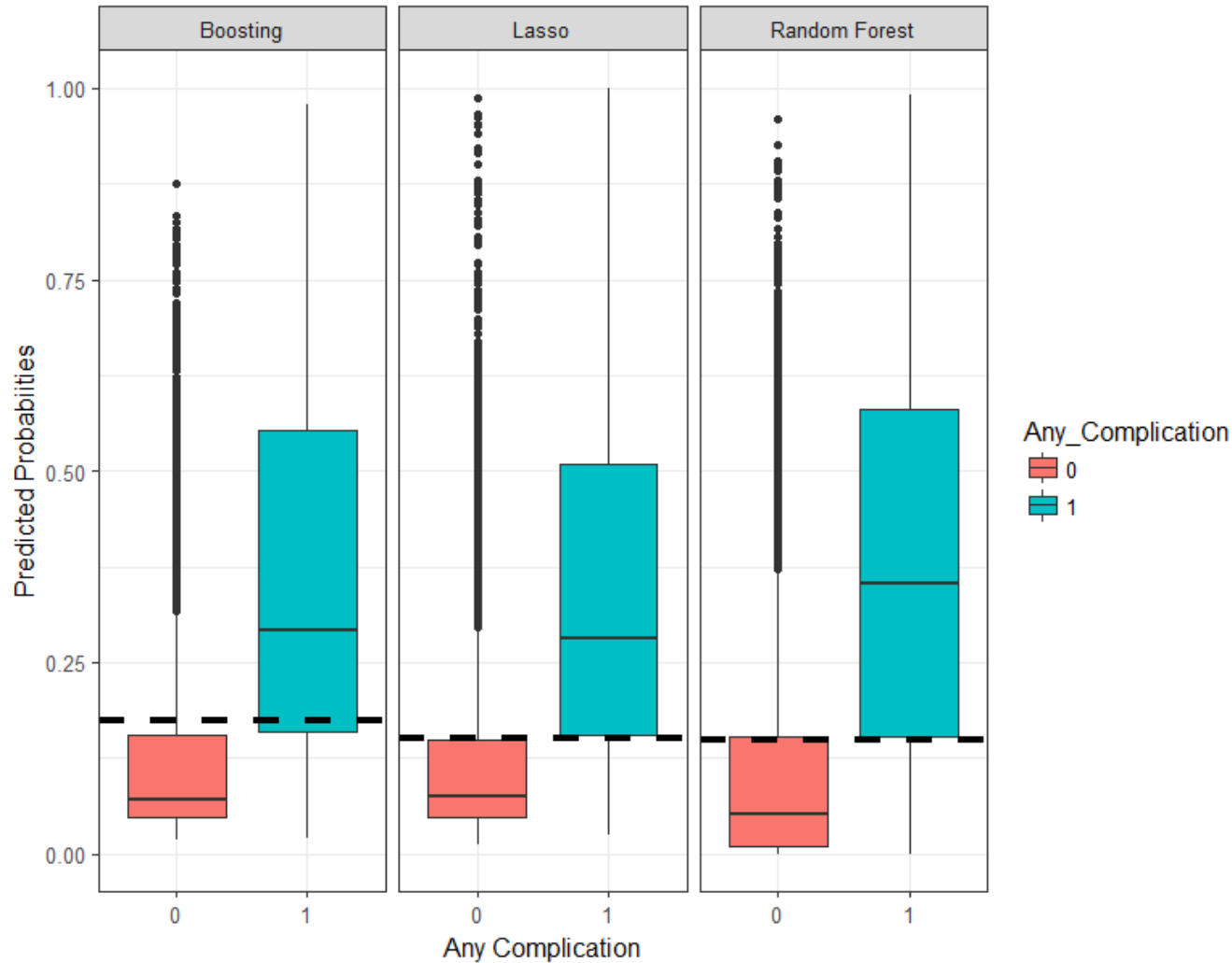


Build to show value

Build to integrate

Build to scale

Differentiating high-risk patients





Build to show value

Build to integrate

Build to scale

Post-operative Complication Risk Calculator

1. Procedure Details

Primary Procedure:

44147

Total procedure codes:

-

2. Demographic and Social History

Patient Age:

70

Patient BMI:

30

Sex:

Male

Choose Patient's Race:

White Caucasian

Level of smoking in past year:

Former Smoker

3. Patient Comorbidities

All Comorbidities:

- Hypertension (Complicated or Uncomplicated)
- Diabetes w/ Chronic Complications
- Solid Tumor without Metastasis
- Diabetes without Chronic Complications

All Medications:

- Anti-Hyperglycemics
- Cardiovascular Drugs
- Antiplatelets

Complication Risk

Complication	Risk (%)	Risk
Any complication	22.50	High
Endocrine complication	6.10	
Gastric complication	5.00	

High-risk patients are flagged if "any complication" risk is over 18%. Specific risks are displayed if over 5%.

Build to show value

Build to integrate

Build to scale



Growing Your Network



Build to show value

Build to integrate

Build to scale



Build to show value

Build to integrate

Build to scale

Building to Scale

Federated Modeling

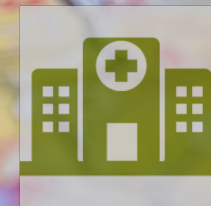
DRH



DUH



DRAH



Build to show value

Build to integrate

Build to scale

Building Infrastructure

DIHI's Data Pipeline





Build to show value

Build to integrate

Build to scale

Building Infrastructure

Designing Data Quality Systems



A Harmonized Data Quality Assessment Terminology and Framework for the Secondary Use of Electronic Health Record Data

Michael G. Kahn, MD, PhD;ⁱ Tiffany J. Callahan, MPH;^j Juliana Barnard, MA;^k Alan E. Bauck;ⁱⁱ Jeff Brown, PhD;ⁱⁱⁱ
Bruce N. Davidson, PhD;^{iv} Hossein Estiri, PhD;^v Carsten Goerg, PhD;^l Erin Holve, PhD, MPH, MPP;^{vi}
Steven G. Johnson, MS;^{vii} Siaw-Teng Liaw, MBBS, PhD, FRACGP, FACHI;^{viii} Marianne Hamilton-Lopez, PhD, MPA;^{ix}
Daniella Meeker, PhD;^x Toan C. Ong, PhD;^{xi} Patrick Ryan, PhD;^{xii} Ning Shang, PhD;^{xiii} Nicole G. Weiskopf, PhD;^{xiv}
Chunhua Weng, PhD, FACMI;^{xv} Meredith N. Zozus, PhD;^{xv} Lisa Schilling, MD^{xi}



Build to show value

Build to integrate

Build to scale

Building Infrastructure

Designing Data Quality Systems

- **Conformance**
- **Completeness**
- **Plausibility – Uniqueness, Atemporal and Temporal**



Build to show value

Build to integrate

Build to scale

Building Infrastructure Designing Data Quality Systems: Temporal Plausibility

PO2_ART FEATURE STABILITY OVER TIME, MEANS





Build to show value

Build to integrate

Build to scale

Sepsis Watch:

Build to Show Value

Mark Sendak



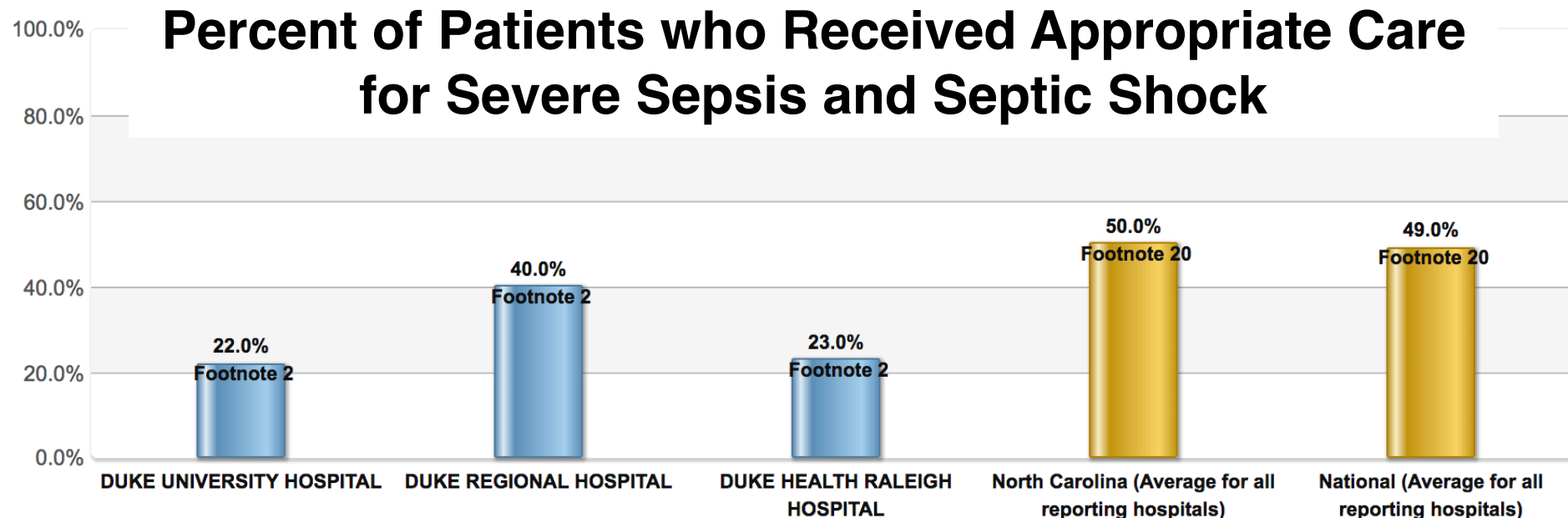
Build to show value

Build to integrate

Build to scale

Work on the Right Problem – Significant Pressure

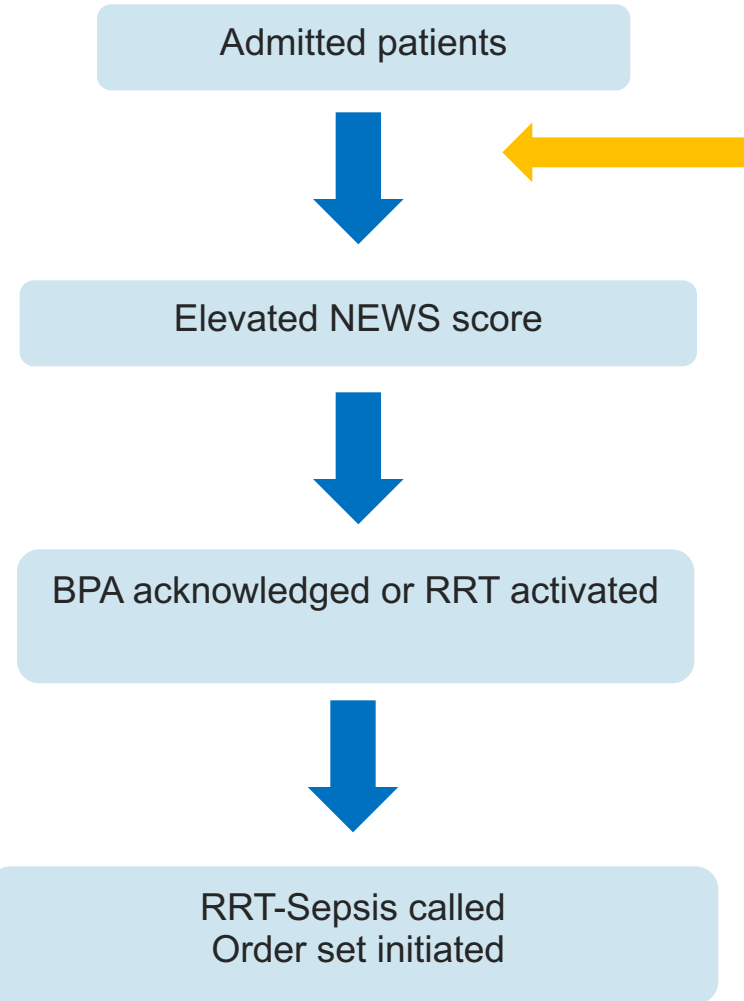
- 750,000 sepsis cases in US annually, high mortality (30-50%)
- \$18,000 per hospital admission, \$23B across all payers
- No clear time of onset, no clear biomarker
- 3-hour treatment bundle failure increases inpatient mortality 14%





Build to show value > Build to integrate > Build to scale

Work on the Right Problem – Prior Solution Failed



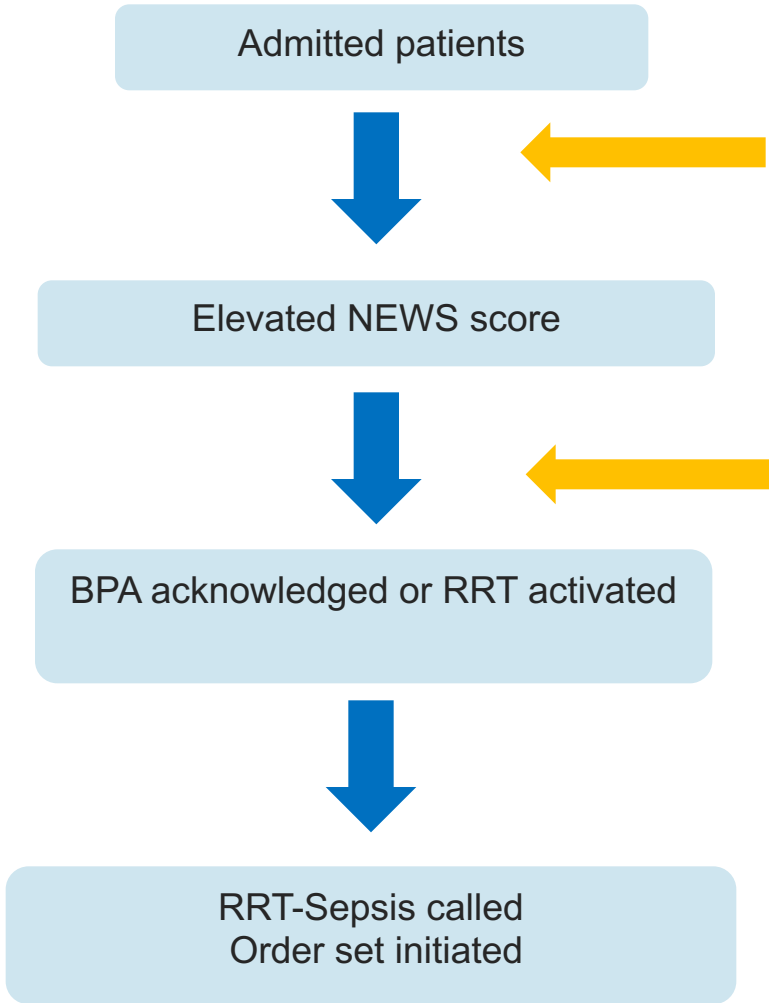
National Early Warning Score (NEWS)*

PHYSIOLOGICAL PARAMETERS	3	2	1	0	1	2	3
Respiration Rate	≤8		9 - 11	12 - 20		21 - 24	≥25
Oxygen Saturations	≤91	92 - 93	94 - 95	≥96			
Any Supplemental Oxygen		Yes		No			
Temperature	≤35.0		35.1 - 36.0	36.1 - 38.0	38.1 - 39.0	≥39.1	
Systolic BP	≤90	91 - 100	101 - 110	111 - 219			≥220
Heart Rate	≤40		41 - 50	51 - 90	91 - 110	111 - 130	≥131
Level of Consciousness				A			V, P, or U



Build to show value > Build to integrate > Build to scale

Work on the Right Problem – Prior Solution Failed



National Early Warning Score (NEWS)*

PHYSIOLOGICAL PARAMETERS	3	2	1	0	1	2	3
Respiration Rate	≤8		9 - 11	12 - 20		21 - 24	≥25
Oxygen Saturations	≤91	92 - 93	94 - 95	≥96			
Any Supplemental Oxygen		Yes		No			

BestPractice Advisory - Long, Diamond

NEWS Score > 7

EARLY WARNING SCORING SYSTEM

This patient has a **NEWS >= 7** which may indicate that they are critically ill. Contact your charge nurse immediately to discuss further treatment and activate an RRT, if appropriate, or indicate below a reason to suppress the warning.

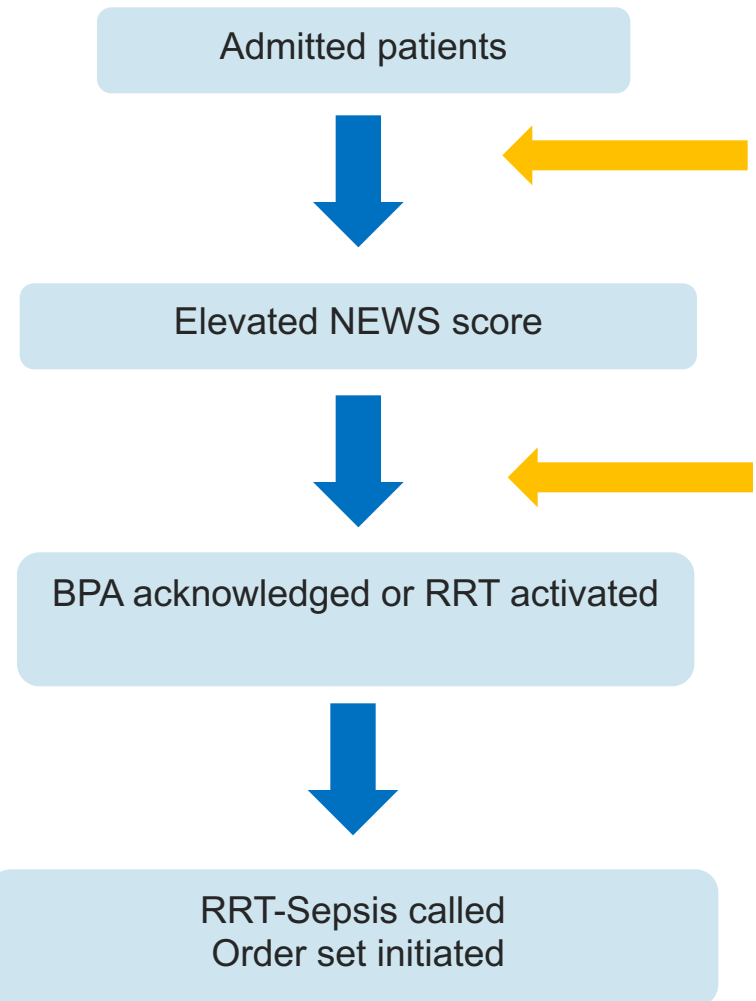
The following data were used to evaluate the NEWS Criteria

Resp: 20
SpO2: 88 %
Any supplemental oxygen?: Yes
Temp: 39 °C (102.2 °F)
BP: 100/80 mmHg
Heart Rate: 120
Level of Consciousness: Alert

Acknowledge reason:



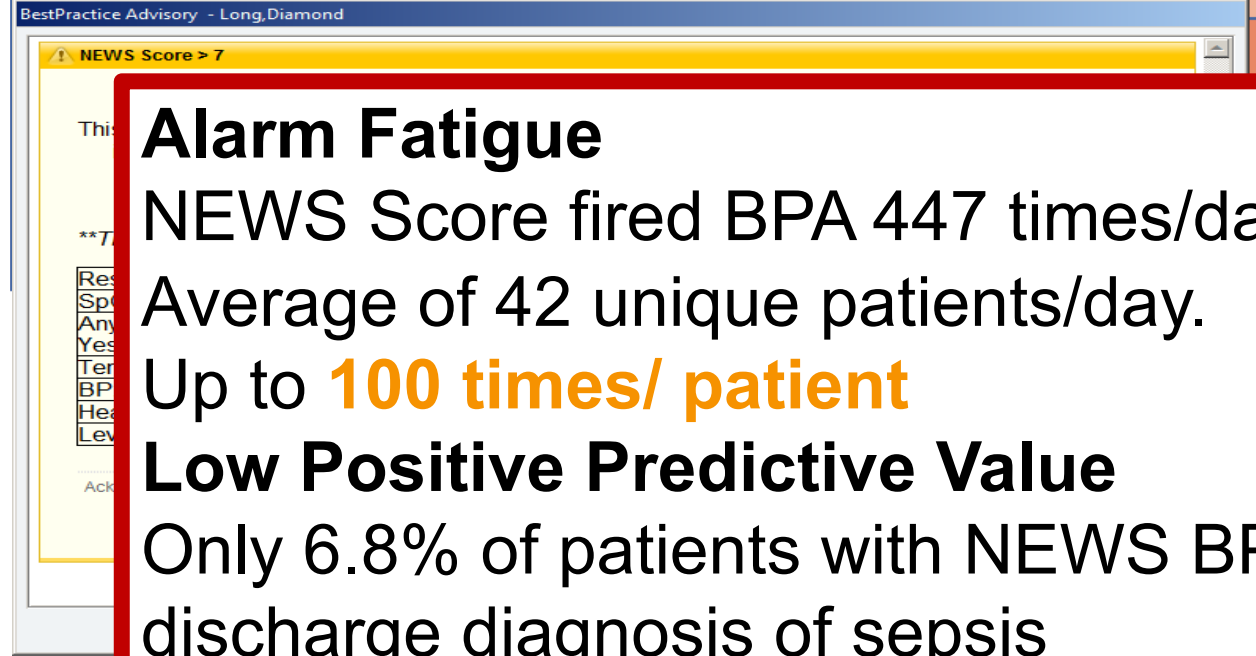
Work on the Right Problem – Prior Solution Failed



National Early Warning Score (NEWS)*

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Respiration Rate	≤8		9 - 11	12 - 20		21 - 24	≥25
Oxygen Saturations	≤91	92 - 93	94 - 95	≥96			
Any Supplemental Oxygen		Yes		No			

BestPractice Advisory - Long, Diamond



Alarm Fatigue
 NEWS Score fired BPA 447 times/day;
 Average of 42 unique patients/day.
 Up to **100 times/ patient**
Low Positive Predictive Value
 Only 6.8% of patients with NEWS BPA had discharge diagnosis of sepsis
~86% of BPAs canceled

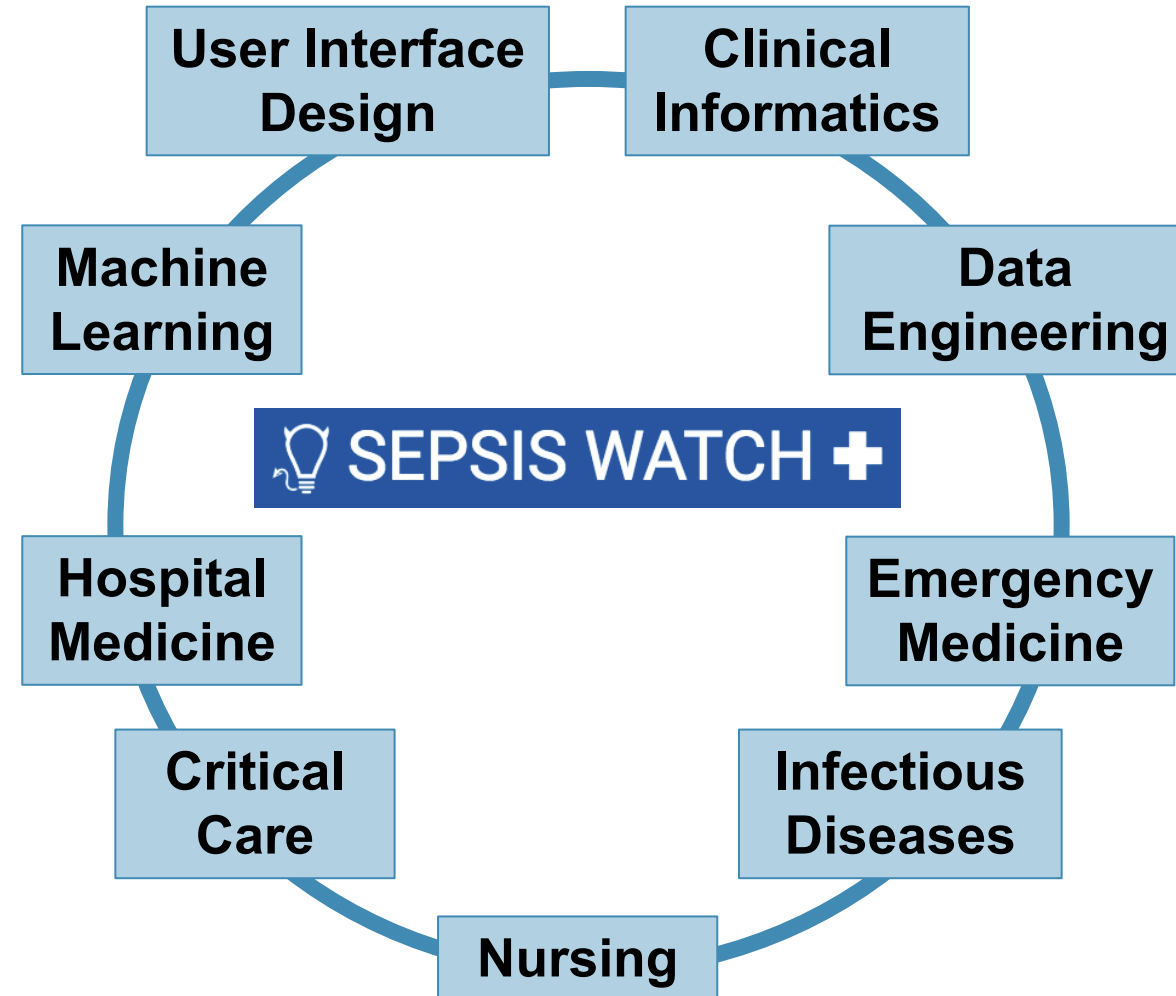


Build to show value

Build to integrate

Build to scale

Bring Together the Right Team



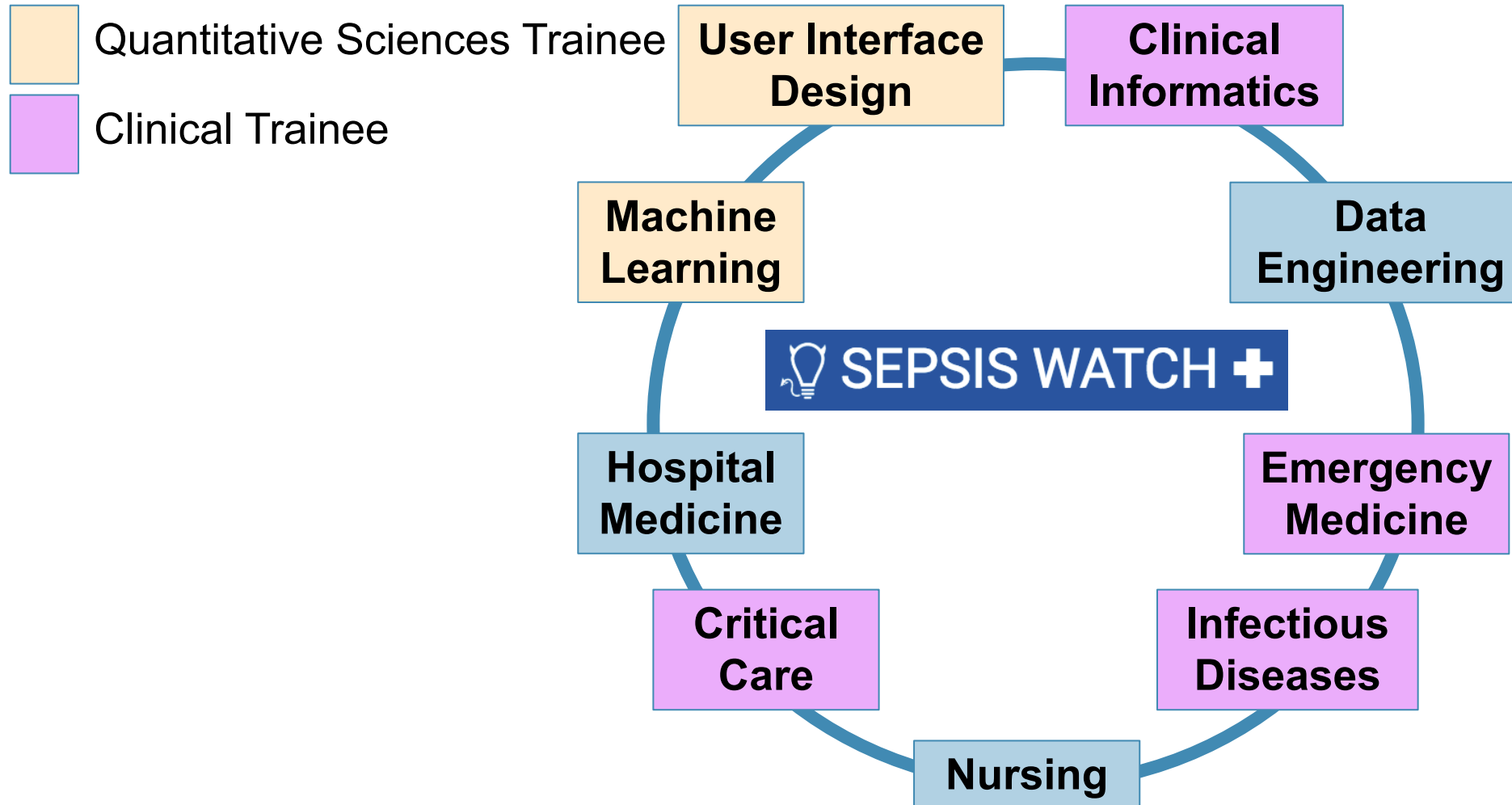


Build to show value

Build to integrate

Build to scale

Bring Together the Right Team





Build to show value

Build to integrate

Build to scale

Engage the Right Leaders

- Twice yearly presentations to health system C-suite
- Monthly meetings with hospital president
- Monthly meetings with health system CTO
- Weekly meetings over 6 months with CMIO and IT leadership



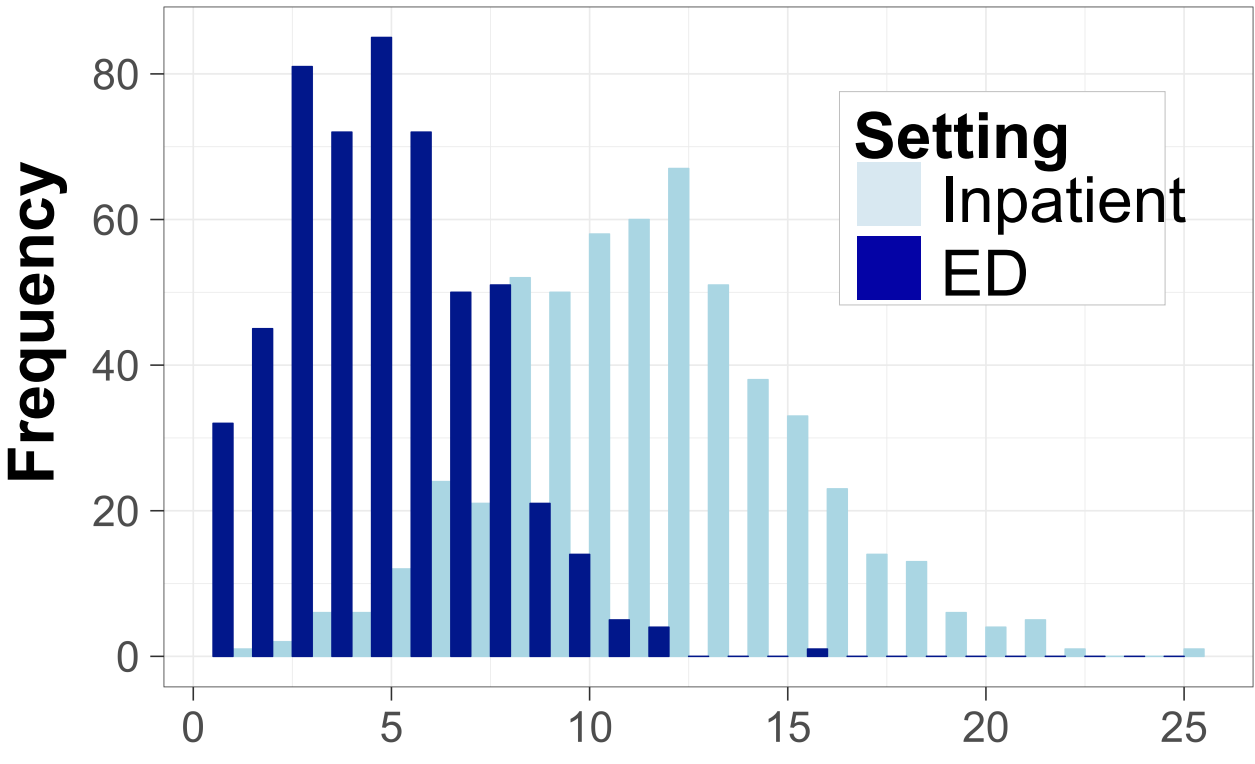
Optimize for Learning – Focus on the ED

	Duke Raleigh Hospital	Duke Regional Hospital	Duke University Hospital
Beds	186	369	957
Encounters	22987	32082	42806
Sepsis Cases	571 (2.5%)	870 (2.7%)	2674 (6.2%)
Daily Sepsis Cases	3.1 cases / day	4.7 cases / day	14.5 cases / day
Sepsis Cases in ED	391 (68.5%)	585 (67.2%)	1241 (46.4%)
Time to Sepsis in ED	1.92 hours	1.83 hours	2.01 hours

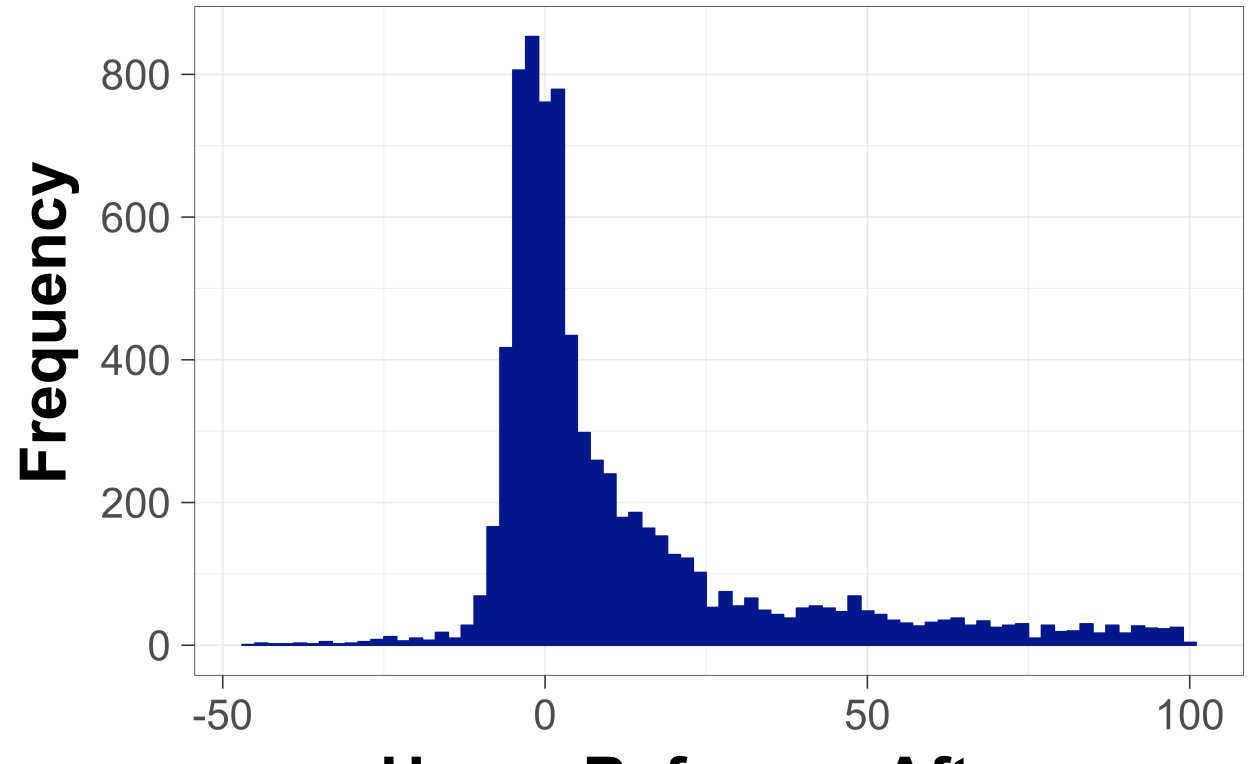


Optimize for Learning – Focus on the ED

Distribution of sepsis events per day by ED (40%) vs inpatient (60%) setting



Distribution of sepsis events by number of hours after admission

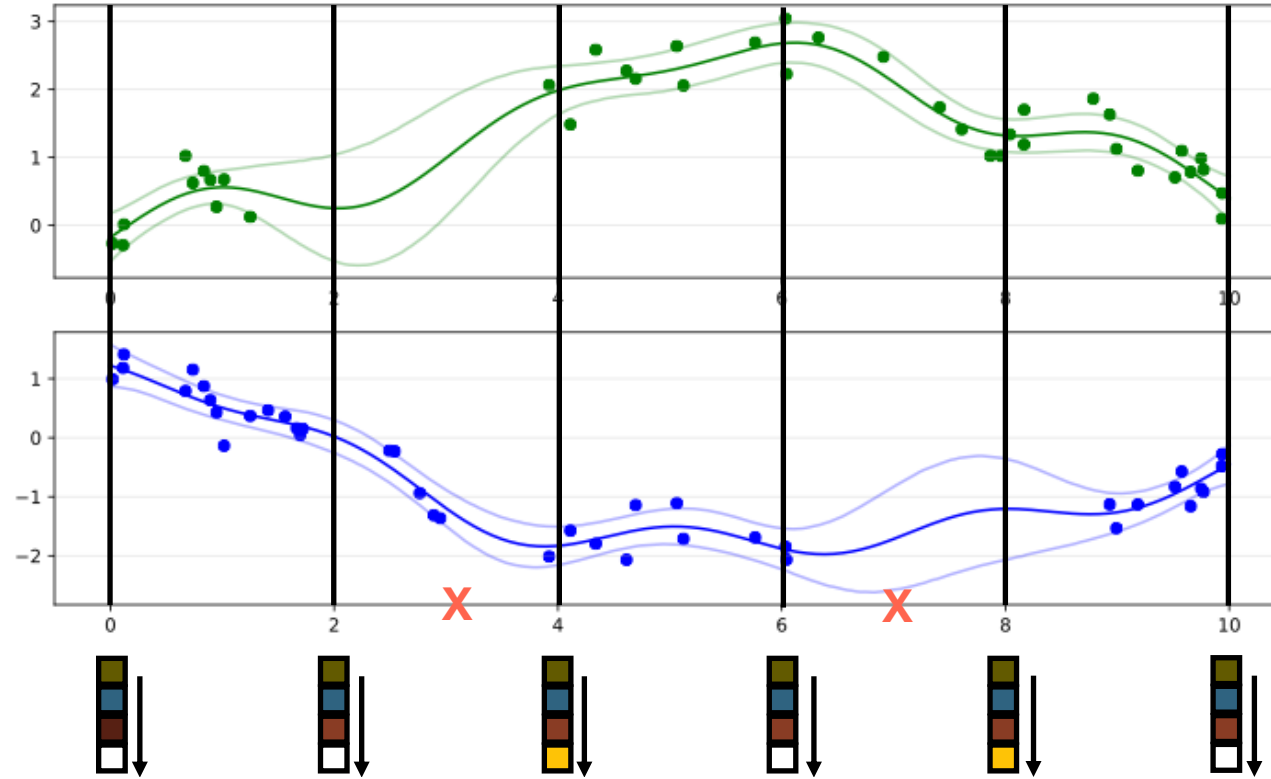




Generate Short Term Wins – Build Cool Tech

Gaussian process imputes & interpolates, maintaining uncertainty

- : Lab 1
- : Lab 2
- : Baseline
- : Medication
- | : Grid Time



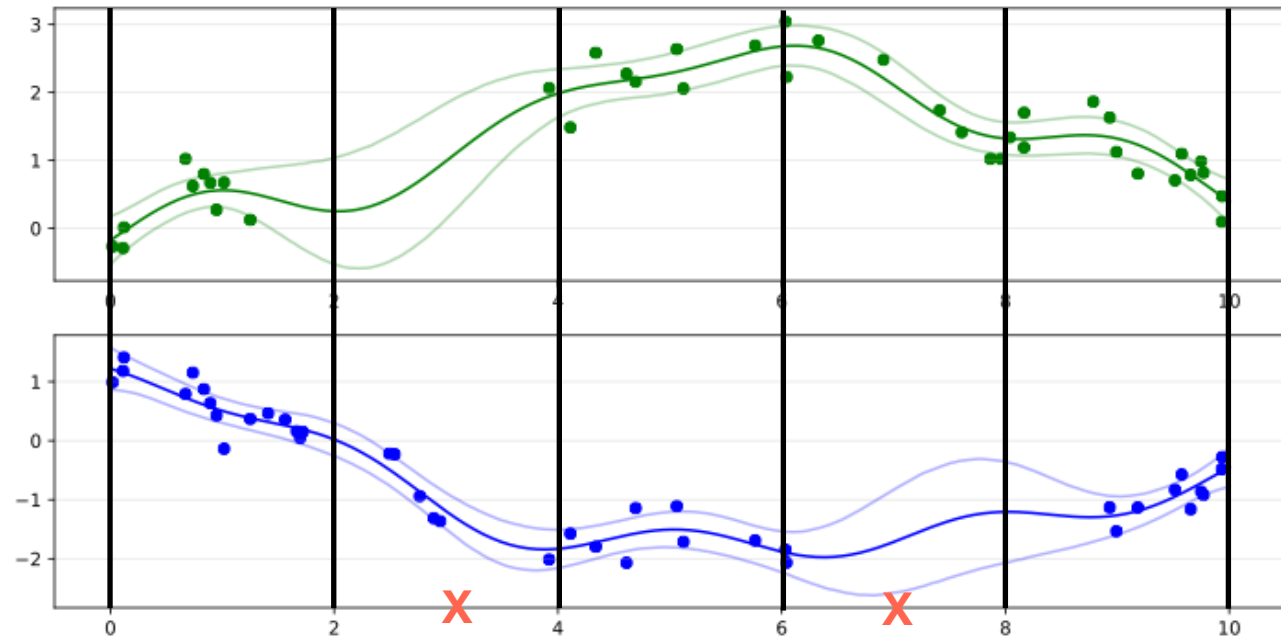


Build to show value > Build to integrate > Build to scale

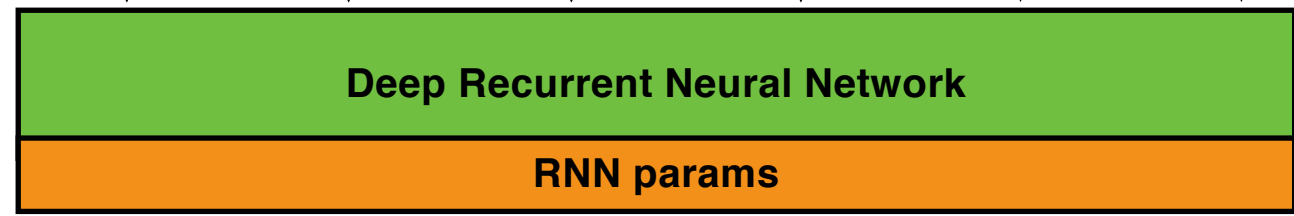
Generate Short Term Wins – Build Cool Tech

Gaussian process imputes & interpolates, maintaining uncertainty

- : Lab 1
- : Lab 2
- : Baseline
- : Medication
- | : Grid Time



Powerful deep learning prediction model



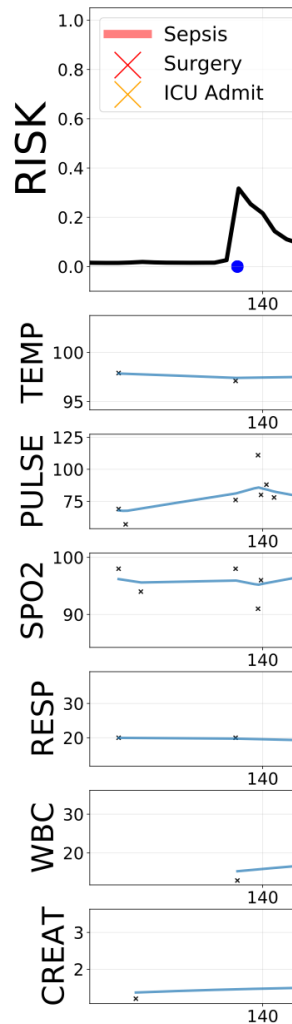


Build to show value

Build to integrate

Build to scale

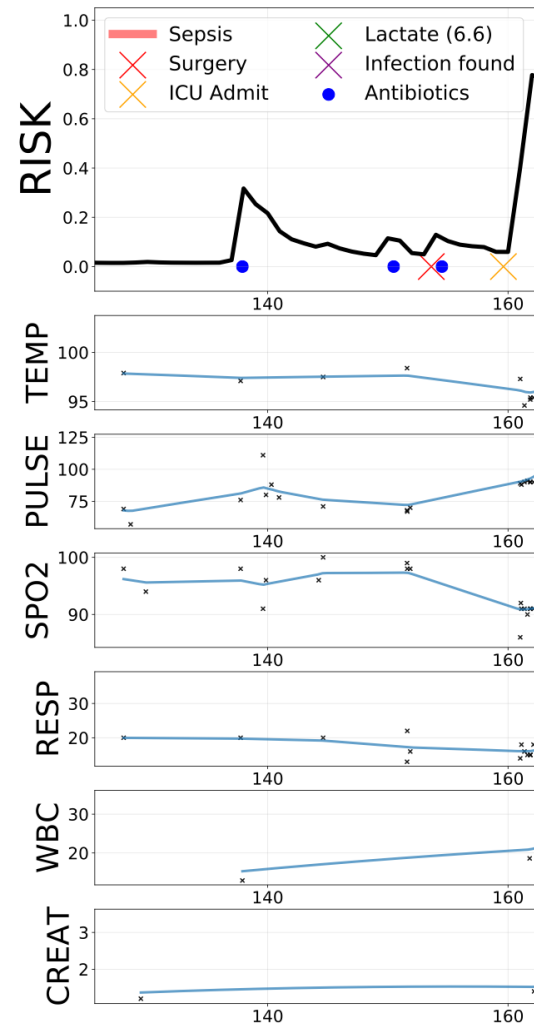
Generate Short Term Wins – Show Model Works



Hours After Admission



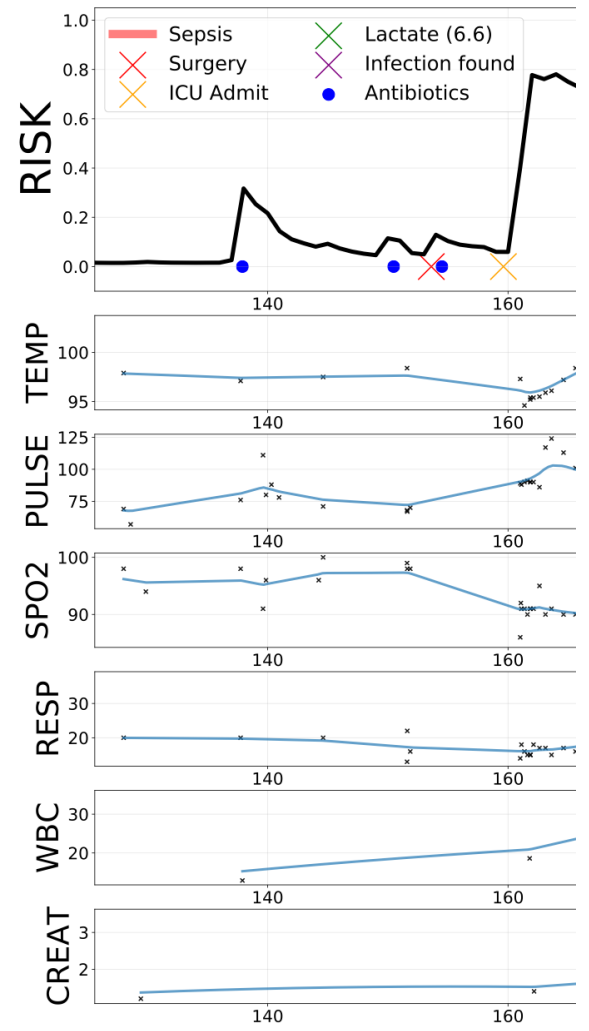
Generate Short Term Wins – Show Model Works



Hours After Admission



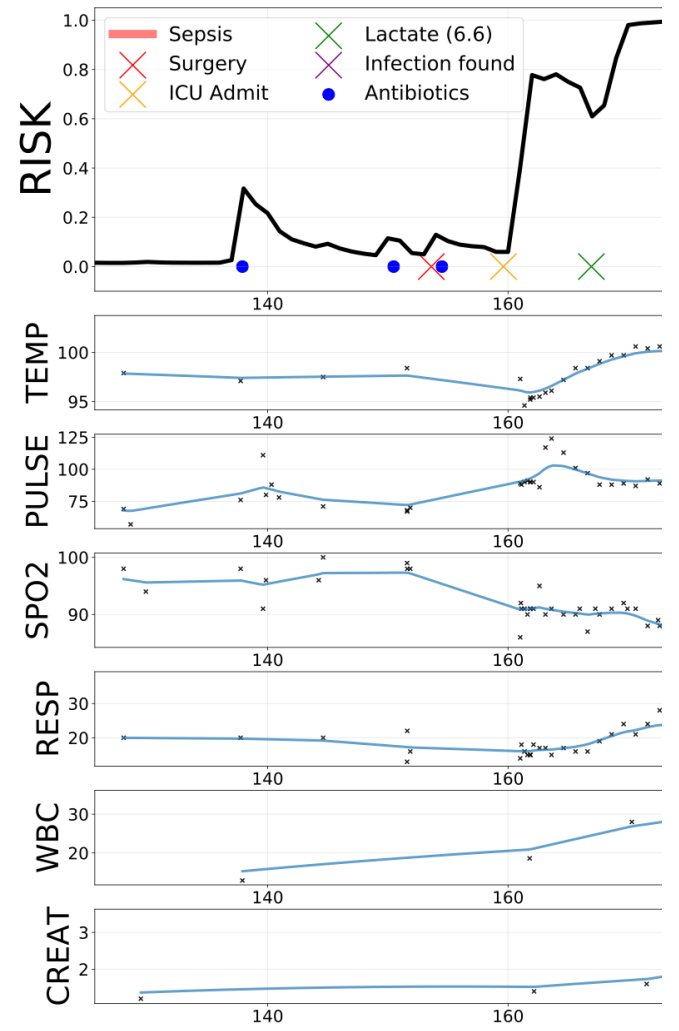
Generate Short Term Wins – Show Model Works



Hours After Admission



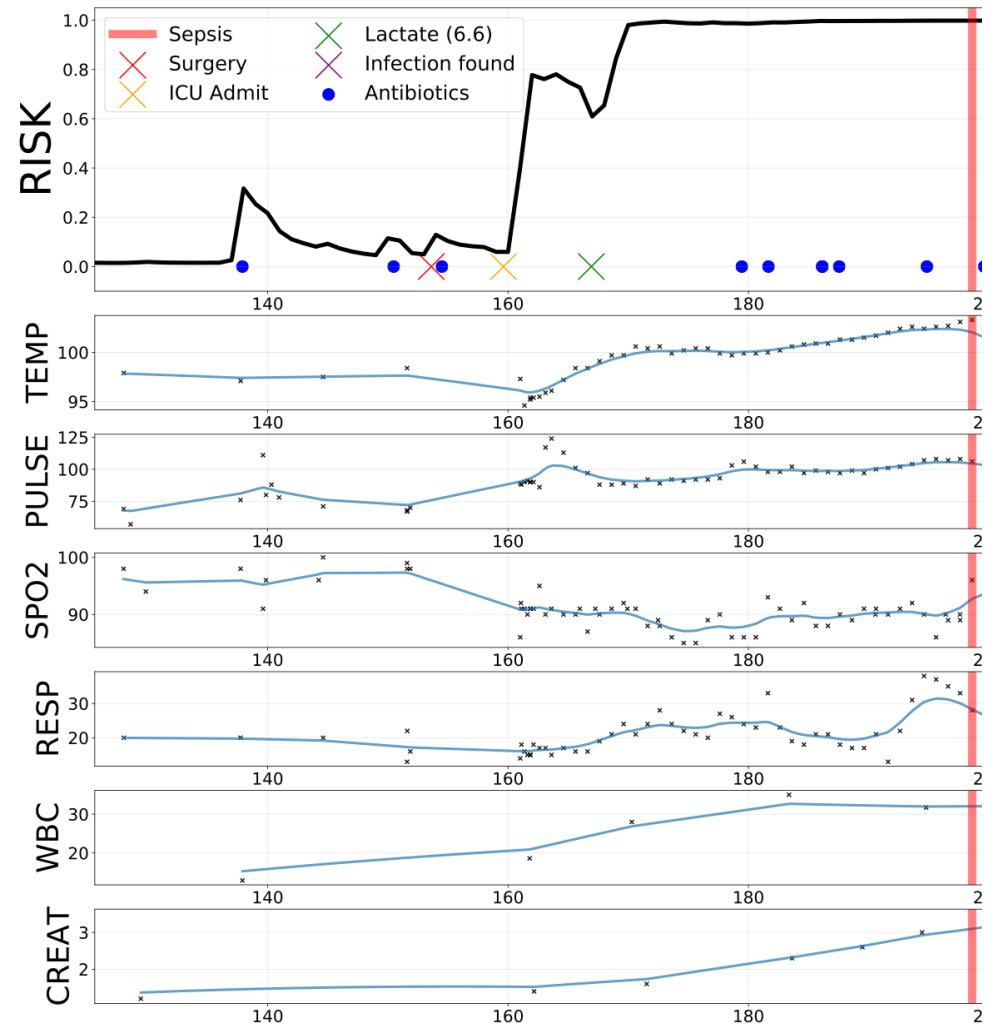
Generate Short Term Wins – Show Model Works



Hours After Admission



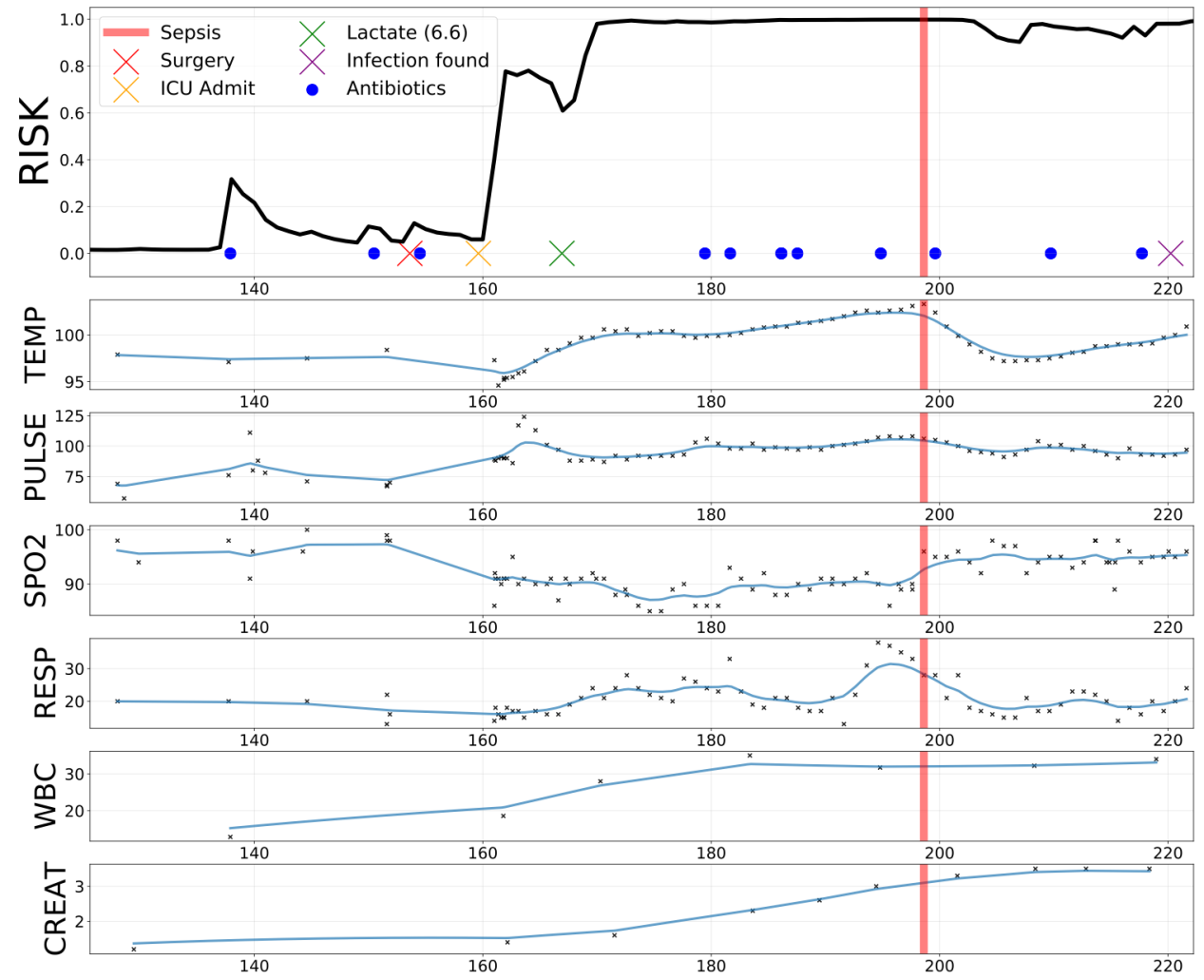
Generate Short Term Wins – Show Model Works



Hours After Admission



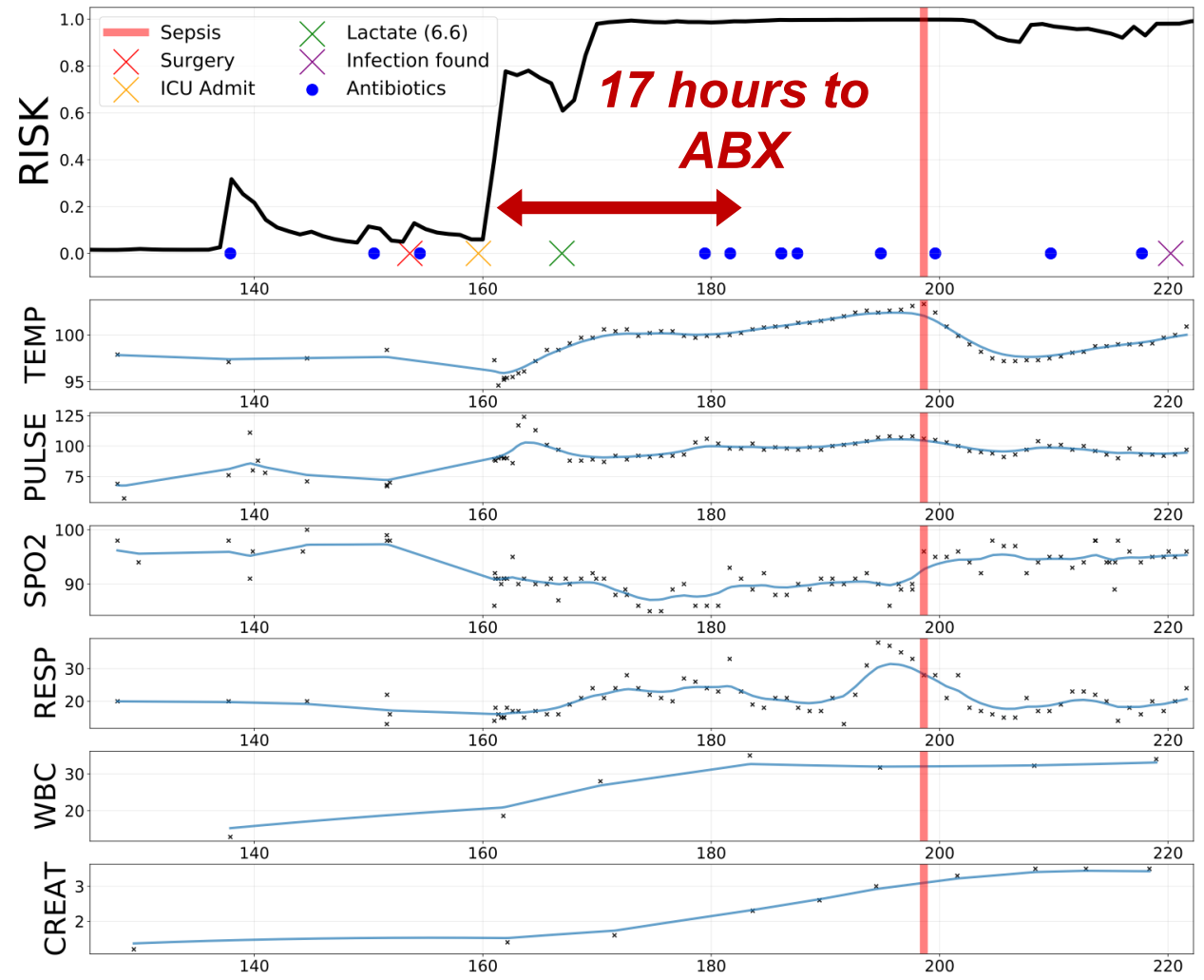
Generate Short Term Wins – Show Model Works



Hours After Admission



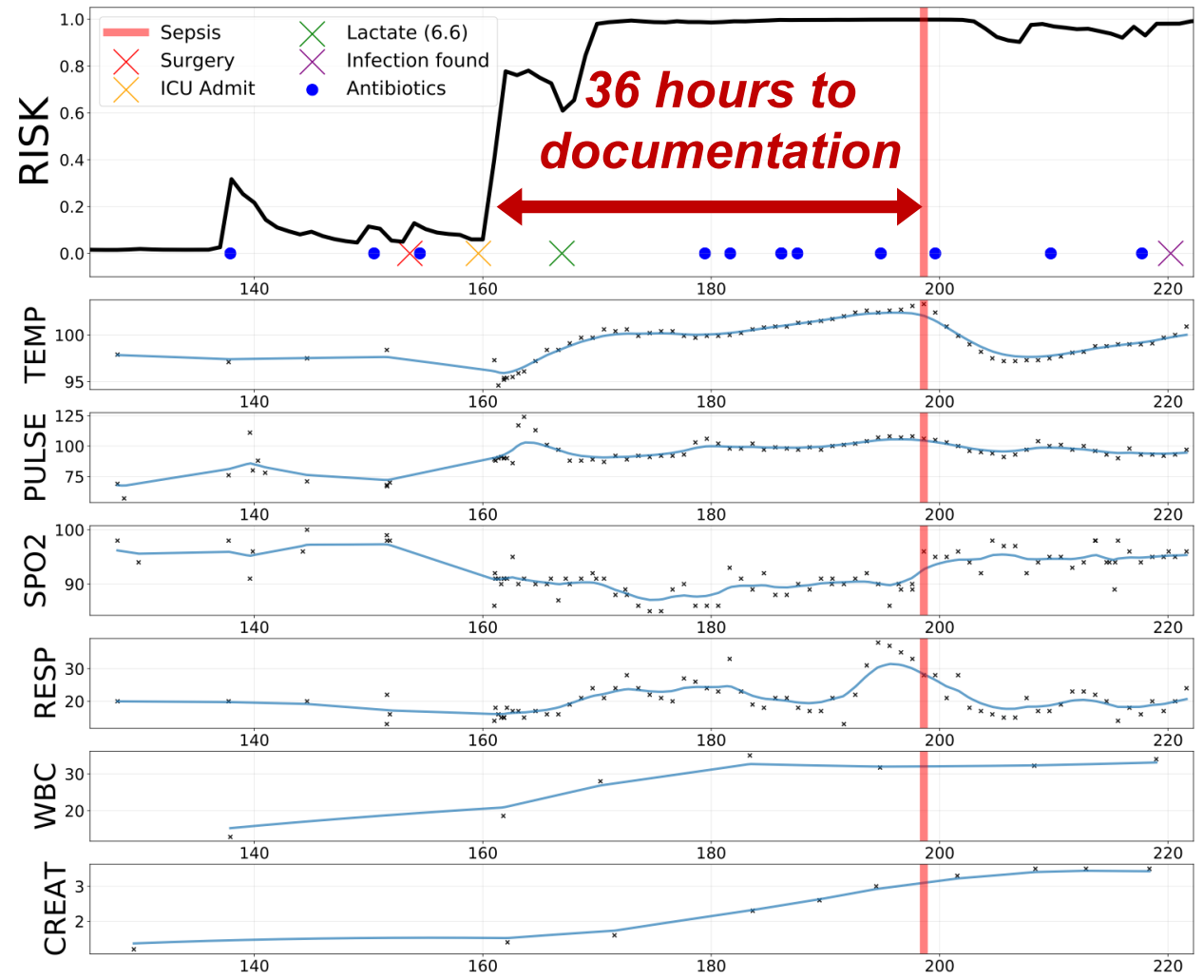
Generate Short Term Wins – Show Model Works



Hours After Admission



Generate Short Term Wins – Show Model Works

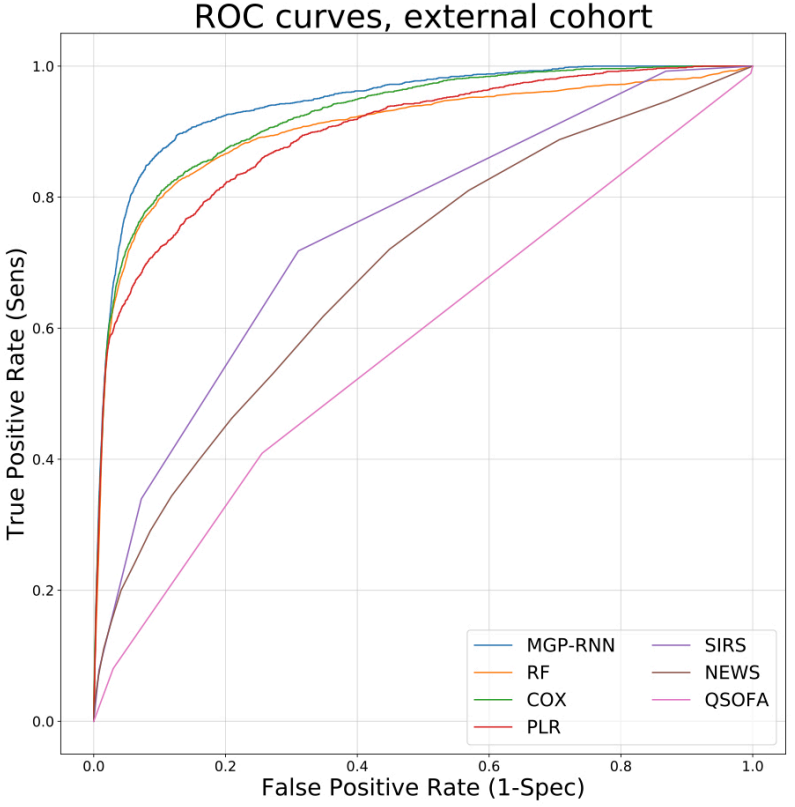


Hours After Admission



Build to show value > Build to integrate > Build to scale

Generate Short Term Wins – Show Model Works



Method	AUROC (95% CI)	
MGP-RNN	0.943	(0.938, 0.948)
RF	0.905	(0.896, 0.913)
COX	0.925	(0.919, 0.931)
PLR	0.897	(0.889, 0.904)
SIRS	0.748	(0.737, 0.757)
NEWS	0.690	(0.678, 0.703)
qSOFA	0.578	(0.567, 0.590)

**Upcoming
publication**



Build to show value

Build to integrate

Build to scale

Sepsis Watch:

Build to Integrate

Will Ratliff



Build to show value

Build to integrate

Build to scale

Why is integration hard?

“There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things.”

~Niccolo Machiavelli



Build to show value

Build to integrate

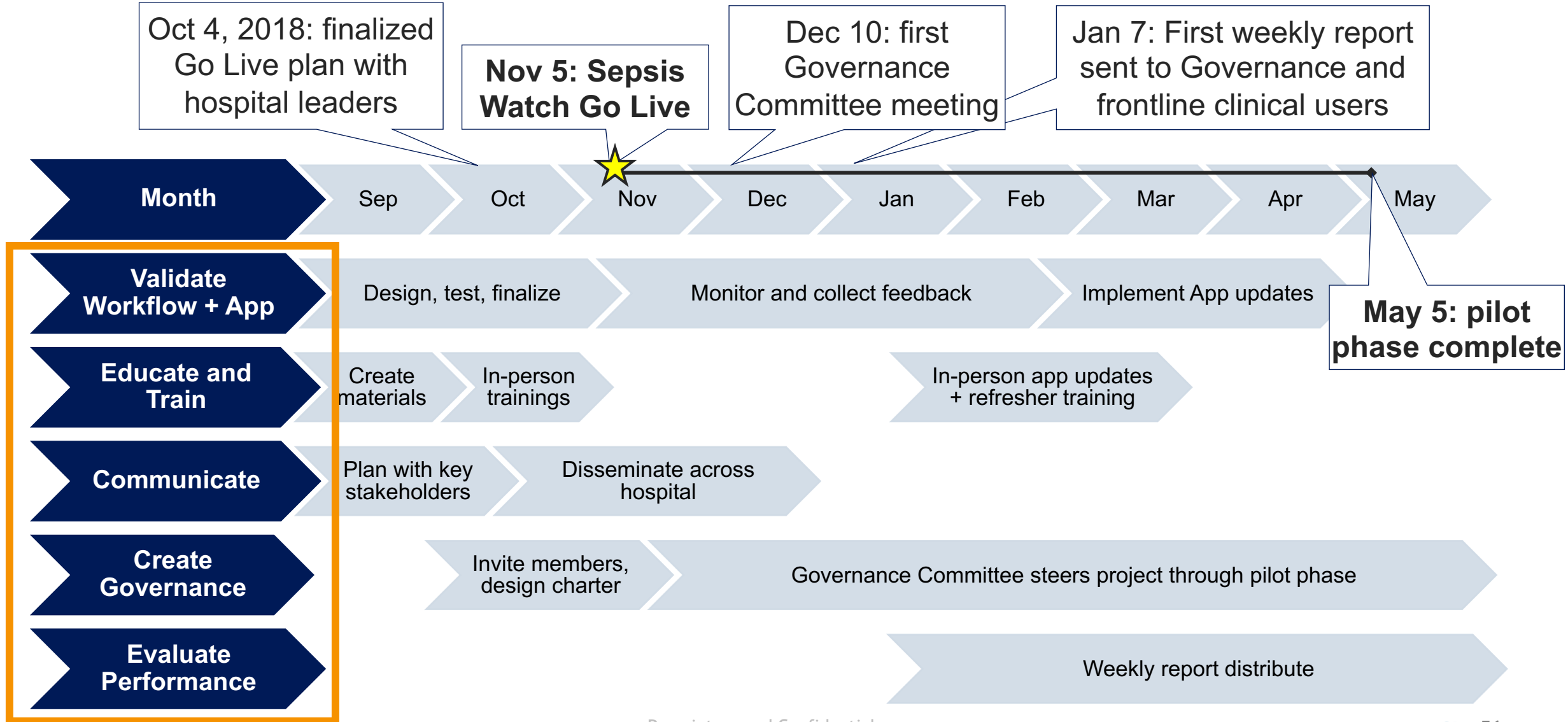
Build to scale

About a year ago today...

- I joined DIHI, knew nothing about Sepsis Watch, and only a little about ML
- State of affairs with Sepsis Watch:
 - Thoughtfully built, but not yet “real” to stakeholders



Sepsis Watch Implementation at DUH – Timeline





Build to show value

Build to integrate

Build to scale

The three failures of implementation

1. Failure to See
2. Failure to Move
3. Failure to Finish

failure modes adapted from “Leading Strategic Change” – Black and Gregersen

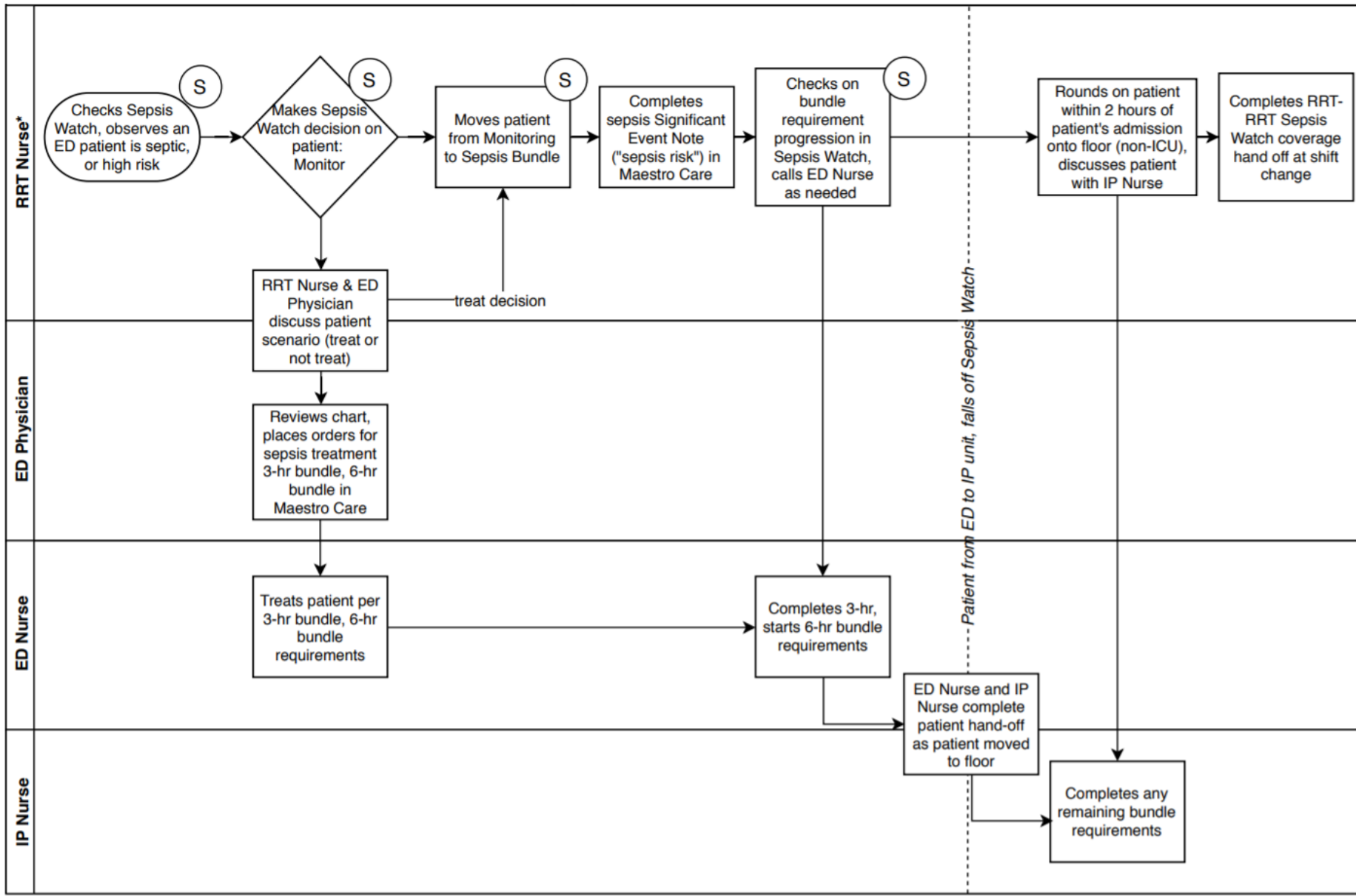
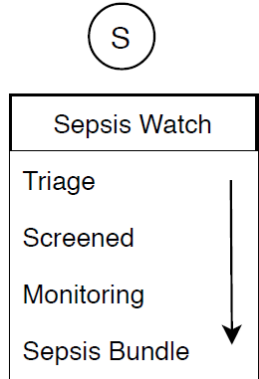


The three failures of implementation

1. Failure to See

Issue	Response
Lock into mental models	Denial: “We don’t need to change”
Dangerous analogies	Inappropriate response: “We shouldn’t let a computer diagnose sepsis!”
Perceived threats	Frame as threat: “Extra work for me... forever?!”

Tactic to overcome
Focus on 1-2 critical changes
Clarify as opportunity – model output is a powerful data point
Label future as “an experiment” (pilot)



*An RRT or patient consult is the top priority of the RRT nurse



Build to show value

Build to integrate

Build to scale

How did we overcome failure to see?

Drumroll....



Build to show value

Build to integrate

Build to scale

How did we overcome failure to see?

Drumroll....



Microsoft Powerpoint



Build to show value

Build to integrate

Build to scale

“Sepsis Watch: The Complete Guide”

Roadmap



What is Sepsis Watch?

[Slide 3](#)

Get to the point – how **Sepsis Watch** can save patient lives at Duke,
AND is **quick to access** and **easy to use**

[Slide 12](#)

Sepsis Watch **How-to Guide**

[Slide 17](#)

Sepsis Watch **workflow**

[Slide 41](#)

Your Sepsis Watch **support team** will be with you

[Slide 61](#)

- 75 slides long
- Soup to nuts (assumes you know NOTHING)
- “This pilot can help save lives...is breakthrough science...and the tool is easy to use”



Sepsis Watch Web Application

Patient "card"

Each "card" represents a single patient at Duke Hospital

SEPSIS WATCH +

Triage **11**
Screened **1**
Monitoring **5**
Sepsis Bundle **4**
JM ▾

Last updated 2 minutes ago.

SEP 3UH2AP · Wells, H · 67 M Bed 852 · Admit 10/11 11:59 AM T 37.5 · P 67 · BP 117/68 · MAP 160 · R 15	SCREEN MONITOR TREAT
☺ Met sepsis criteria 10/11 11:07 AM	
SEP MFCM5Z · Mcdonald, G · 61 M Bed 557 · Admit 10/11 11:27 AM T 37.7 · P 68 · BP Unk · MAP Unk · R 17	SCREEN MONITOR TREAT
☺ Met sepsis criteria 10/11 12:17 PM	
HIGH UJZ6JWS · Wallace, A · 70 F Bed 101 · Admit 10/11 11:22 AM T Unk · P 65 · BP 119/66 · MAP 76 · R 22	SCREEN MONITOR TREAT
MED 5MEV2UI · Pope, F · 80 F Unk Loc · Admit 10/11 11:40 AM T 38.2 · P 64 · BP 110/76 · MAP Unk · R 16	SCREEN MONITOR TREAT
LOW GPVQ8Q8 · Carli, T · 75 F Bed 948 · Admit 10/11 11:28 AM T 37.6 · P 69 · BP 110/61 · MAP 196 · R 16	SCREEN MONITOR TREAT
LOW OXA8ZYY · Facchini, P · 65 F Bed 929 T 37.5 · P 69 · BP 106/80 · MAP 15 · R 16	SCREEN MONITOR TREAT

SEP Wells, H - 67 M
 3UH2AP Bed 852
 Admitted 4 hours ago

SEPSIS CRITERIA MET ☺
 Met 10/11 11:07 AM

LABS AND VITALS 📄

T 37.5	WBC 6.3
P 67	Lactate 1.9
BP 117/68	MAP 160
R 15	

BUNDLE ITEMS IN PAST 3 HRS 📄

- ✓ Lactate
- Blood Cultures
- Antibiotics ?
- IV Fluids ?

Sepsis Watch tabs

There are four Sepsis Watch tabs. These tabs are meant to help organize patients and prioritize patient care. We are currently viewing the "Triage" tab

Additional info on selected patient card

When you tap on a patient card, you can see more info about that patient on the right-hand side of the screen



The three failures of implementation

2. Failure to Move

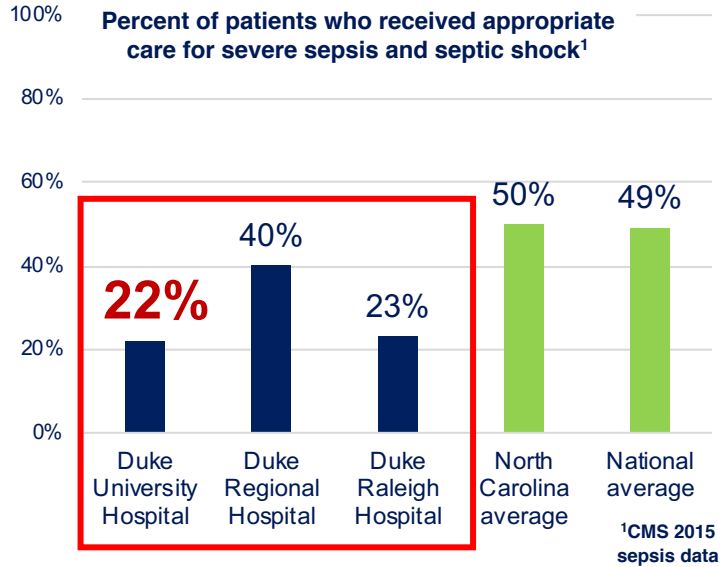
Issue	Response
new path unclear	maintain status quo (passive or overt resistance)
lack of confidence that change can happen	paralysis

Tactic to overcome
communicate vision and path forward.... CONSTANTLY
show gratitude , support effort of champions

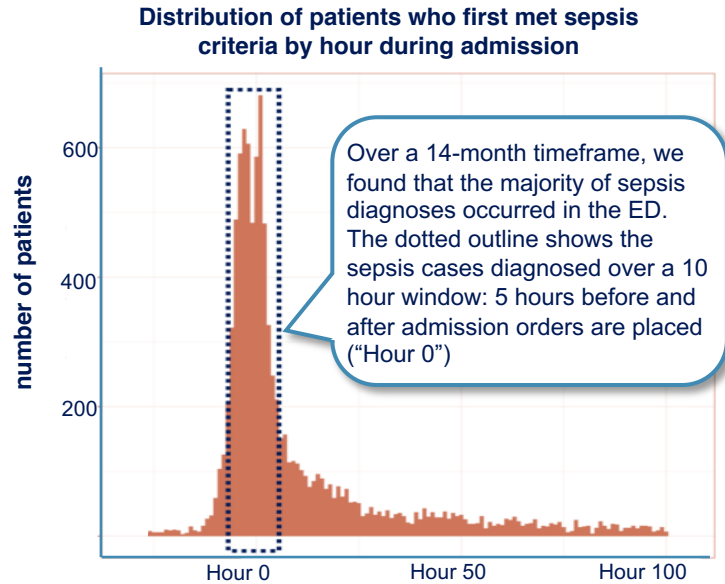


What is Sepsis Watch?

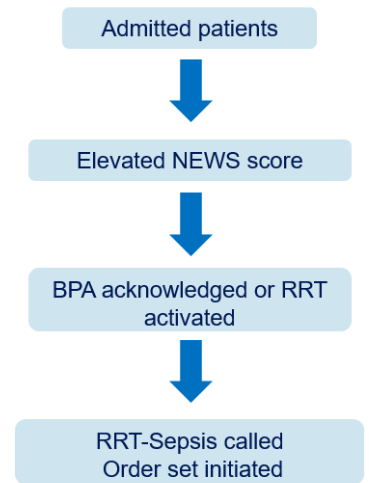
1 What is the problem? Sepsis



2 Where does the problem occur? The ED



3 Why are we failing to solve the problem today? Slow, false alarms



- (fake) NEWS**
- Only 6.8% of patients with NEWS (National Early Warning Score) BPA had discharge diagnosis of sepsis
 - BPA fired 447 times/day on 42 unique patients/day on average (up to ~100x/patient).
 - 63% of BPAs canceled.

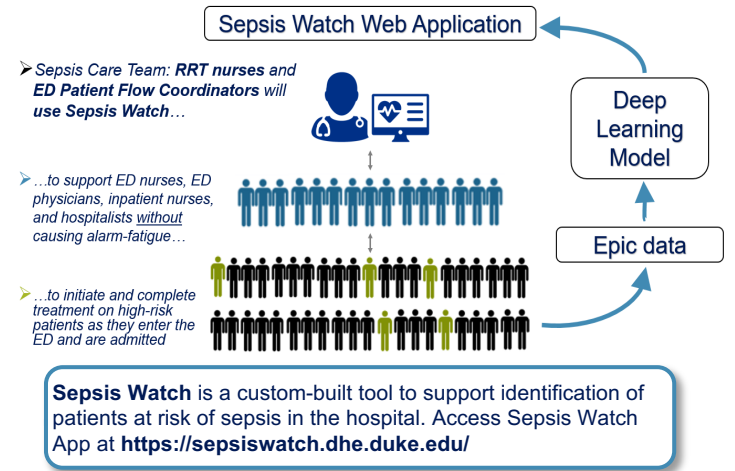
1 Define adult sepsis at Duke

2 or more SIRS criteria	<ul style="list-style-type: none"> - Temperature >38°C or <36°C (6 hours) - HR >90 (6 hours) - RR >20 (6 hours) - WBC count >12, <4, or % bandemia >10% (24 hours)
Suspect Infection	<ul style="list-style-type: none"> - Blood culture order (24 hours)
1 element of end organ failure	<ul style="list-style-type: none"> - Creatinine >2.0 (24 hours) - INR >1.5 (24 hours) - Total bilirubin >2.0 (24 hours) - SBP <90 or decrease in SBP by >40 (6 hours) - Platelets <100 (24 hours) - Lactate ≥2 (24 hours)

2 Create machine learning model to predict sepsis quickly and accurately

- **42,000+ inpatient encounters analyzed** at Duke Hospital over 14 months, **21.3%** with a sepsis event.
- **32+ million data points incorporated:** 25 million vital sign measurements, 2 million med admins, 5.2 million labs.
- **34 physiological variables** (5 vitals, 29 labs).
 - At least one value for each vital in 99% of encounters.
 - Some labs rarely measured (2-4%), most measured 20-80% of the time.
- **35 baseline covariates** (e.g. age, transfer status, comorbidities).
- **10 medication classes** (antibiotics, opioids, heparins).

3 Design web application to show real-time model results and track treatment





Build to show value > Build to integrate > Build to scale

Sepsis Watch Training Site

“Sepsis Watch: The Complete Guide”

Duke Institute for Health Innovation | 75 slides long

Roadmap

- What is Sepsis
- Get to the point AND is quick
- Sepsis Watch
- Sepsis Watch
- Your Sepsis V

What is Sepsis Watch?

1. What is the problem? Sepsis
Percent of patients who received appropriate care for severe sepsis and septic shock*

2. Where does the problem occur? The ED
Distribution of patients who first met sepsis criteria by hour during admission

3. Why are we failing to solve the problem today? Slow, false alarms
(fake) NEWS
• Only 6.8% of patients with NEWS (National

The Problem: Struggle with sepsis

22%

Duke University Hospital

The Solution: Sepsis Watch

- 2 or more SIRS criteria
- Suspect Infection
- 1 element of end organ failure

DukeHealth

Sepsis Watch Feedback Survey

This survey is to collect feedback on the Sepsis Watch pilot. It is divided into two sections. The first section, "General Feedback...", is a single question asking for general feedback on the Sepsis Watch app itself. The second section, "Case-Specific Feedback", is a set of three questions asking for information on a specific scenario where the treatment workflow is breaking down (e.g., a communication gap).

Sepsis Training Site:

- Complete Guide
- One Pager
- Sepsis Watch Feedback Survey
- ED & RRT Contact #s
- Process map



Sepsis Watch Governance Committee:

- Associate Medical Director, Duke Hospital Medicine Program
- Medical Director of the Analytics Center of Excellence
- Chief Nursing & Patient Care Services Officer
- Assoc Chief Nursing Officer (x3)
- Nurse Manager (RRT)
- Nurse Manager (ED)
- Medical Director, Duke University Emergency Department
- Vice President, Emergency Services and Patient Flow
- DIHI Director
- ED MD
- ED nurse
- RRT nurse



The three failures of implementation

3. Failure to Finish

Issue	Response
Fatigue	Revert to status quo, exit
Unsure if you are “moving the needle”	Revert to status quo, exit

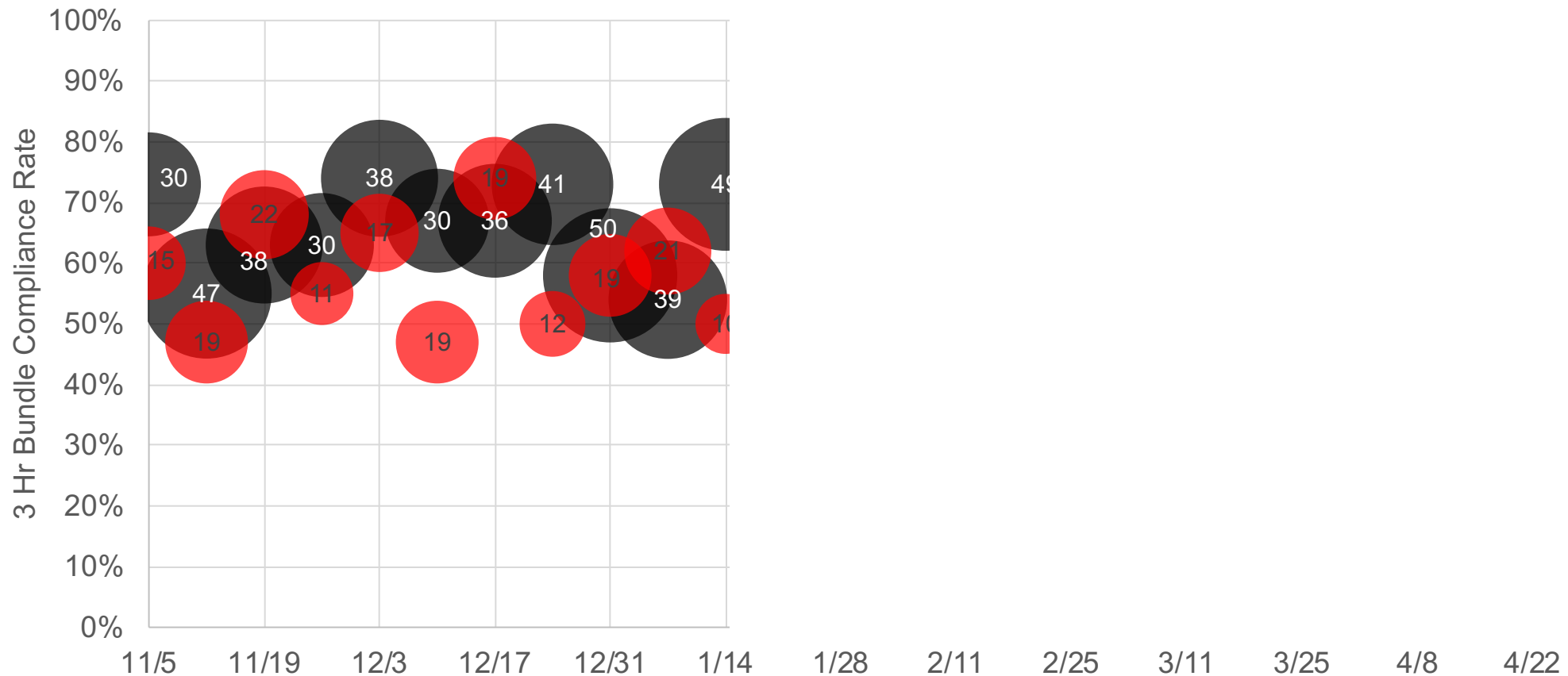
Tactic to overcome
Chart progress, celebrate any early wins
Elicit feedback and use it to adjust



How did we overcome failure to finish?

- High risk at start of Bundle Treatment
- Met sepsis criteria at start of Bundle Treatment

Bundle Compliance - Red and Black Weekly Trend



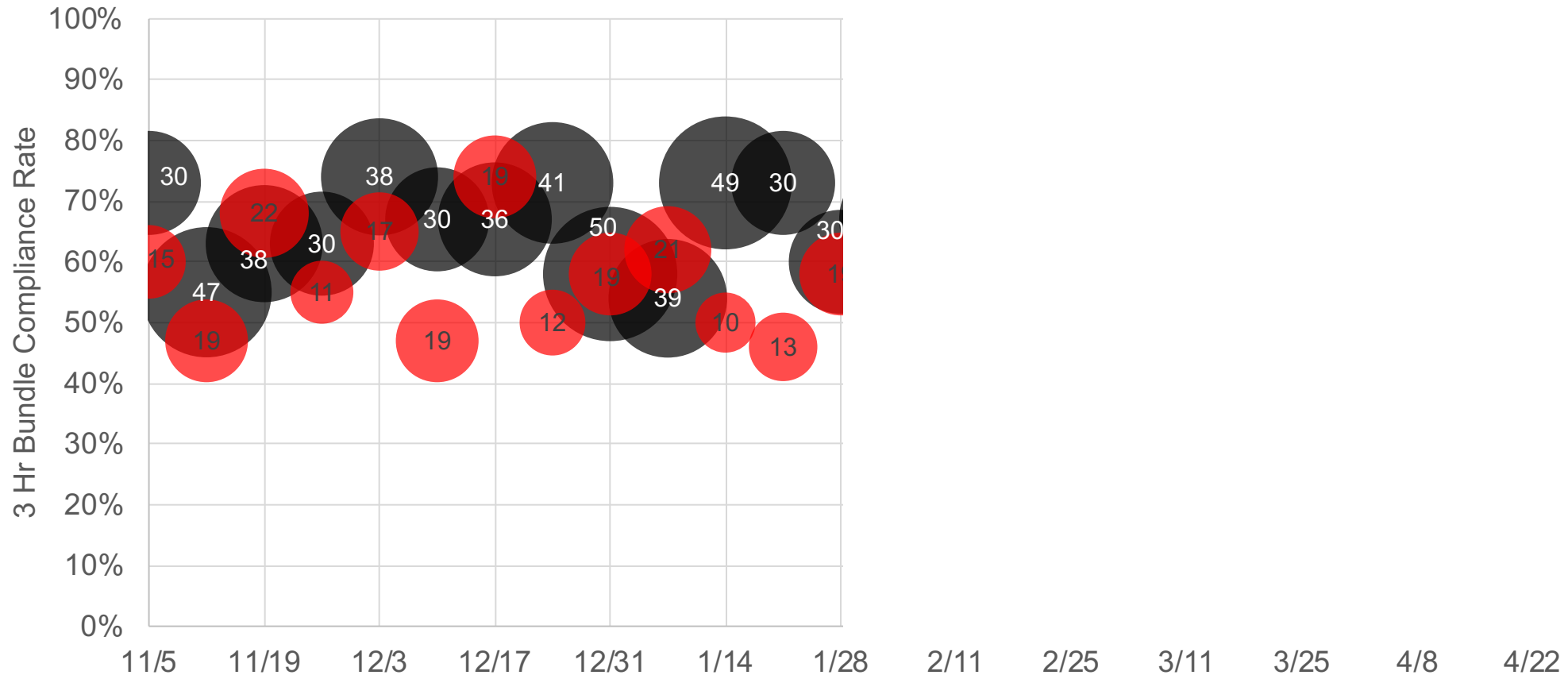
Bubble size (number labeled) = number of total cases (compliance denominator)



How did we overcome failure to finish?

- High risk at start of Bundle Treatment
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Bundle Compliance - Red and Black Weekly Trend



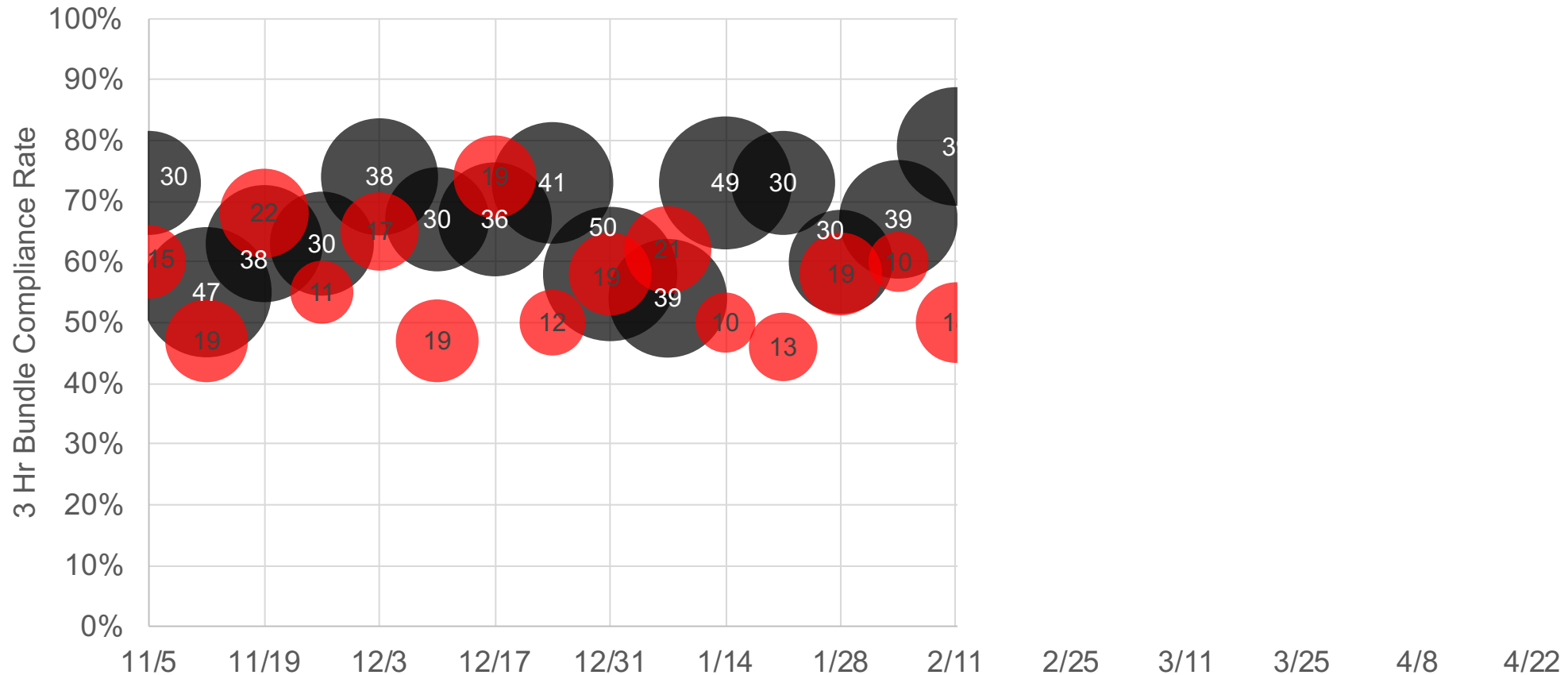
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Bundle Compliance - Red and Black Weekly Trend



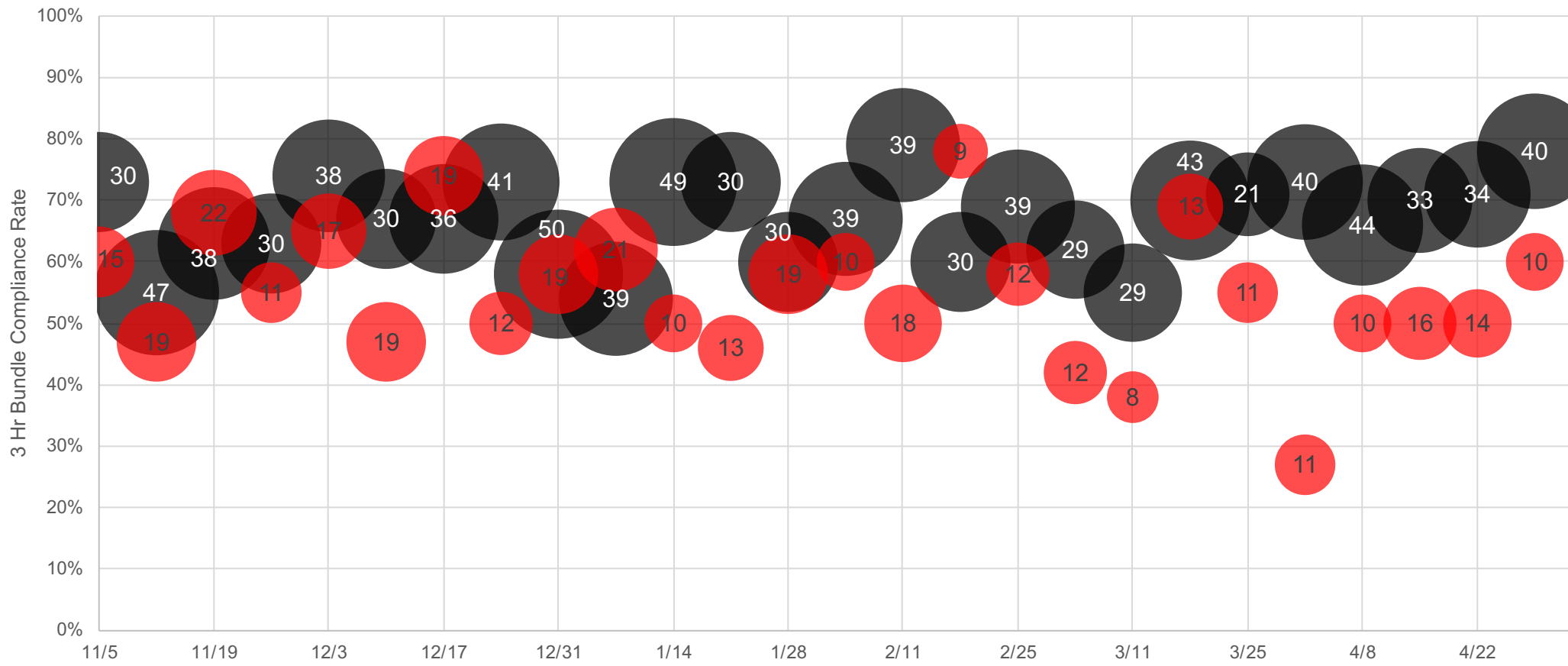
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How did we overcome failure to finish?

- High risk at start of Bundle Treatment
- Met sepsis criteria at start of Bundle Treatment

Bundle Compliance - Red and Black Weekly Trend



Bubble size (number labeled) = number of total cases (compliance denominator)



Feb 2019: Sepsis Watch App Updates

All from RRT nurse feedback:

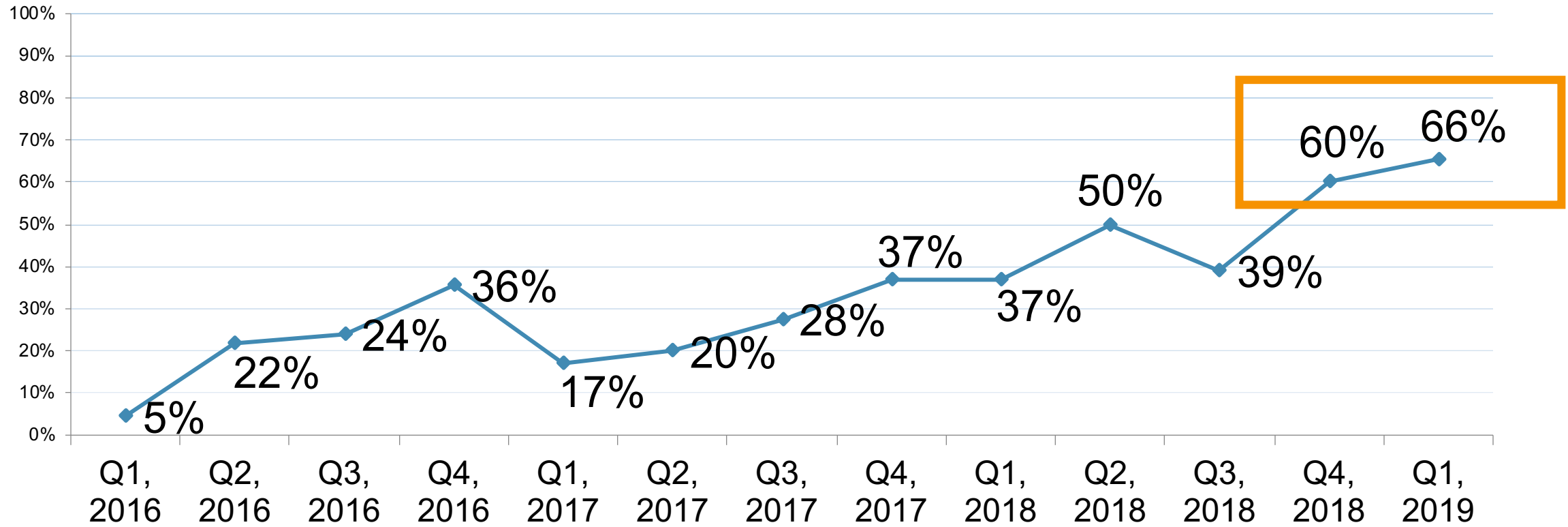
- Improved commenting on patient cards
- Manual check boxes on Sepsis Bundle Tab
- Sorting patients down page who already had bundle administered



SEP	1M7FLX7 · De Santis, D · 66 F	SCREEN
	Unit 14 · Bed 783	MONITOR
	Admit 5/16 12:10 PM	TREAT
T 98.8 P 92 BP 100/87 MAP 20 R 18		COMMENT
check on lactate lab value		94
		SUBMIT
☹ Met sepsis criteria 5/16 12:24 PM		



SEP 1 Bundle Compliance Trend at Duke



★ → Sepsis Watch Go Live



Build to show value

Build to integrate

Build to scale

From Models to Bedside

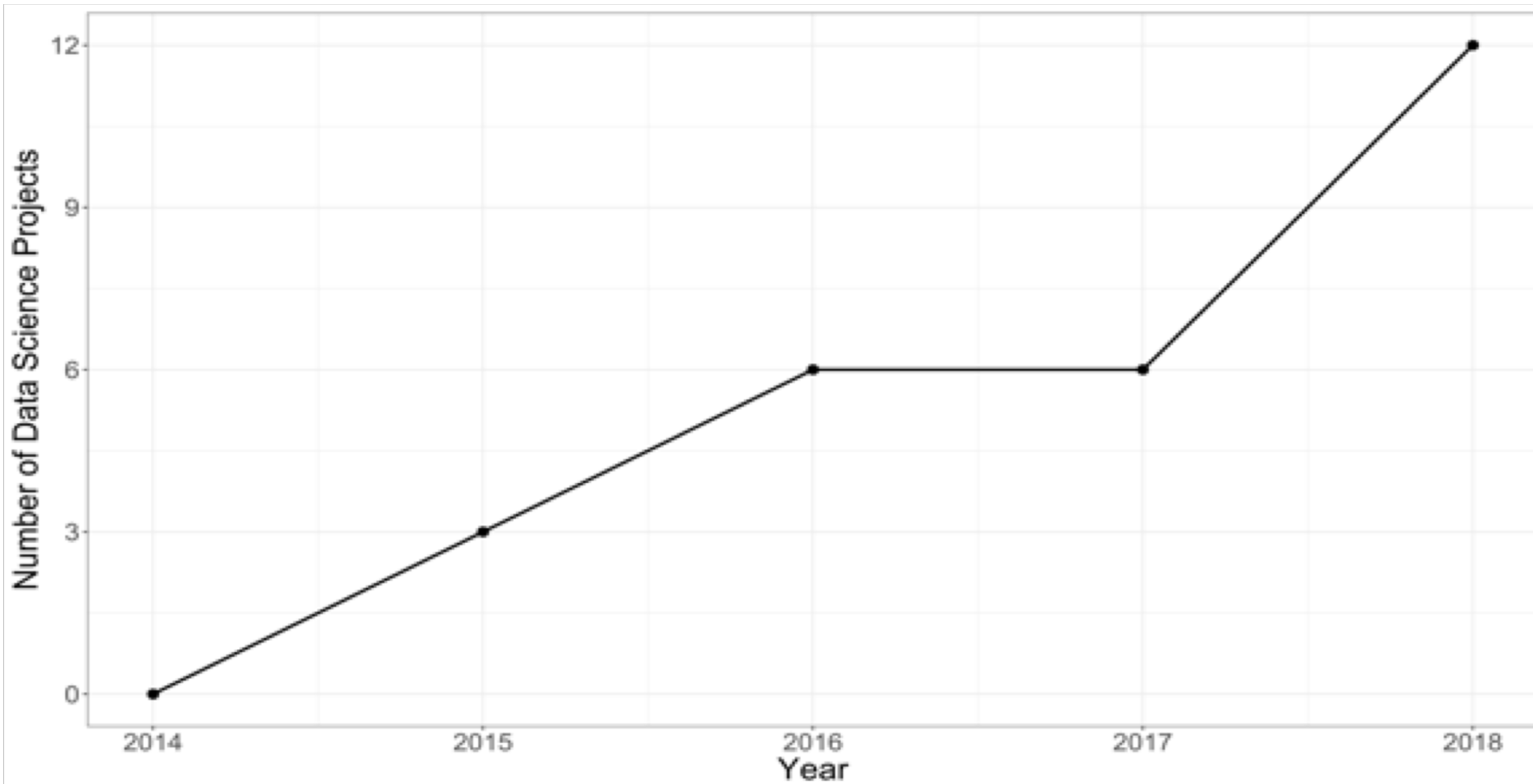
Michael Gao + Marshall Nichols



Build to show value

Build to integrate

Build to scale

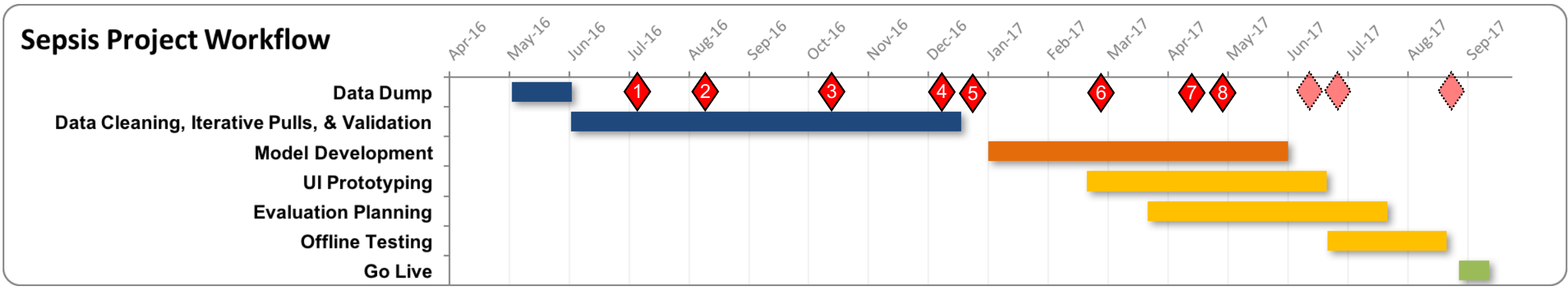






Build to show value > Build to integrate > Build to scale

Project Timelines



Data Processing

- ❖ Cleaning scripts for medications data
- ❖ Cleaning scripts for labs data
- ❖ Cleaning scripts for diagnoses data
- ❖ Data dictionary of variables
- ❖ Curated DUH inpatient data set

Model Building

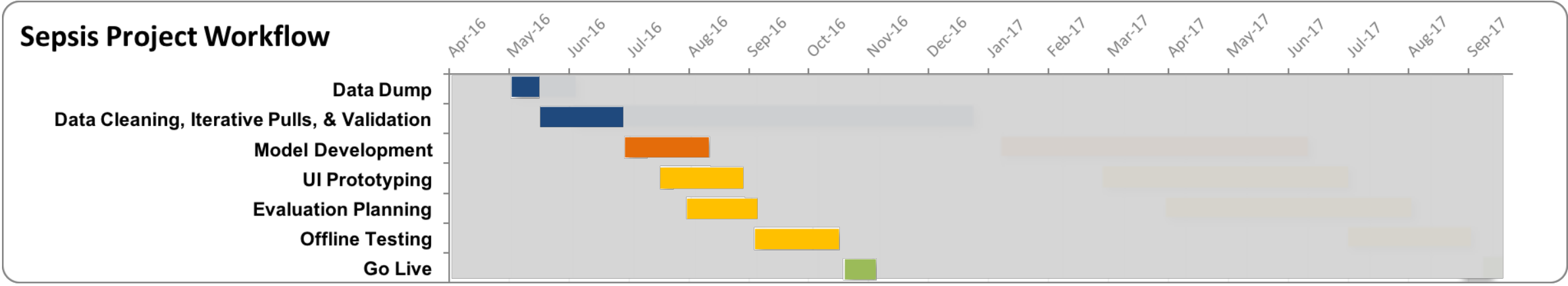
- ❖ Function to define time of clinical event
- ❖ Financial Model
- ❖ Deep Learning Model

Implementation

- ❖ User Interface Software
- ❖ Evaluation Software
- ❖ Simulation Software
- ❖ Real-time inpatient data feeds



Project Timelines



Data Processing

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- ❖ Real-time inpatient data feeds



Build to show value > Build to integrate > **Build to scale**

Scale our Reach





Build to show value

Build to integrate

Build to scale



Duke University Hospital



Duke Regional Hospital



Duke Raleigh Hospital



Build to show value

Build to integrate

Build to scale



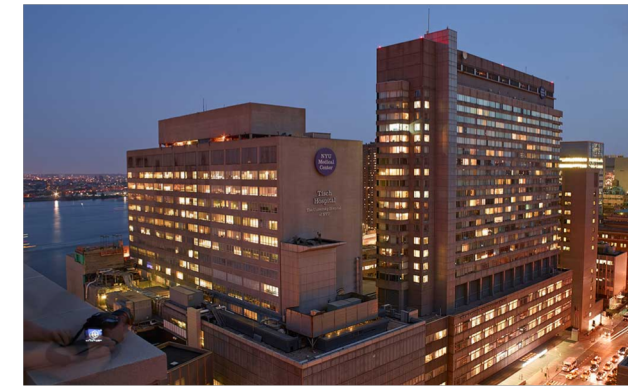
Duke University Hospital



Duke Regional Hospital



Duke Raleigh Hospital



NYU Langone



Build to show value > Build to integrate > Build to scale



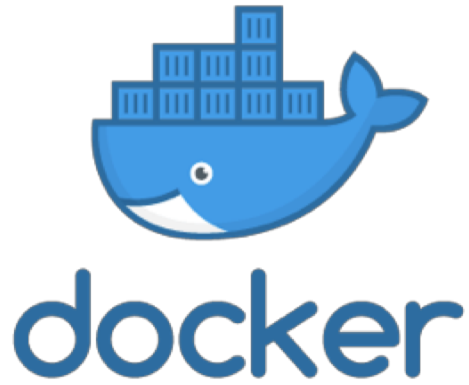


Build to show value

Build to integrate

Build to scale

3 Major Parts





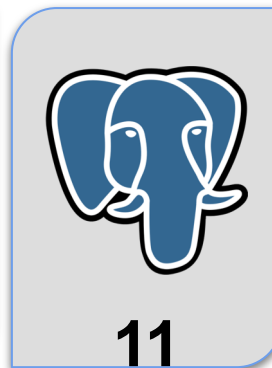
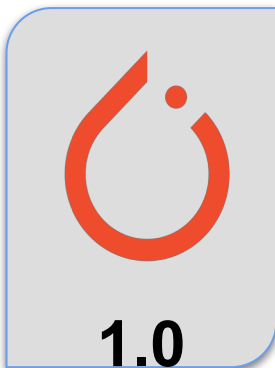
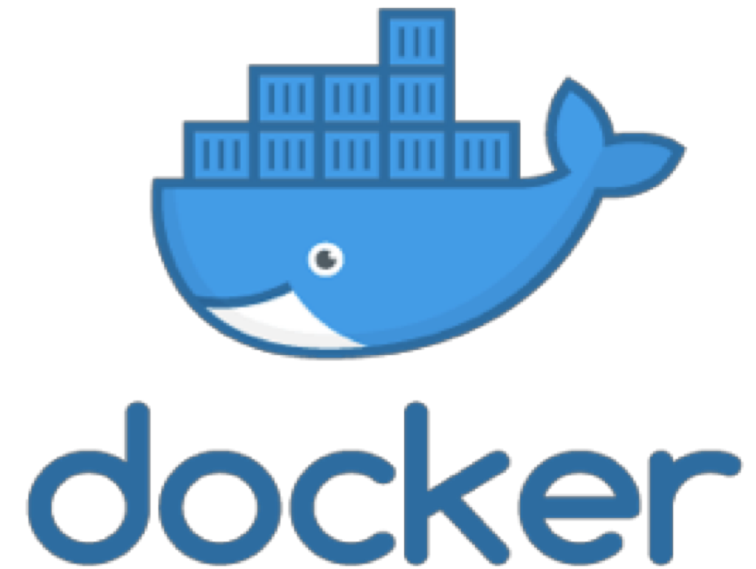
Build to show value

Build to integrate

Build to scale

Isolated, Replaceable Parts

- Containerized Software
- Disposability
- Version Controlled, Codified
Container Definitions
- Operating System Agnostic
- Build it once, ship it anywhere



Control of Environment!

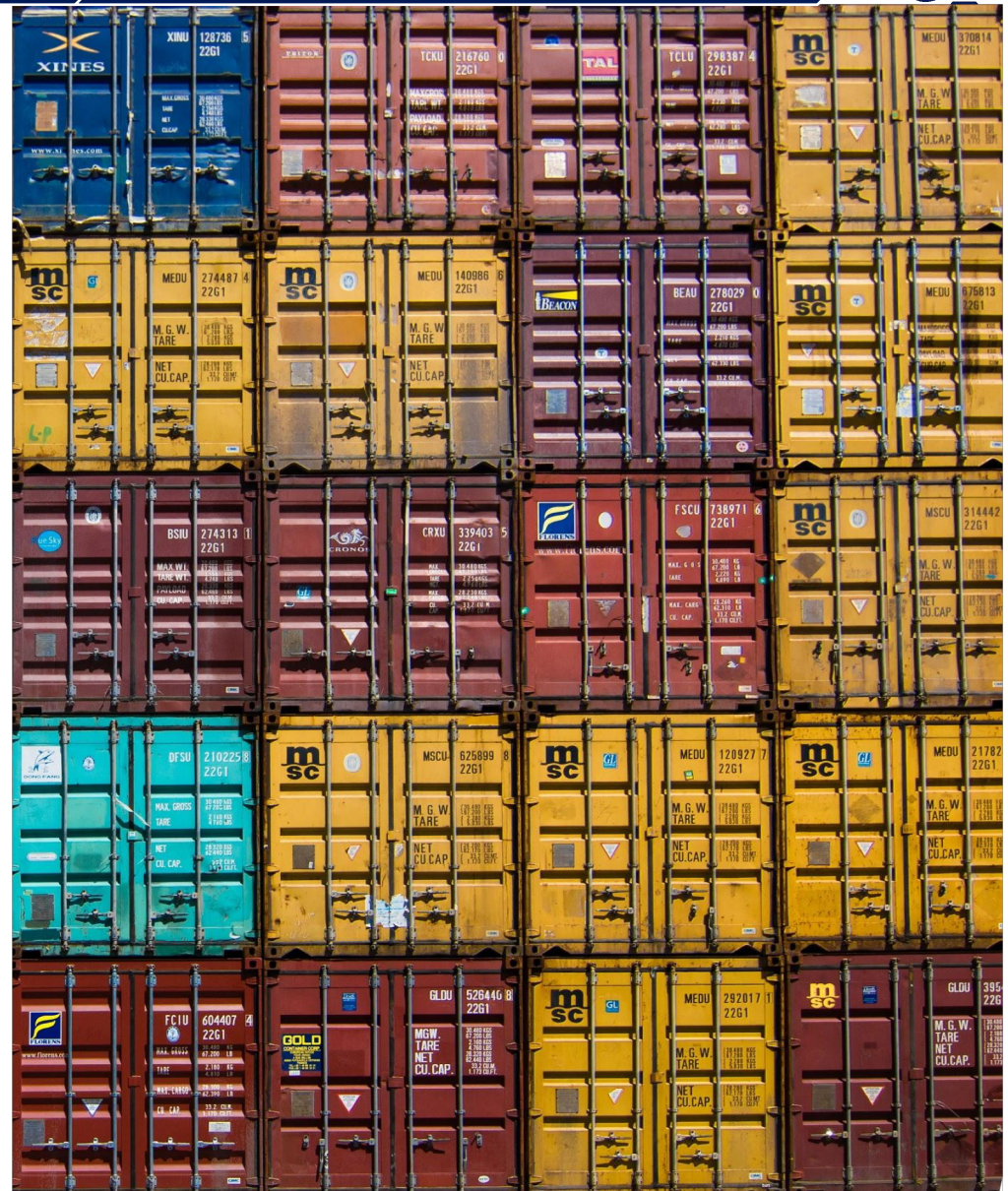


Build to show value > Build to integrate > Build to scale

Sepsis DAGs:

- 1728 fetch + clean tasks per day (q5m)
- 288 Clinical heuristic runs per day (q5m)
- 24 Model runs per day (q1h)
- 1 Quality Control log scan (q24h)
- 1 Log cleanup job (prn)

Photo by [Guillaume Bolduc](#) on [Unsplash](#)





Build to show value

Build to integrate

Build to scale

With hundreds of simultaneous tasks. How do we prevent:



Build to show value

Build to integrate

Build to scale

With hundreds of simultaneous tasks. How do we prevent:





Build to show value

Build to integrate

Build to scale

Queues!





Message Queues!

for Resilience & ...More Isolation

- Holds tasks until resources are available to complete them
- Lets Airflow schedule tasks to specific **queues**.
- Workers assigned to **queues** based on the code they can run
- Schedule 100s of tasks and run them 4-5 at a time.
- **Enables Scaling through Adding Workers**

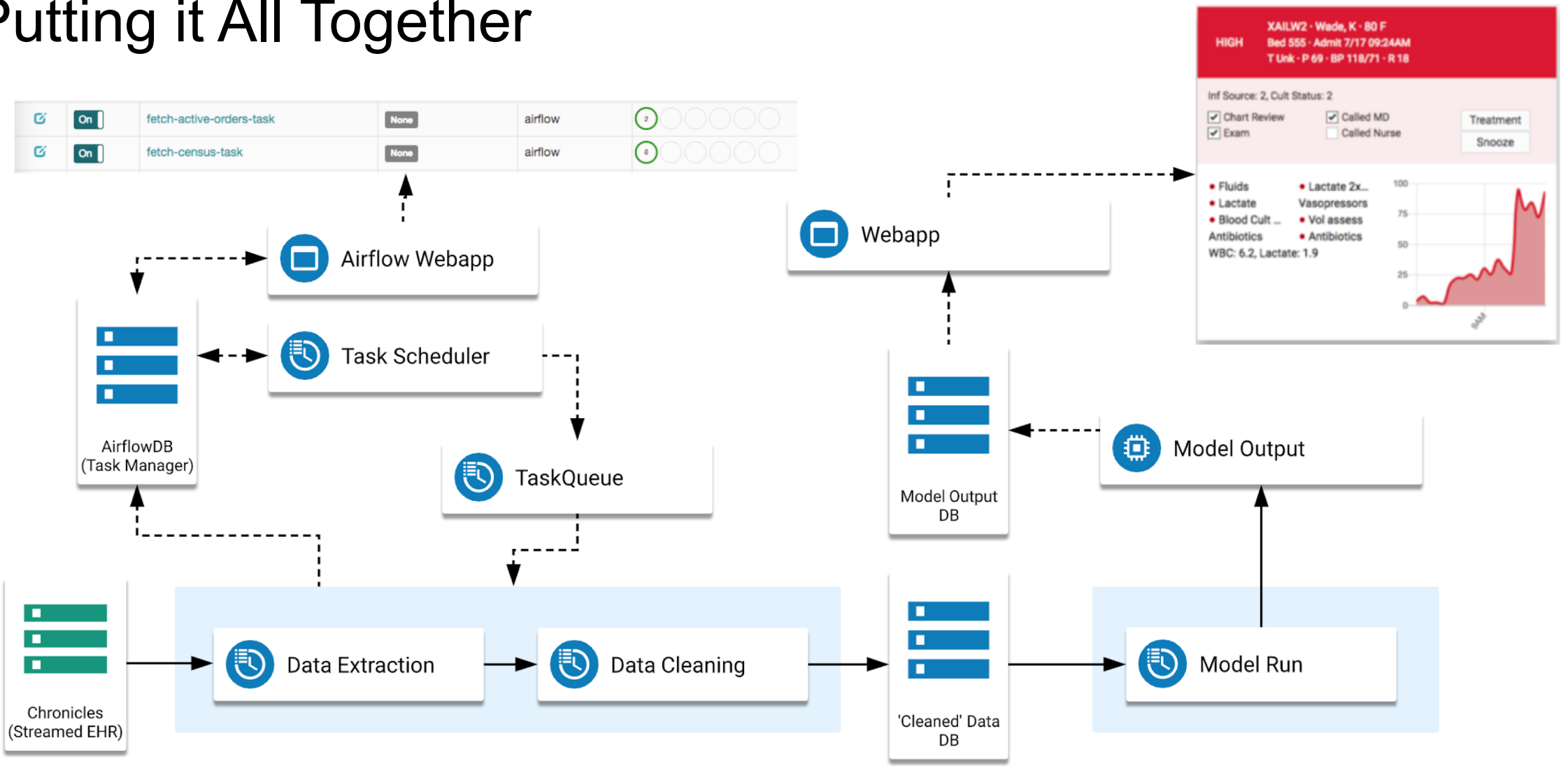


Control of Workload!



Build to show value > Build to integrate > Build to scale

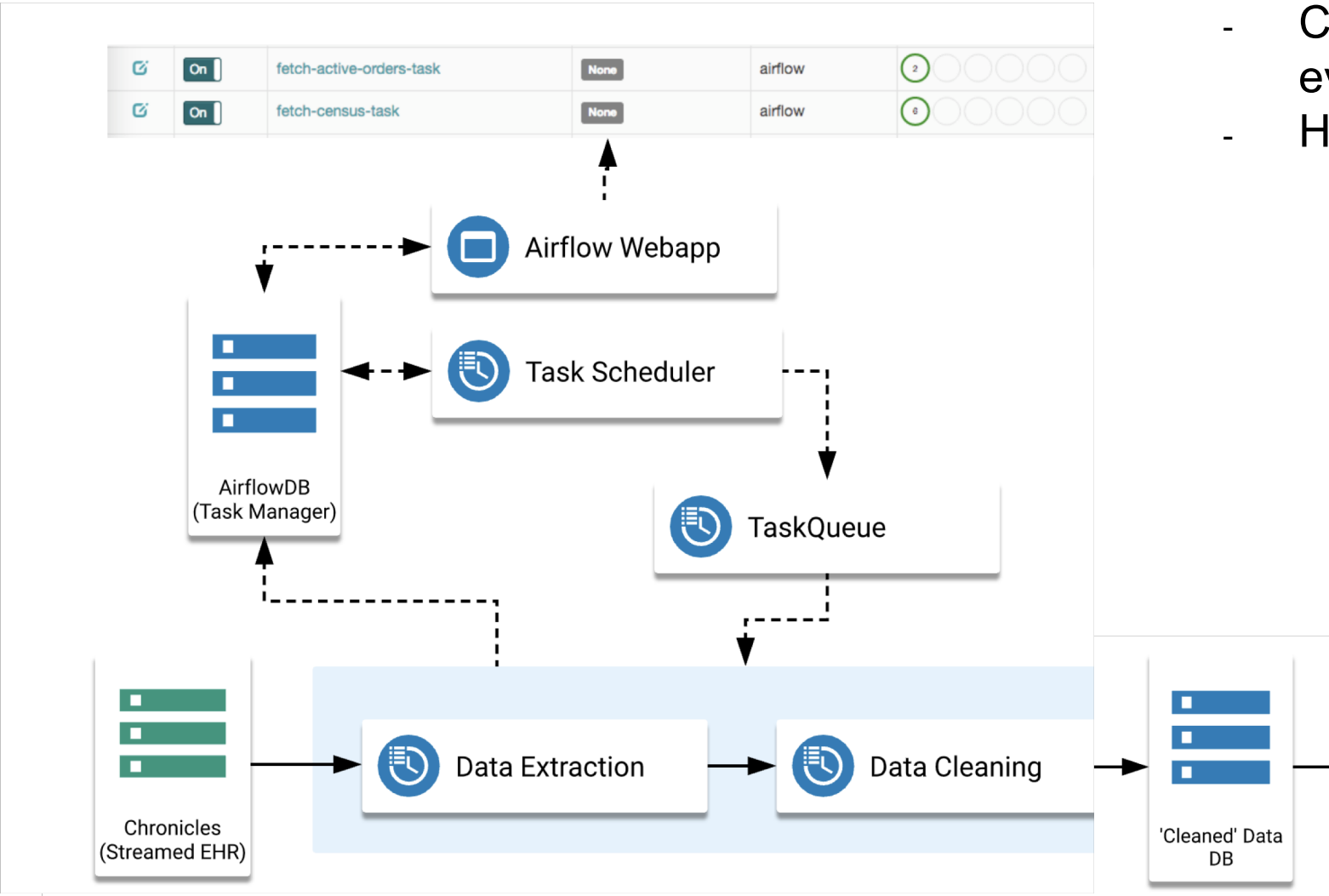
Putting it All Together





Build to show value > Build to integrate > **Build to scale**

Together at Scale



- Common structure used for everything
- How do I add a new model?



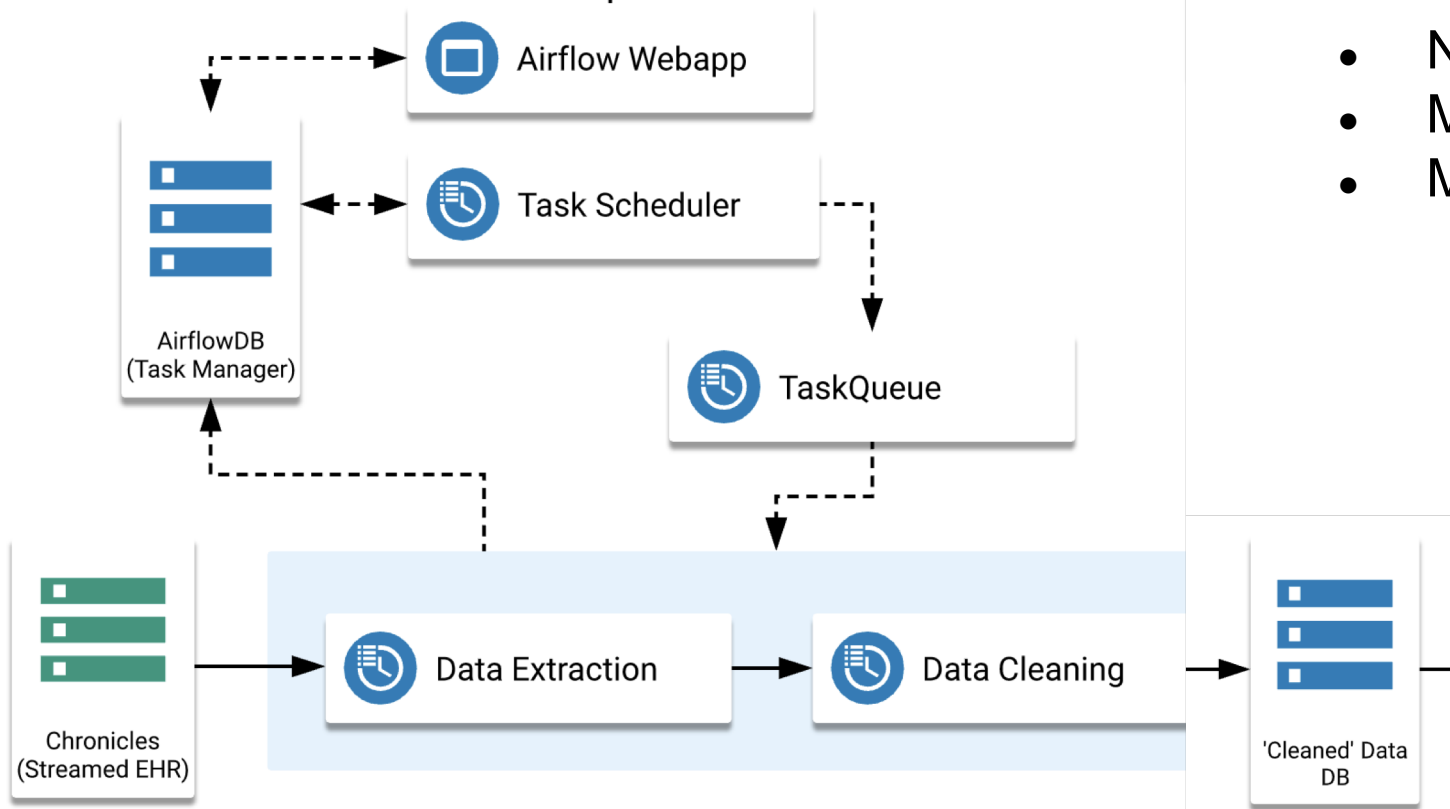
Build to show value

Build to integrate

Build to scale

Together at Scale

<input checked="" type="checkbox"/>	<input type="checkbox"/>	fetch-active-orders-task	None	airflow	2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input checked="" type="checkbox"/>	<input type="checkbox"/>	fetch-census-task	None	airflow	8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

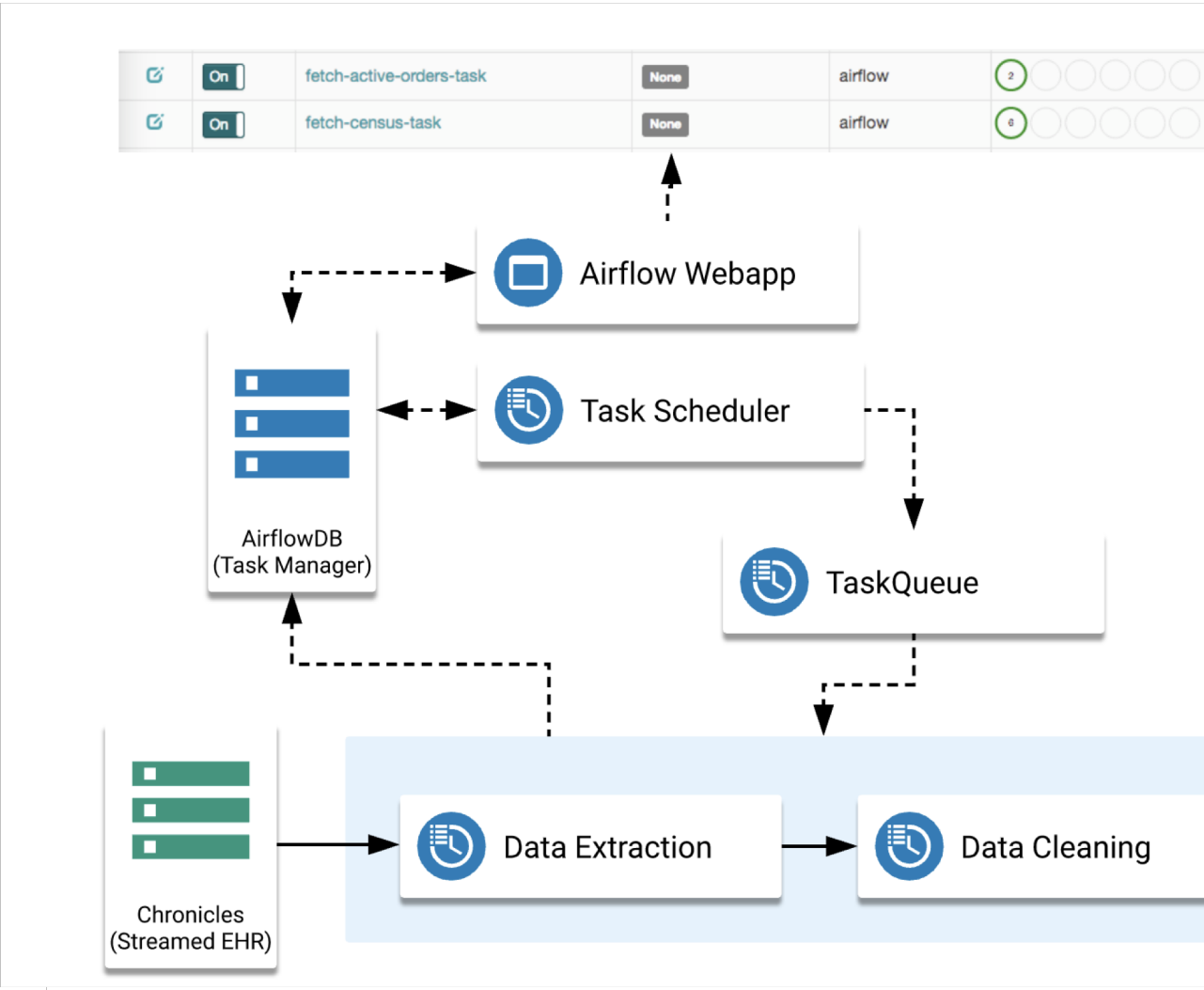


- Common structure used for everything
- How do I add a new model?
 - New DAG / execution task list
 - Maybe a new Message queue?
 - Maybe a new Worker Container?

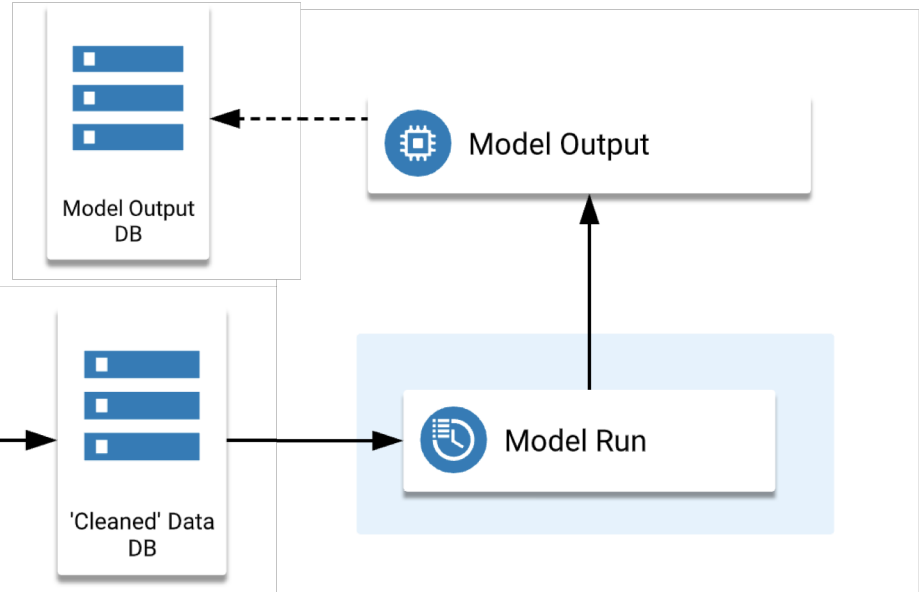


Build to show value > Build to integrate > Build to scale

Together at Scale



- Common structure used for everything
- How do I add a new model?
- New Model Output Database
- All Codified, Version Controlled and Trivial to build up and tear down





Build to show value

Build to integrate

Build to scale

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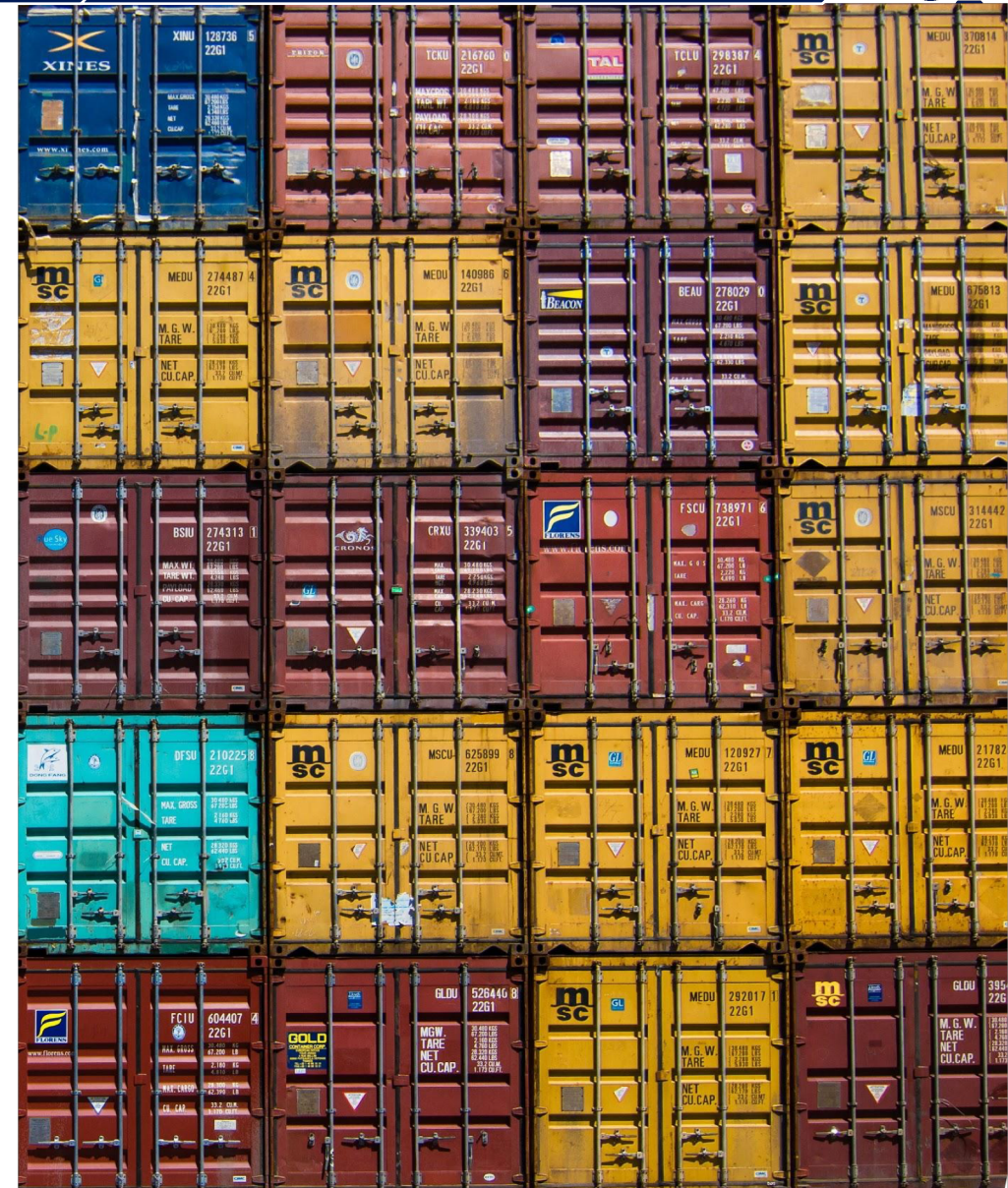


Photo by [Guillaume Bolduc](#) on [Unsplash](#)



Build to show value

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Sepsis DAGs:

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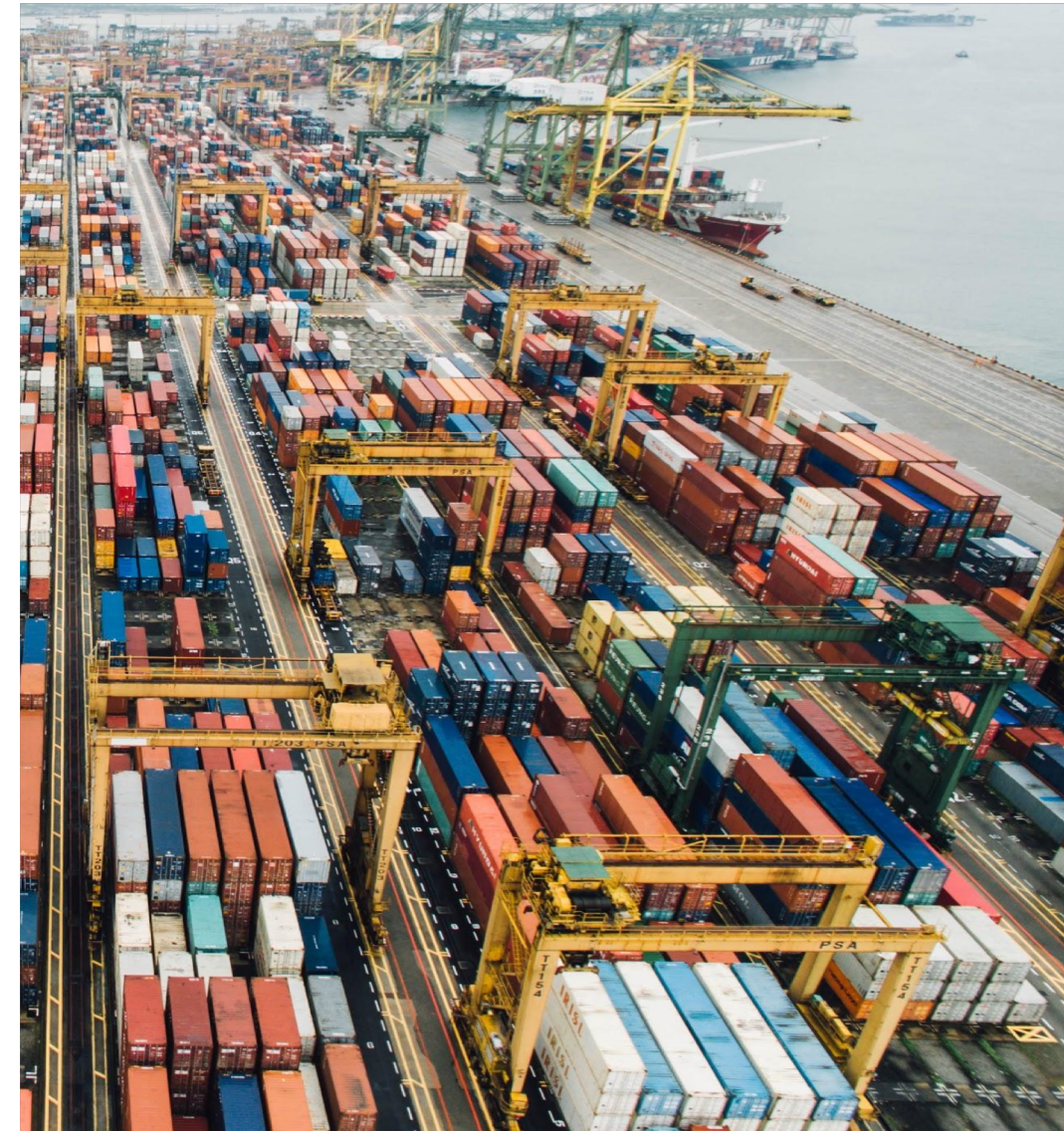
Prepared to scale:

Hyperglycemia

Adult
Decompensation

Inpatient
Mortality

Pediatric
Decompensation





Build to show value

Build to integrate

Build to scale

Challenges in Implementation



Build to show value

Build to integrate

Build to scale

Research Code is not Production Code



Build to show value

Build to integrate

Build to scale



VS





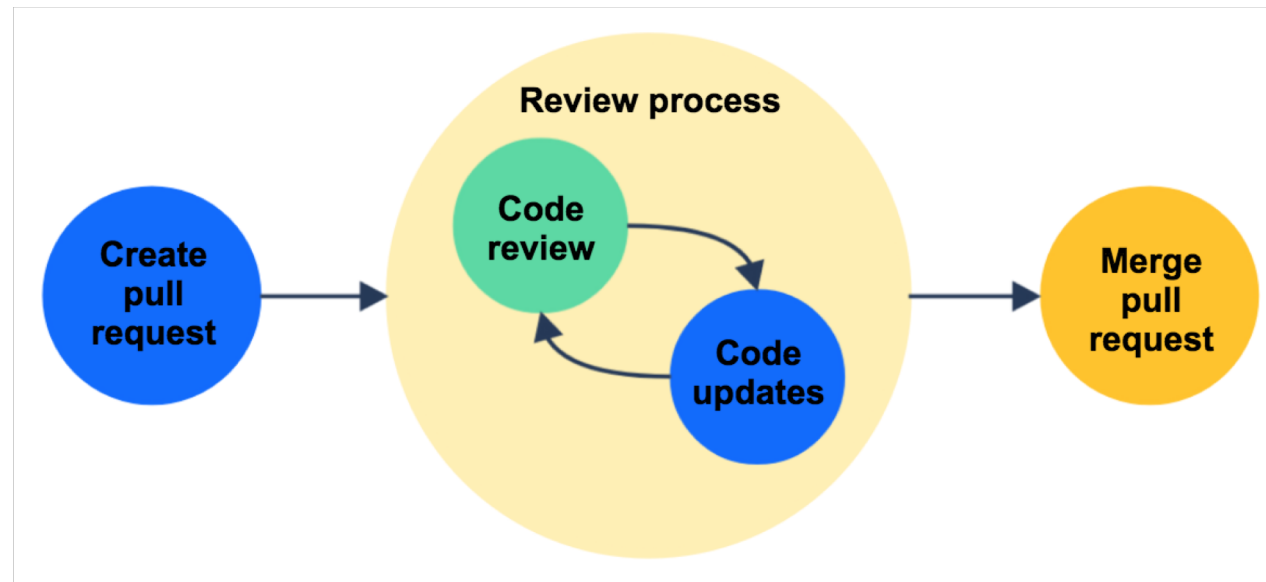
Build to show value

Build to integrate

Build to scale

Code Reviews / Unit Testing / Integration Testing

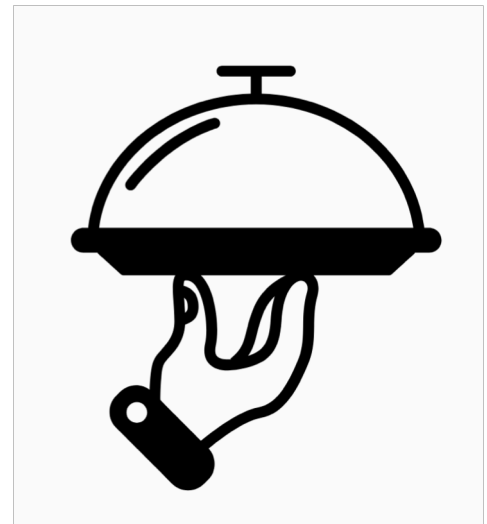
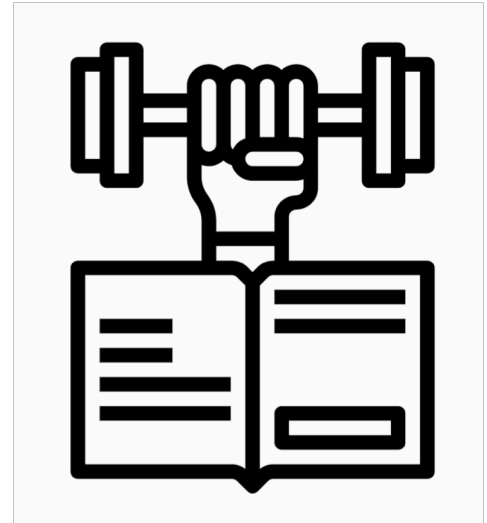
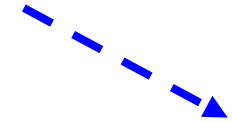
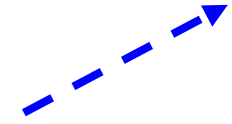
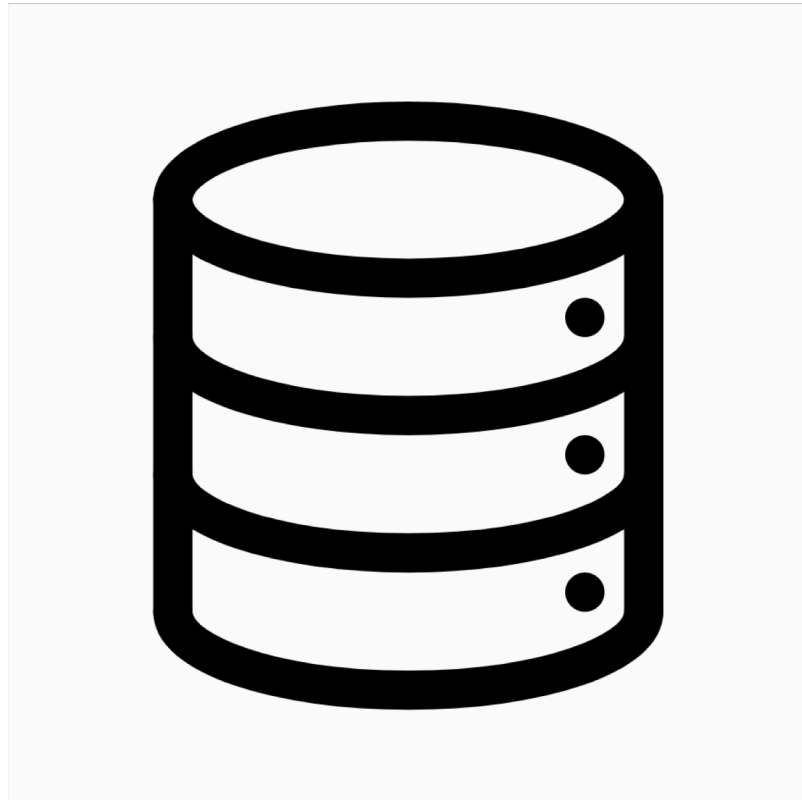
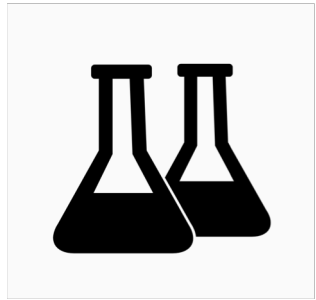
- Keep users in mind
 - Sepsis: Nurses see more risk scores than anyone
- Build confidence
 - If your model doesn't break, people are more likely to trust future implementations
- Instituted a policy for code reviews and testing
 - The more eyes, the better





Build to show value > Build to integrate > **Build to scale**

Feature Stores





Build to show value

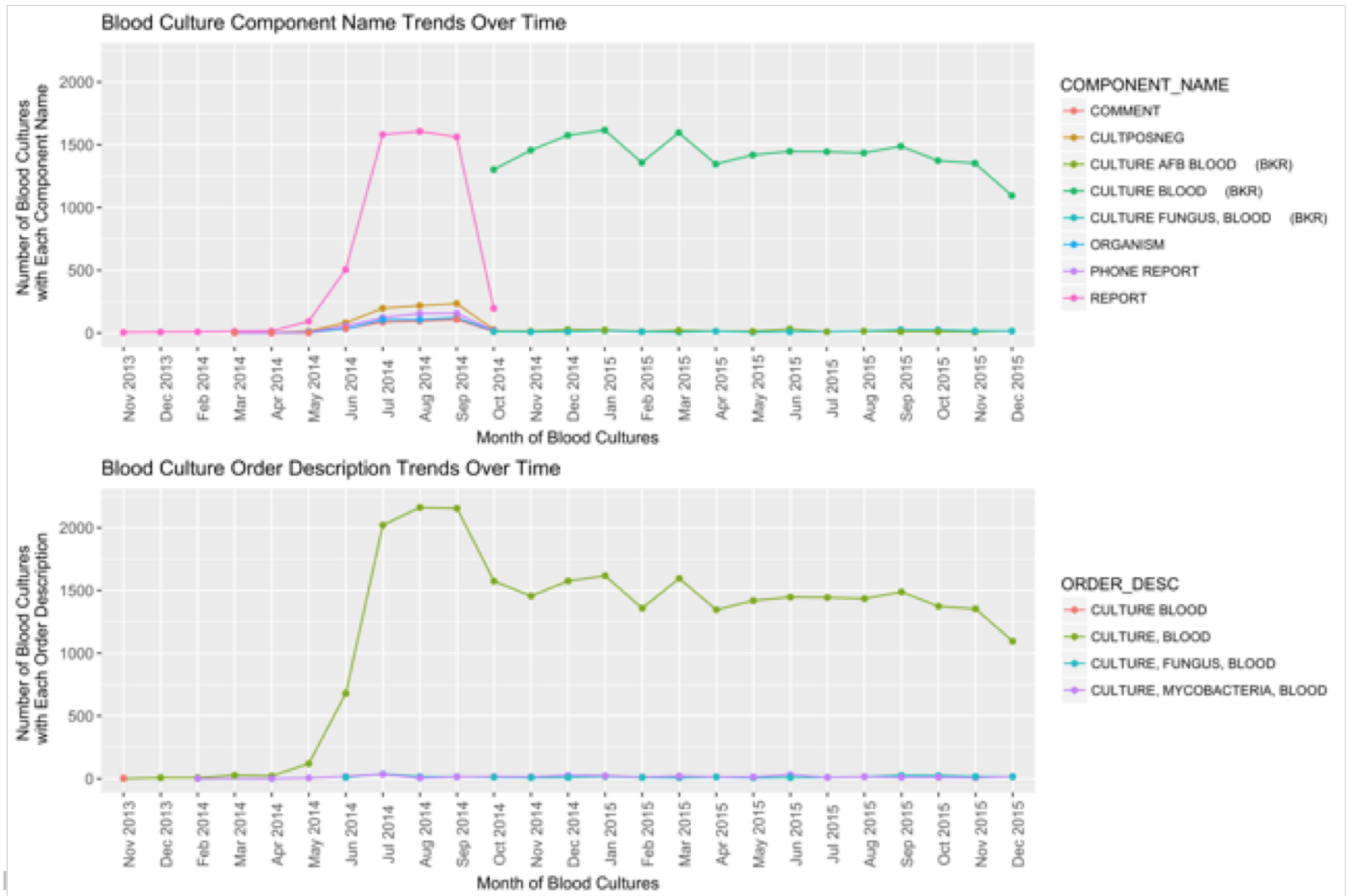
Build to integrate

Build to scale

The EHR is not static (or clean)



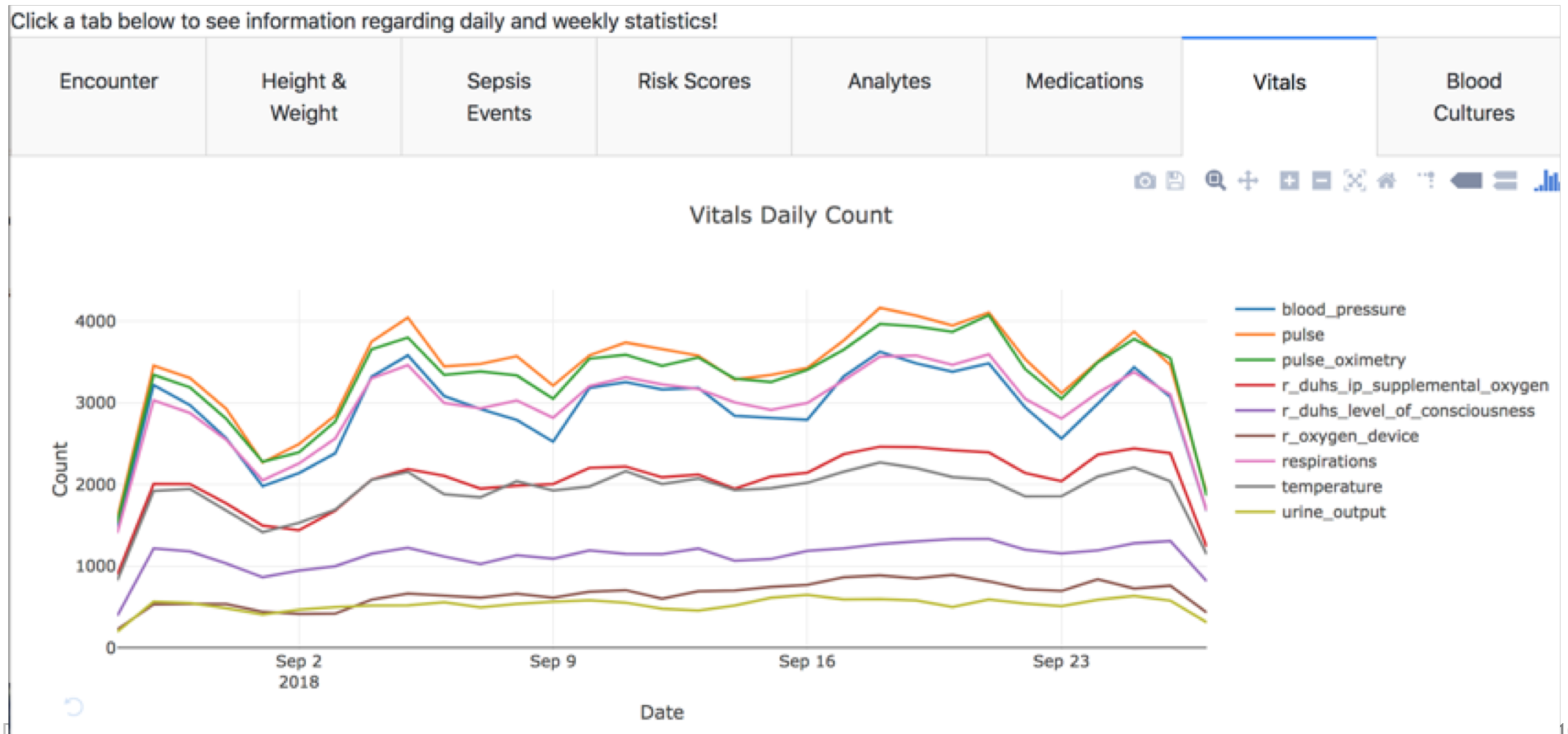
Blood Cultures Disappeared!





Build to show value > Build to integrate > Build to scale

Input Monitoring





Build to show value

Build to integrate

Build to scale

System Status

Most Recent Analyte

September 27 2018 at 10:34 AM EDT-0400

Most Recent Risk Score

September 27 2018 at 10:02 AM EDT-0400

**Most Recent Encounter Meeting
Sepsis Definition**

September 27 2018 at 03:08 AM EDT-0400

Most Recent Med Admin

September 27 2018 at 10:39 AM EDT-0400

Most Recent Blood Culture

September 27 2018 at 09:47 AM EDT-0400

Most Recent Vital

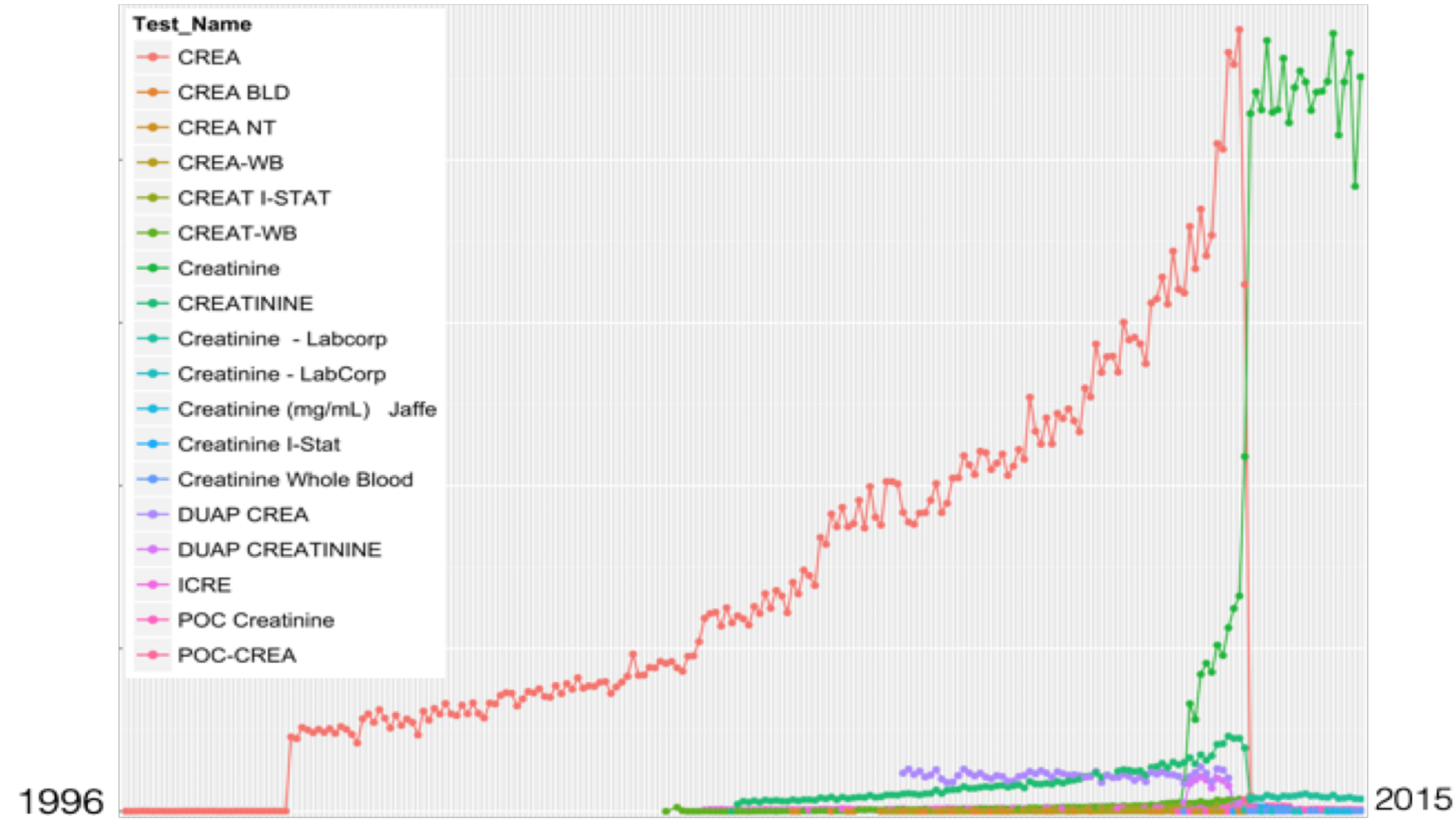
September 27 2018 at 10:37 AM EDT-0400

Most Recent Encounter Start

September 27 2018 at 10:38 AM EDT-0400



Entity Resolution





Build to show value

Build to integrate

Build to scale

Unit Conversion

VITAL_NAME	VALUE	UNIT
DUHS WEIGHT AFTER BREASTFEEDING	304	Oz
DUHS_WEIGHT	205	lb
R WEIGHT SCALE	60	kg
R WEIGHT SCALE	100	lb



Build to show value

Build to integrate

Build to scale

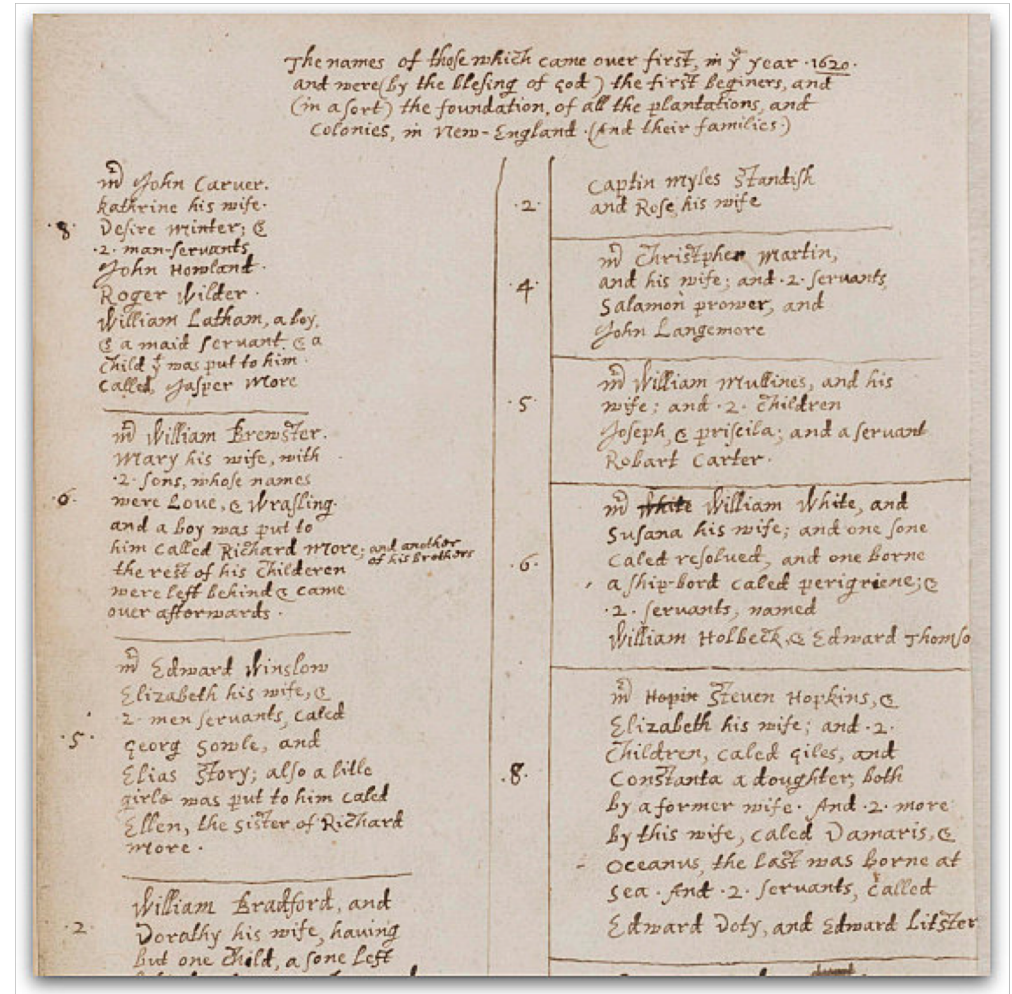
Keeping Track of Models and their Metrics



Tracking Model Versions / Performance

Model Manifests

- All models write to their own tables
- A model manifest must contain version numbers, input data requirements, structure of inputs, etc.
- All model metadata is kept with model results





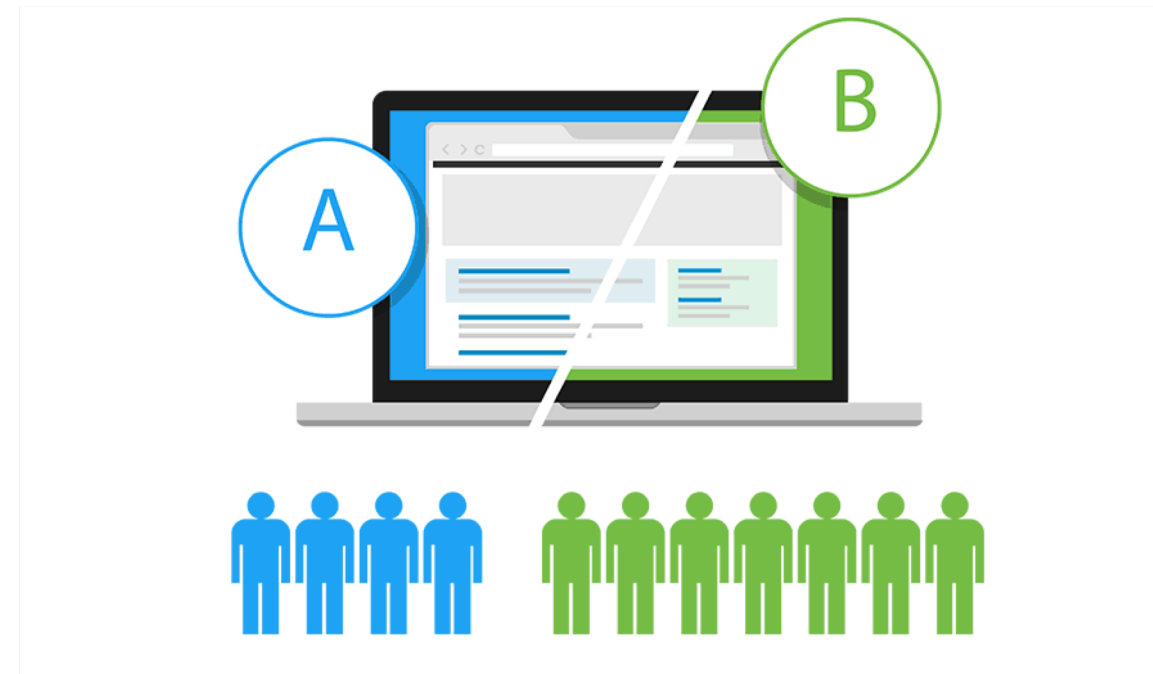
Build to show value

Build to integrate

Build to scale

Metrics Tracking

- Continuous Performance Evaluation
- Outcome distribution remains relatively static
- Can directly compare multiple models against each other





Build to show value

Build to integrate

Build to scale

Where does this leave us?

If you are developing a new model:

- Can leverage existing production-ready code to build your features
- Use existing cleaned data (conversion of units, grouping into clinical concepts)

Once you are done fitting the model:

- Generate a model manifest
- Create a container to run the model
- Request code review



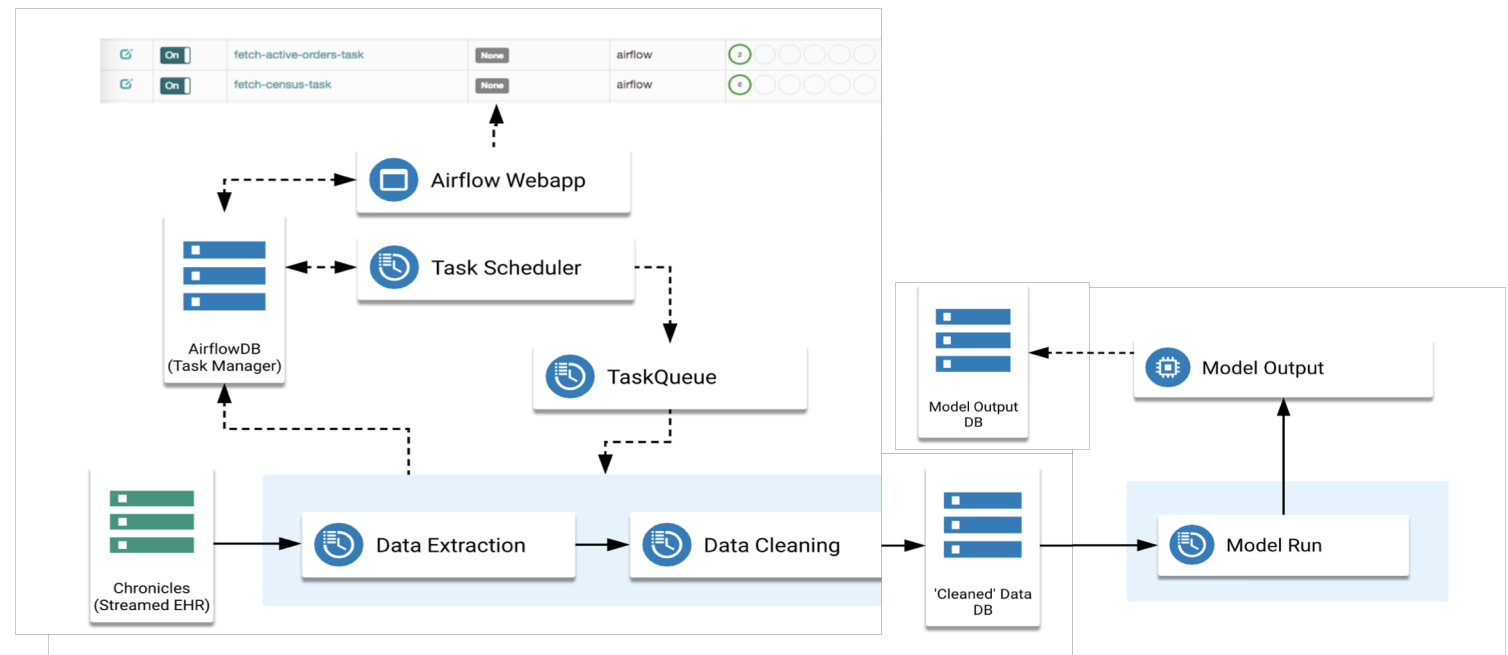
Build to show value

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Build to scale

Once your model is running...

- Collect metrics as it runs in silent mode (Real-time / Scheduled)
- Work with clinical team to pilot implementation
- Make results available to dashboards
- Evaluate!





Build to show value

Build to integrate

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Models currently in production

- Sepsis Watch
- Several posters at this conference!
 - Inpatient and 30-day mortality
 - Steroid-induced hyperglycemia
 - Cardiogenic Shock risk prediction
 - More to come!



Wrapping Up



DIHI's Guiding Principles

Build to show value

Build to integrate

Build to scale

Build Responsibly



Our Vision

- We are all here for the same reason
- We believe that we can build systems and frameworks that enable true innovation
- Thoughtful machine learning solutions will be ubiquitous
- We will help to improve:
 - Patient Experience and Outcomes
 - Population Health
 - Cost of care



Thank you!

