Building a Medical IoT Platform for a Learning Healthcare System: A Case Study in Systems Engineering

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User Requests

"We need complete, accurate and contextually aware data"

"Health data must be contextually aware"

"We need to change what is expected of technology in healthcare"

"Why can't this be automatically put in the medical record?"

"Why can't I manage my devices remotely?"

"Why can't I pause an infusion pump when the person is overdosing?"

"Can I know in real-time how many ventilators I have?"

"I need to keep a patient alive for 5 days without a doctor present with what I carry in my backpack"

"how do I take my 30 years of experience and use it to help a new physician provide high quality healthcare?"

"I want to monitor every patient at every bed in every country I have a hospital"

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Problems

J. Goldman, MD MGH

- Architecture
- Data
- Process

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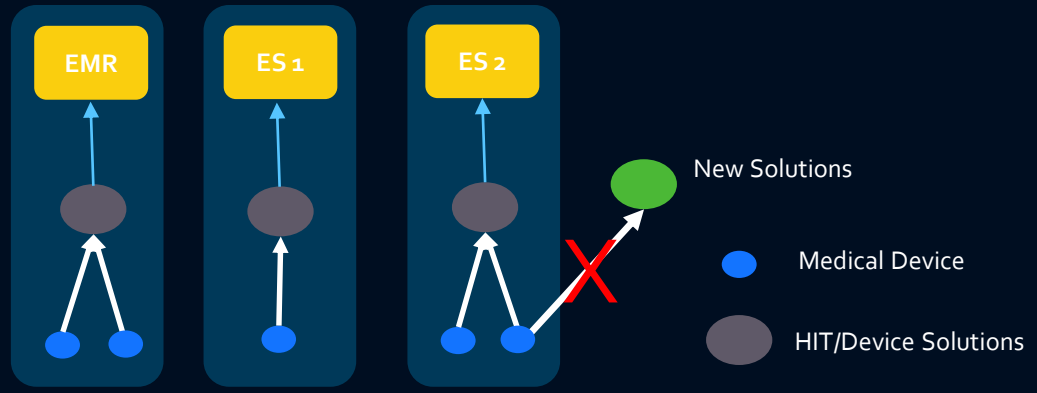
Architecture



- Device, point solutions and EHR are proprietary and vertically integrated.
- Integration is expensive, complicated & incomplete
- No way of bringing the data back to innovate

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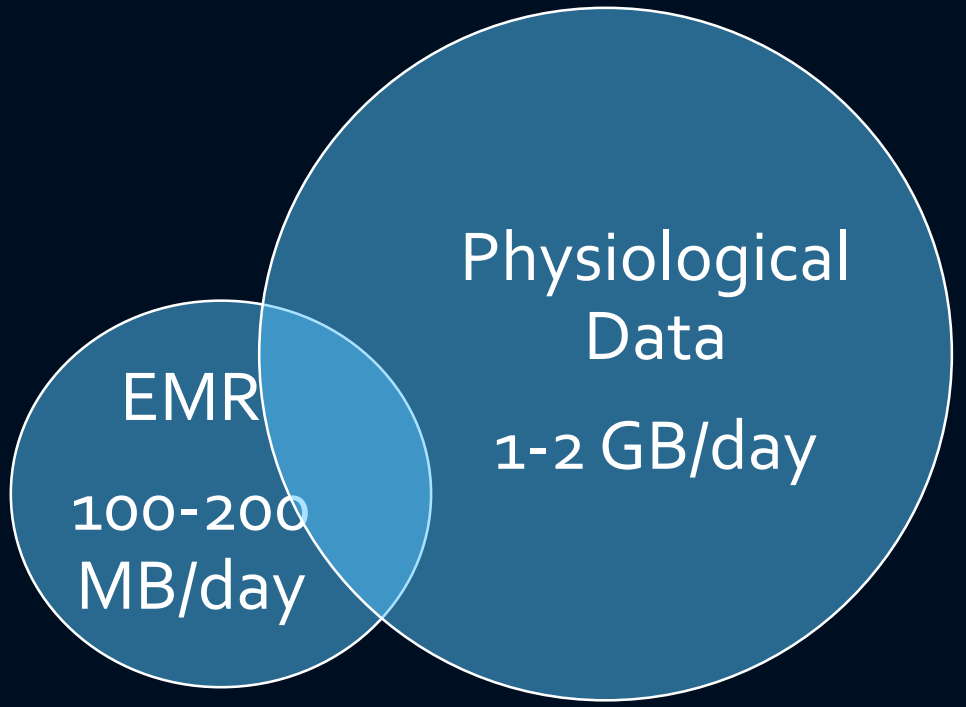
Data

- EMR data is infrequent
- Poor data quality
- Proprietary vertically integrated data creates analytics and clinical solution challenges
- Lacks consistent time stamps
- Lacks contextually complete data



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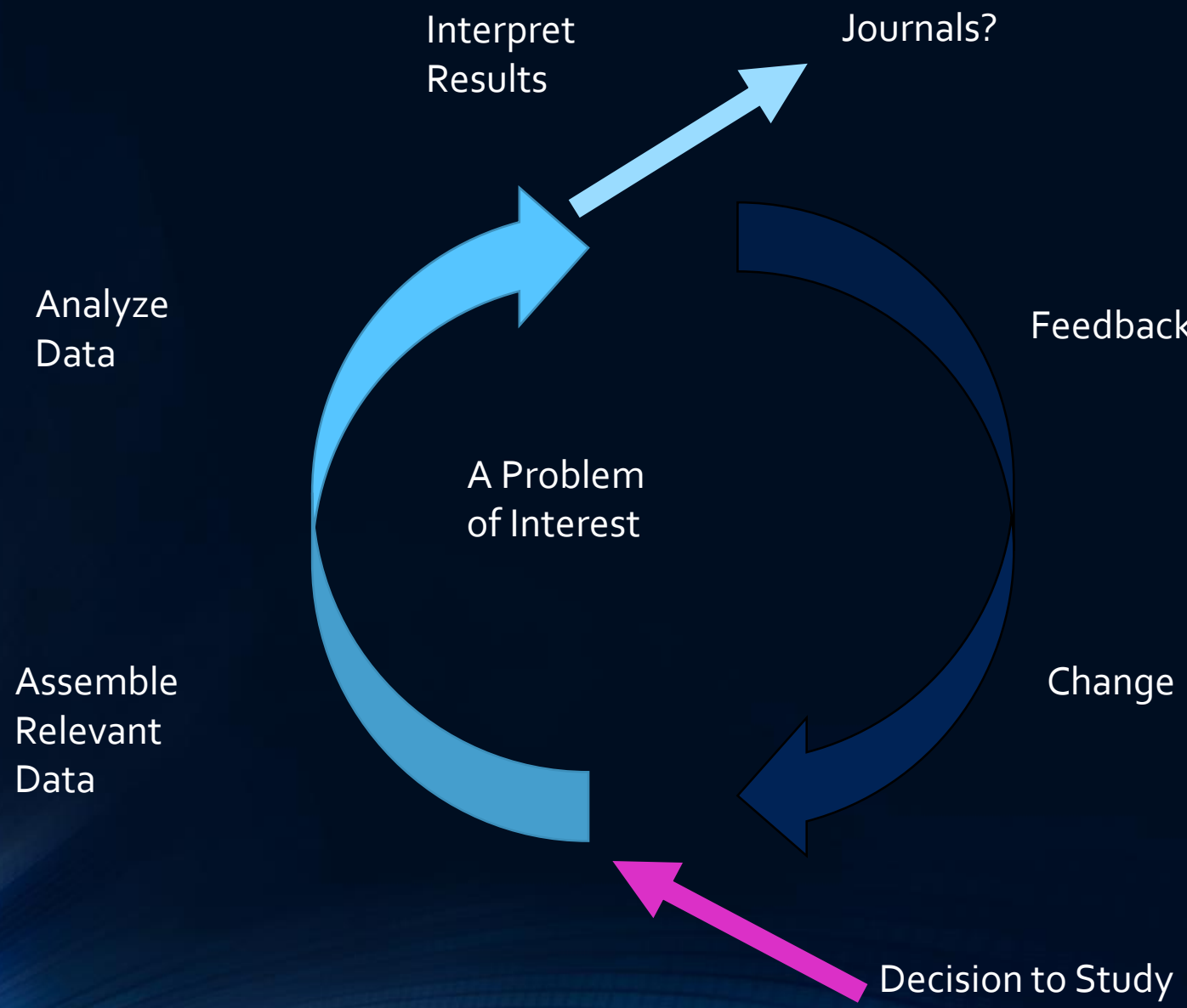
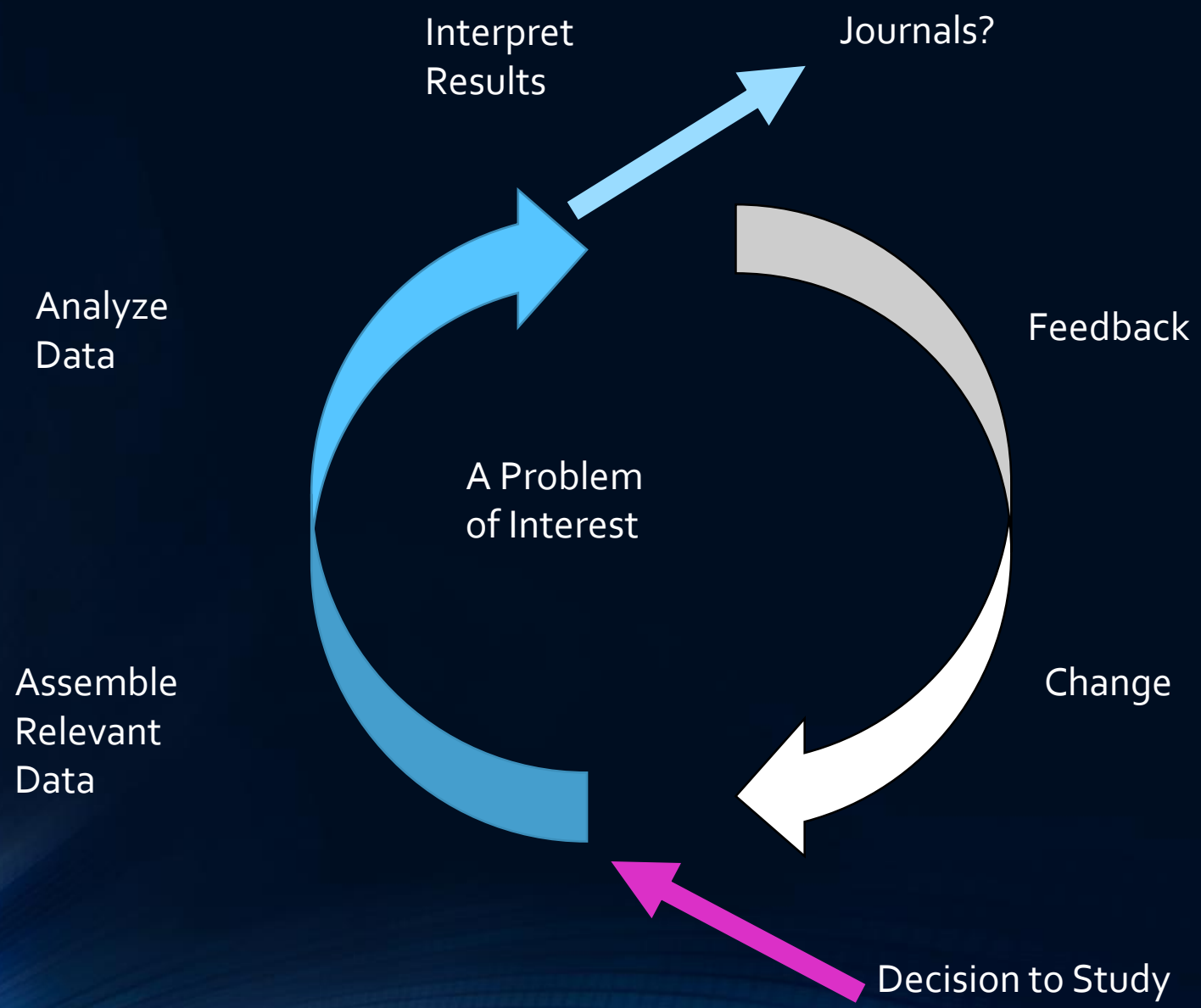
Process



http://www.learninghealthcareproject.org/section/background/learning-healthcare-system

Process



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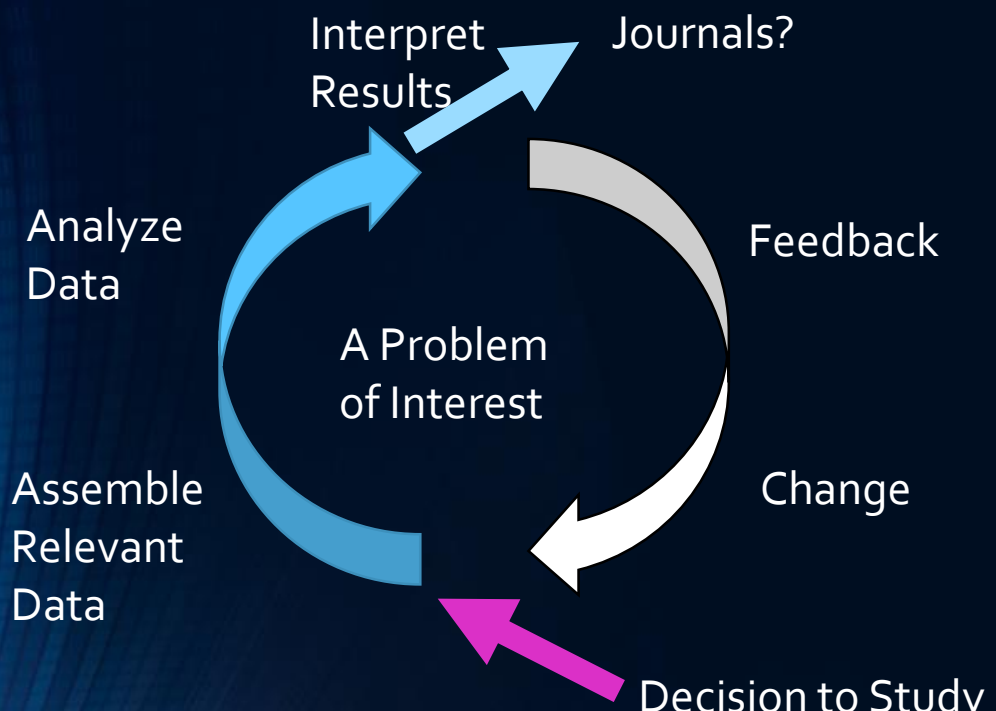
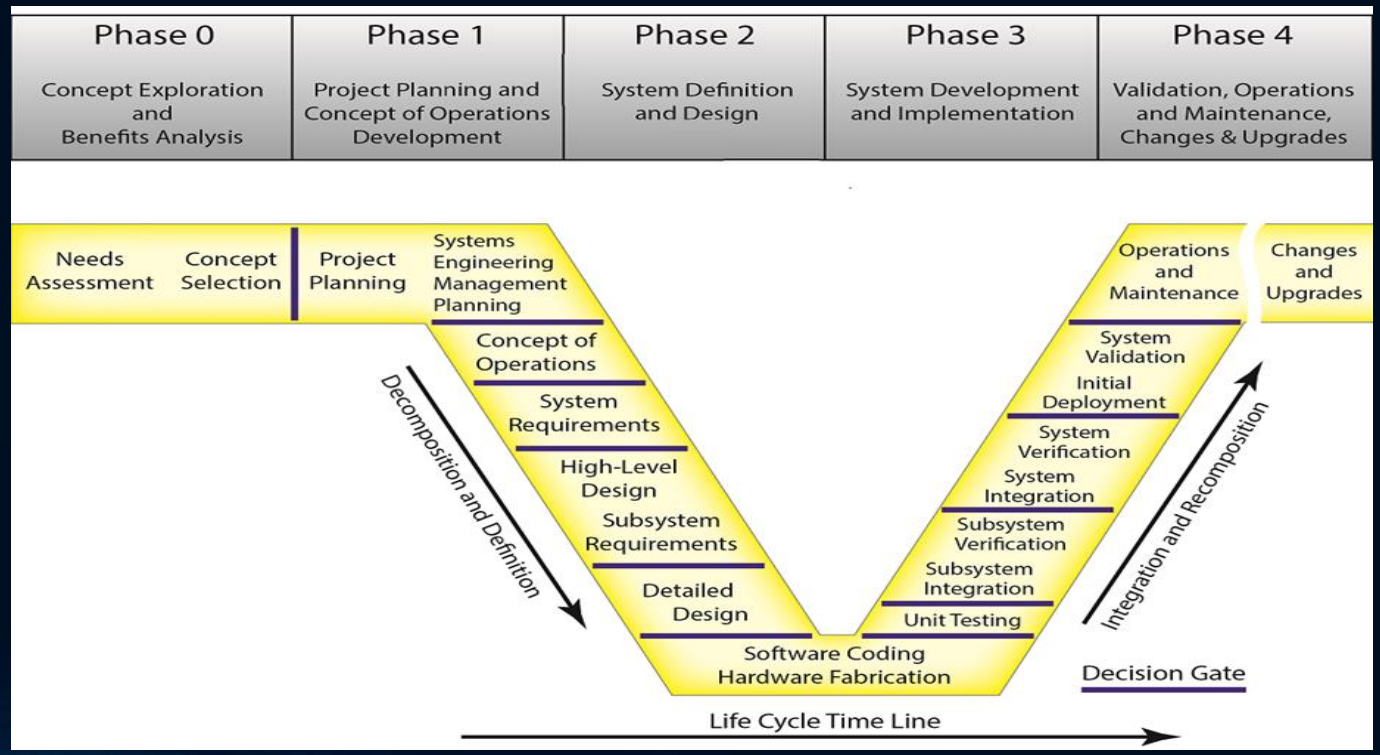
Learning Healthcare System + Systems Engr





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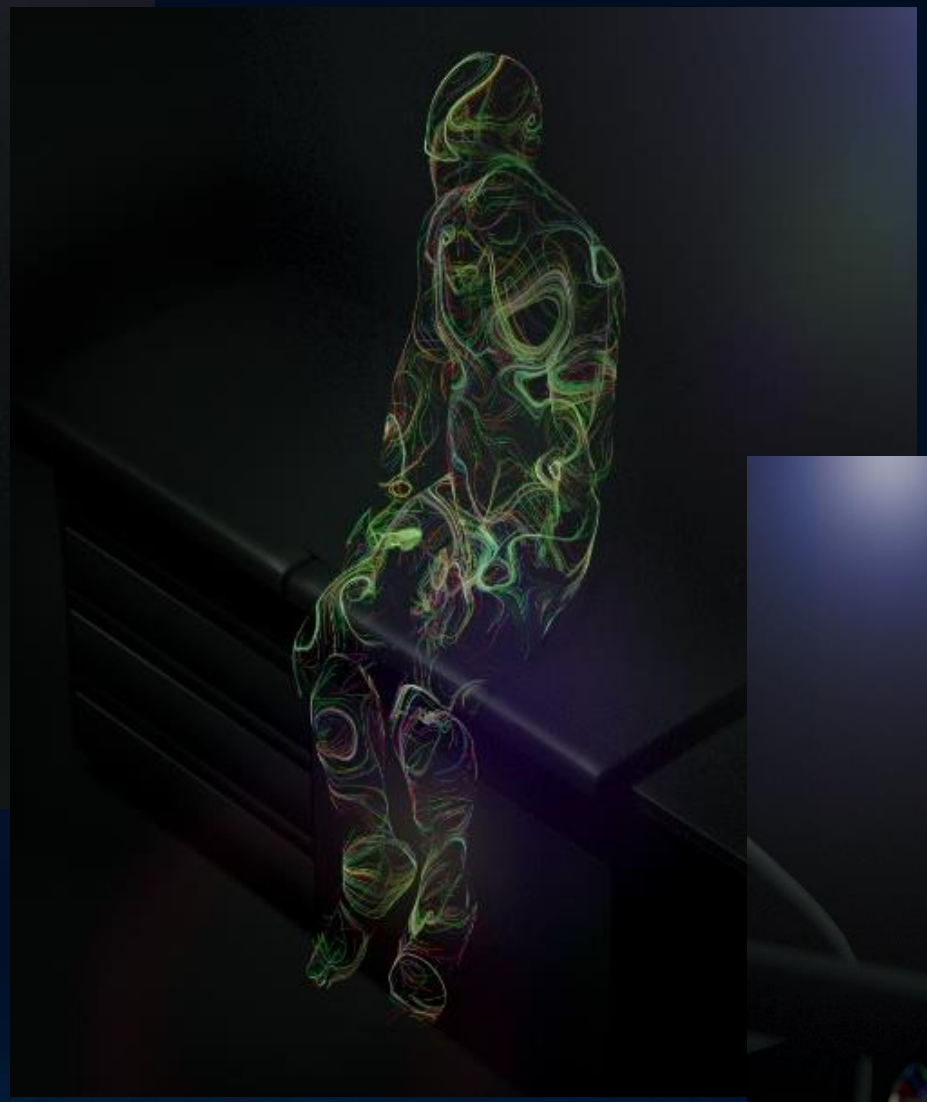
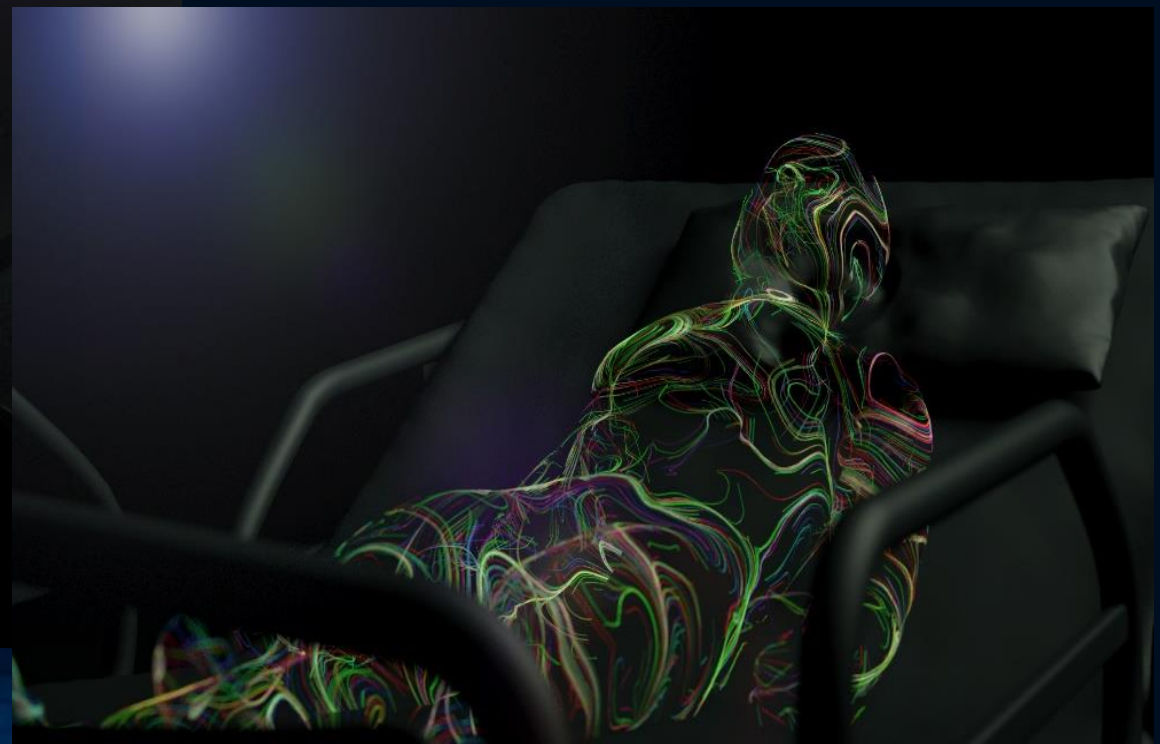
Patient Centered
(Patient is the Source of Data)





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How Do You Close the Loop?

- Using an ICE architecture highly granular patient data can be collected (ASTM F2761)
  - ~1.5 – 2 GB per day per critical care bed
- Data is collected from multiple devices in a vendor agnostic, data centric, structured data model
- Data can be used for real-time and historical analytics
- Data can be viewed from both a clinical and operational perspective

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Clinical Data View

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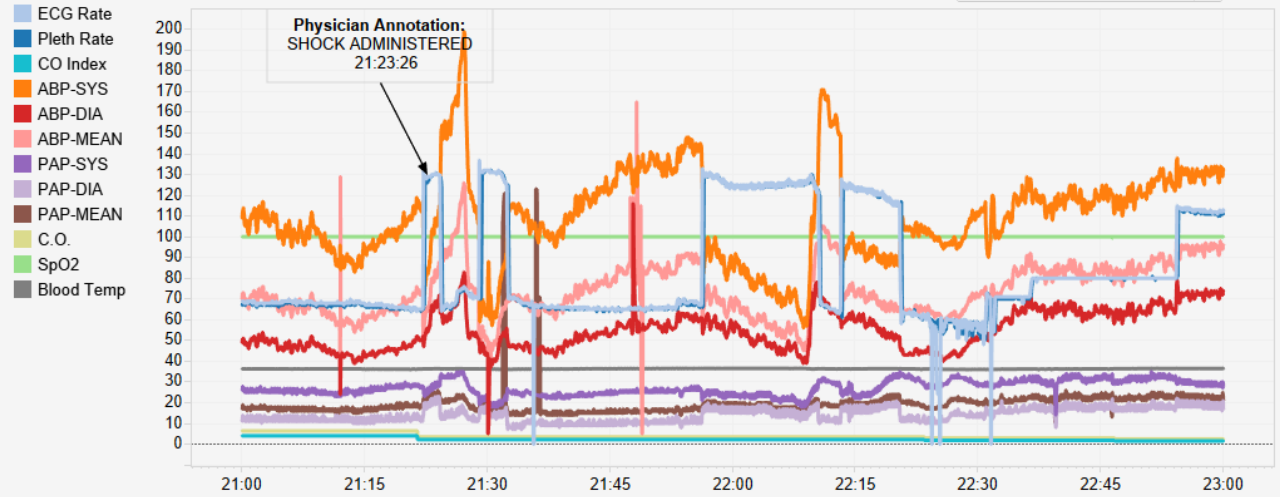
Date & Time August 24, 2016 9 PM — August 24, 2016 10 PM

Back to Patient Info | View Alarms

PATIENT MM1234567 Name: Smith, Joan
Sex: F Age: 74Y Location: ICU2 Bed 33

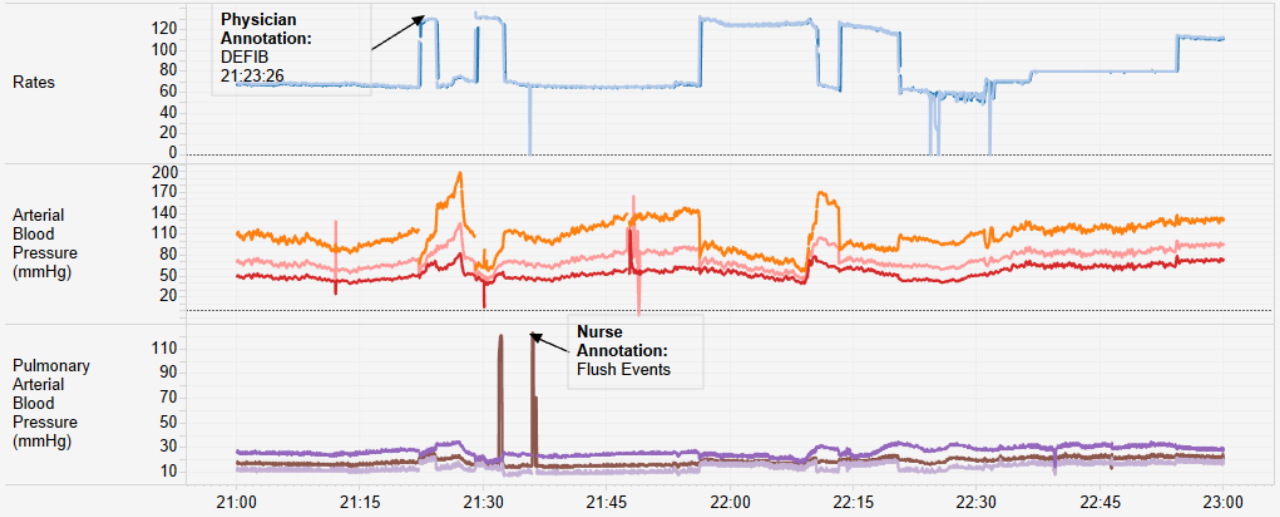
Clinical Trends Graph

Select values to view in Clinical Trends View: (All)



Detailed View

Select values to view in Detailed View: (Multiple values)



Ventilator Settings

Vent Mode: SIMV-VC

(All)

Mech RR	12.0				
Trigger Window	25.0				
End Flow	25.0				
Pressure Rise T..		100.0	100.0	100.0	100.0
Pmax	30.0	30.0	30.0	30.0	30.0
PSV Rise Time	50.0				
FiO2	50.0	50.0	50.0	50.0	50.0
Tube Size	7.5	7.5	7.5	7.5	7.5
Nebulizer Time	15.0	15.0	15.0	15.0	15.0
Pt Weight	70.0	70.0	70.0	70.0	70.0
Pt Height	170.0	170.0	170.0	170.0	170.0
ARC Level	35.0	35.0	35.0	35.0	35.0
RR		12.0	12.0	12.0	12.0
	21:00	21:15	21:30	21:45	22:00

	22:15	22:30	22:45	23:00

Waveforms - *Select Values in Detailed View to View Relevant Waveforms*

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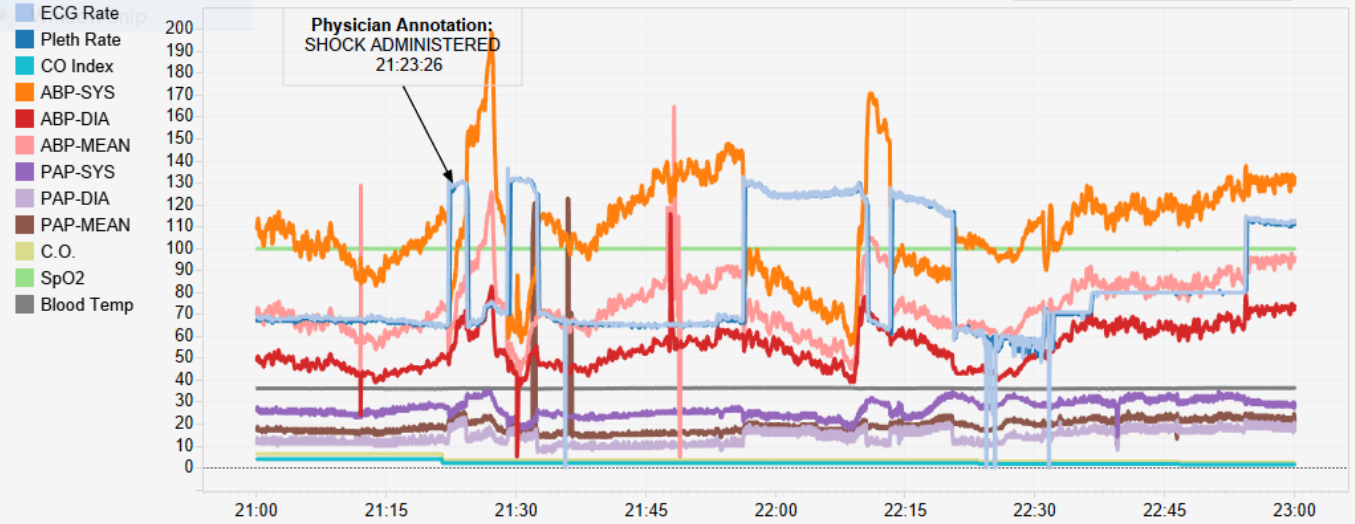

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Nebulizer Time	15.0	15.0	15.0	15.0	15.0
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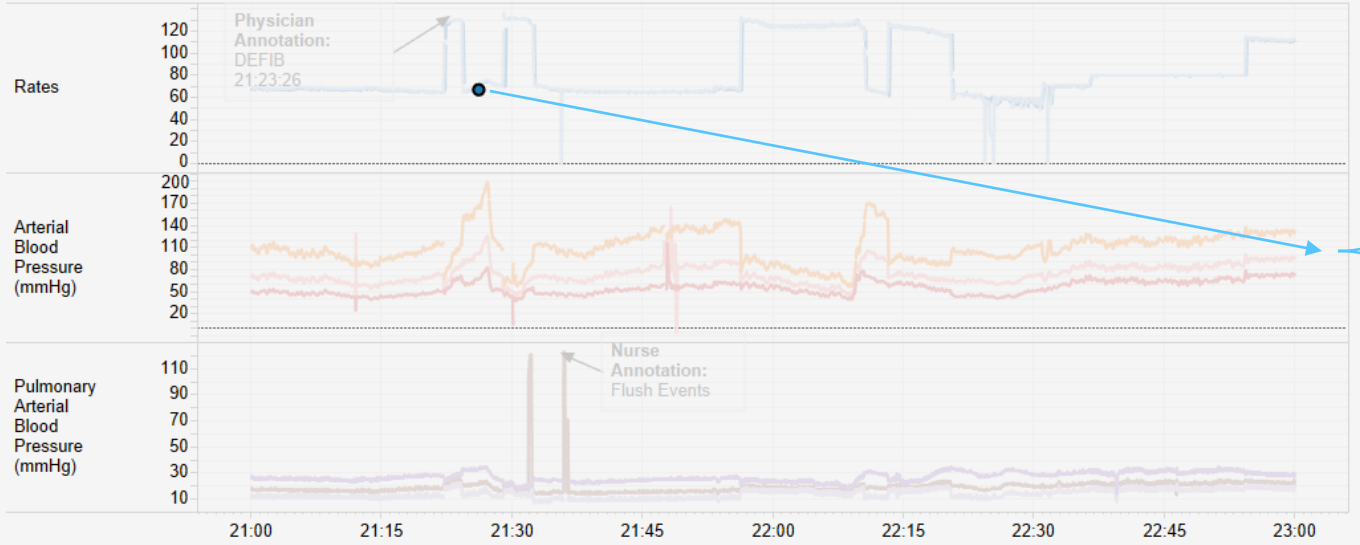
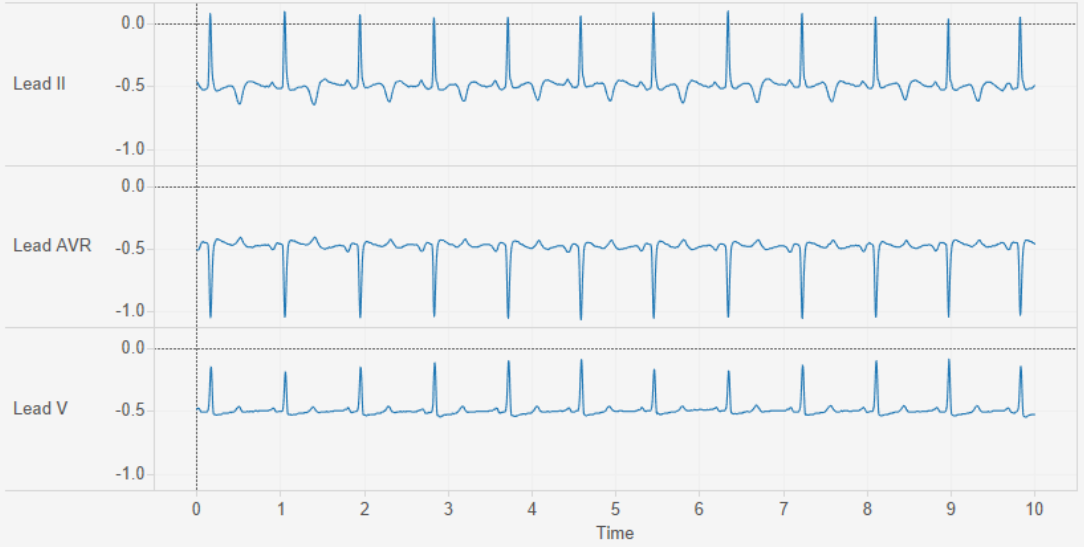


Waveforms - *Select Values in Detailed View to View Relevant Waveforms*



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View Trends & Waveforms | Back to Patient Info

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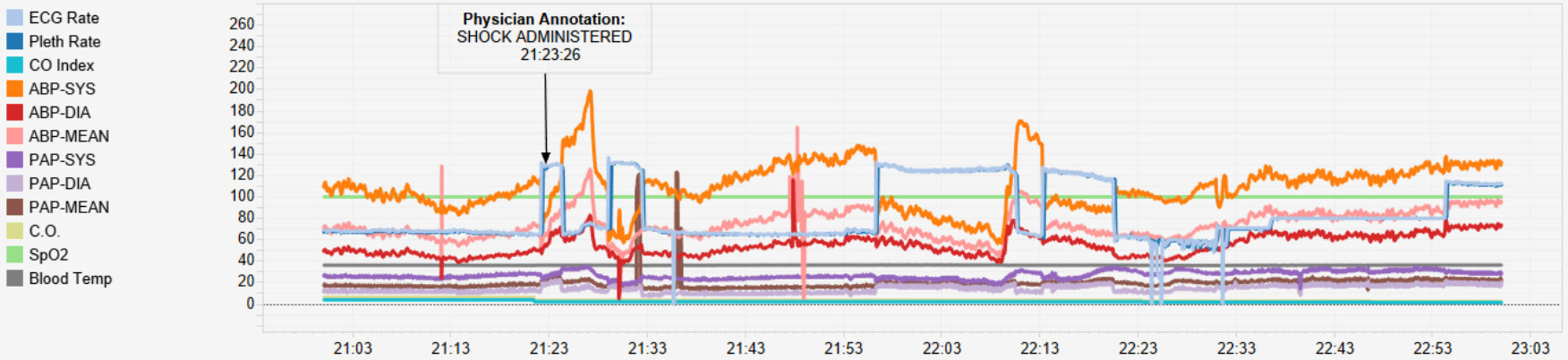
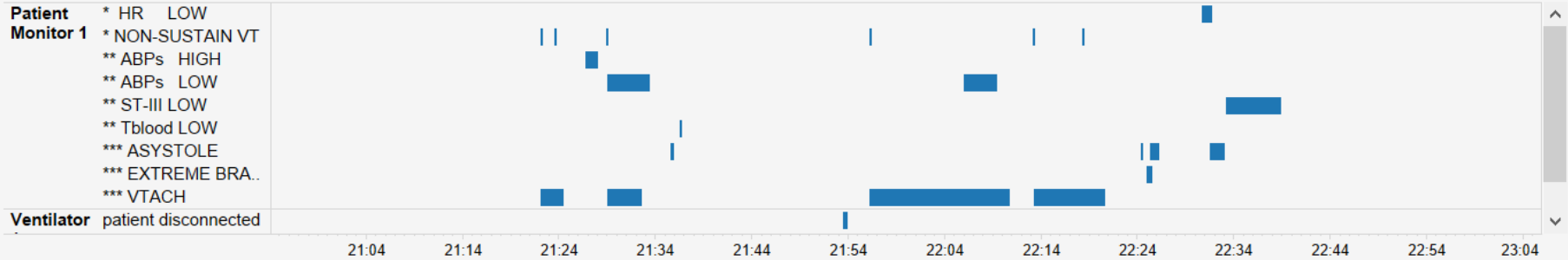
Clinical Trends Graph



Select values to view in Clinical Trends View: (All)

Physiological Alarms

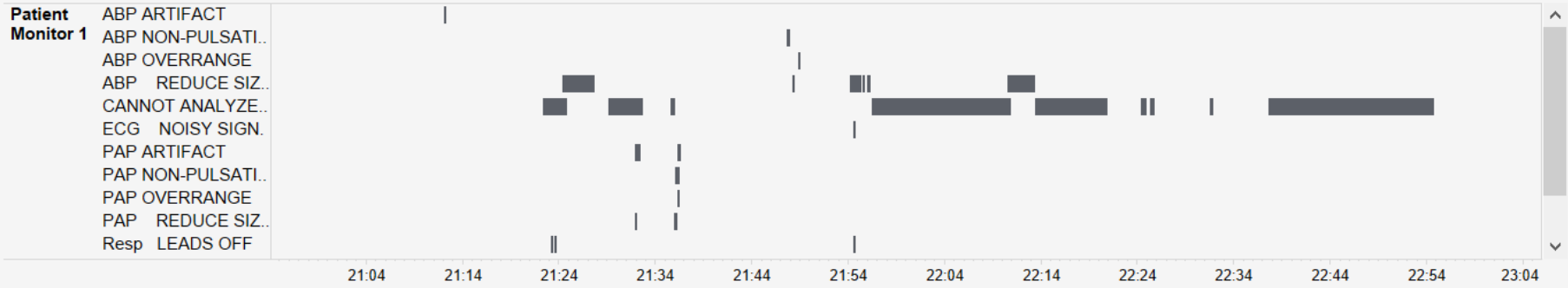
Select device to view alarms: (All)



Physiological Alarm Total Durations

Alarm Message	Device	Seconds	Hours
patient disconnected	Ventilator 1	2	0.001
plimit reached	Ventilator 1	4	0.001
* NON-SUSTAIN VT	Patient Monitor 1	7	0.002
** Tblood LOW	Patient Monitor 1	7	0.002
*** EXTREME BRADY	Patient Monitor 1	23	0.006
* HR LOW	Patient Monitor 1	50	0.014
** ABPs HIGH	Patient Monitor 1	66	0.018
*** ASYSTOLE	Patient Monitor 1	124	0.034
** ST-III LOW	Patient Monitor 1	321	0.089
** ABPs LOW	Patient Monitor 1	415	0.115

Technical Alarms



Technical Alarm Total Durations

Alarm Message	Device	Seconds	Hours
PAP OVERRANGE	Patient Monitor 1	1	0.000
ABP OVERRANGE	Patient Monitor 1	2	0.001
ECG NOISY SIGN.	Patient Monitor 1	2	0.001
SpO2 POOR SIGNAL	Patient Monitor 1	2	0.001
ABP ARTIFACT	Patient Monitor 1	5	0.001
Resp LEADS OFF	Patient Monitor 1	5	0.001
ABP NON-PULSATILE	Patient Monitor 1	6	0.002
PAP NON-PULSATILE	Patient Monitor 1	12	0.003
PAP REDUCE SIZE	Patient Monitor 1	14	0.004
PAP ARTIFACT	Patient Monitor 1	25	0.007
SpO2 LOW PERF	Patient Monitor 1	31	0.009

Bed Utilization Analysis

6 month analysis

Total Patient Admission Events

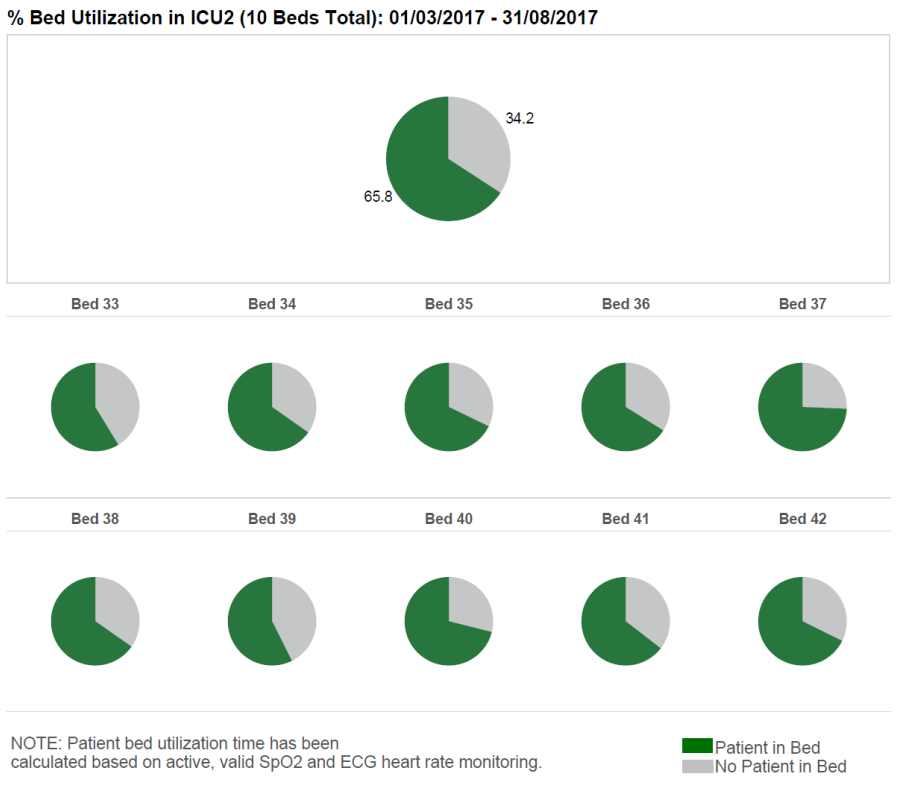
Total # of Unique Admitted Patients	Average # of Unique Patients Admitted per Day
914	5.0

Patient Bed Utilization (hrs)

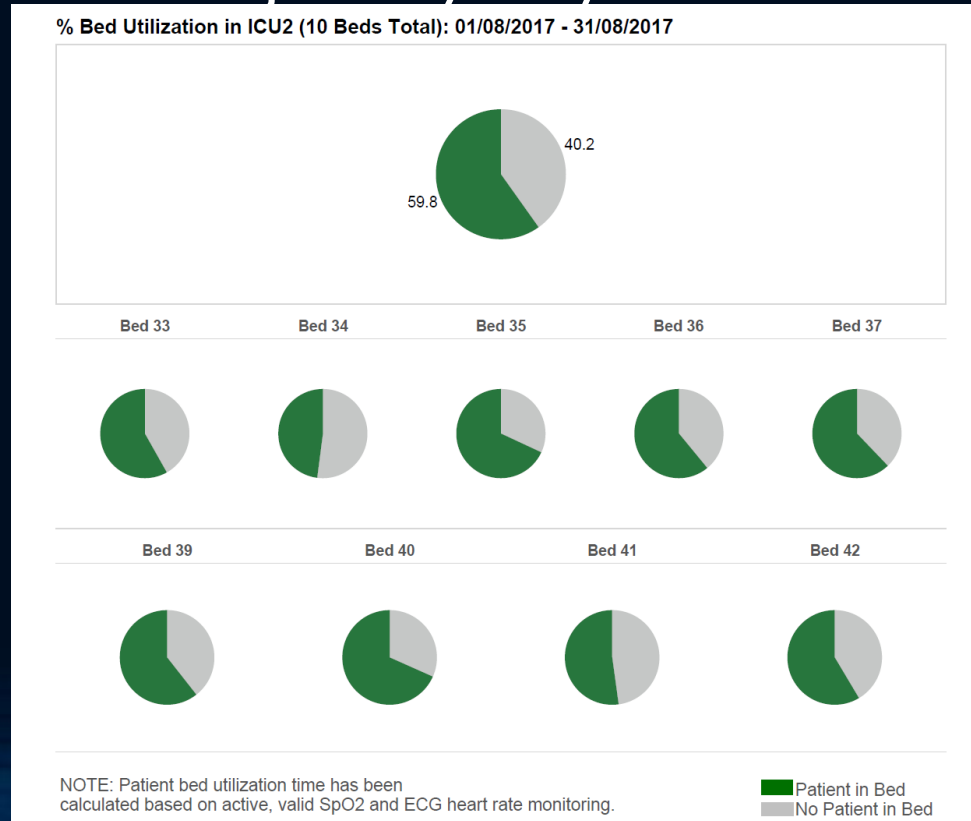
Total ICU2 Bed Utilization (hrs)	Total ICU2 Bed Utilization (days)	Avg ICU2 Bed Utilization per Bed per Day (hrs/day)
29,060.18	1,210.84	15.79

Data can be used for operations retrospectively and in real time.

6 month analysis using platform data

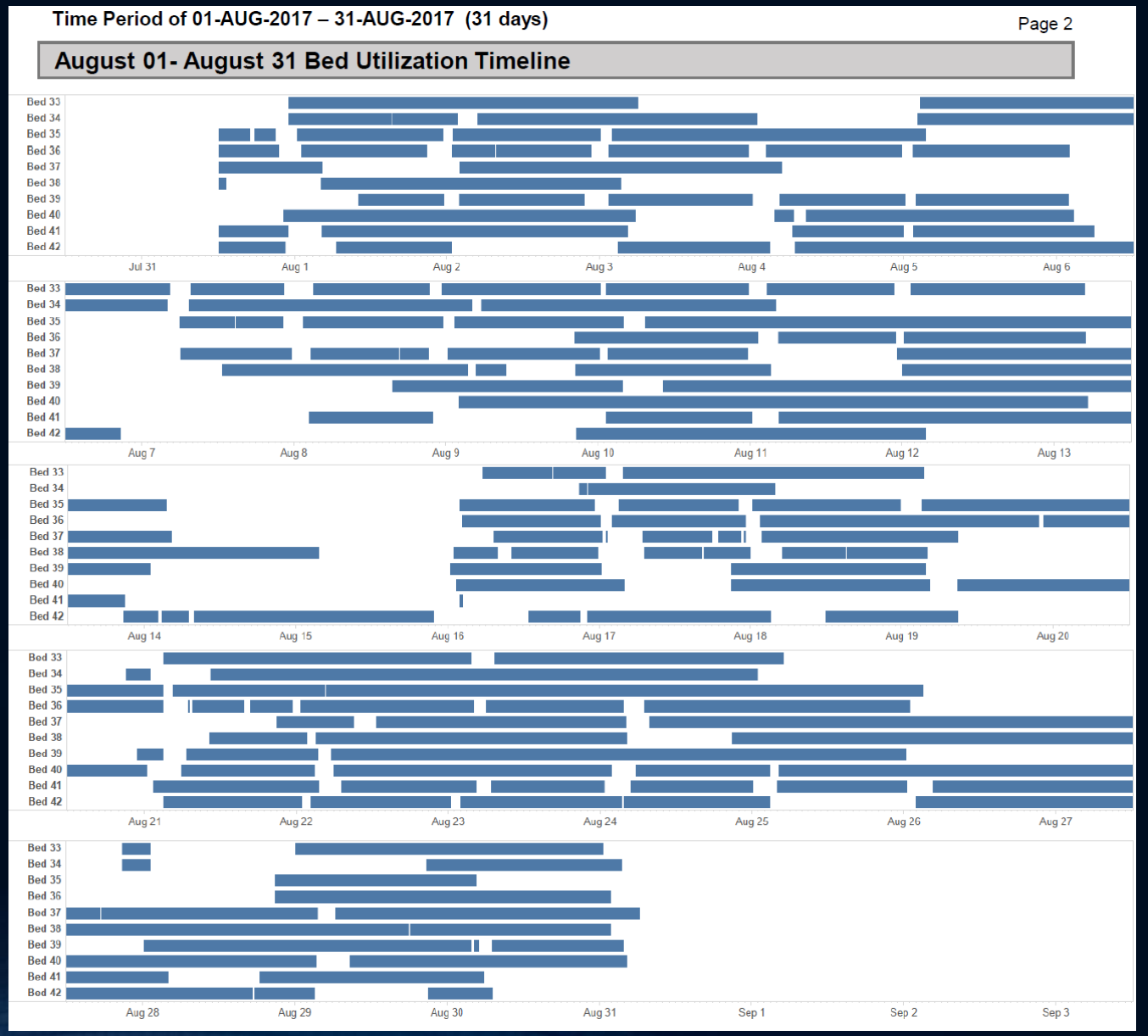


August 2017 analysis



Individual Bed Utilization by Day/Hour

- Blue - bed is occupied
- Can be provided in near real time (i.e. operations dashboard)
- Granularity to sub sec



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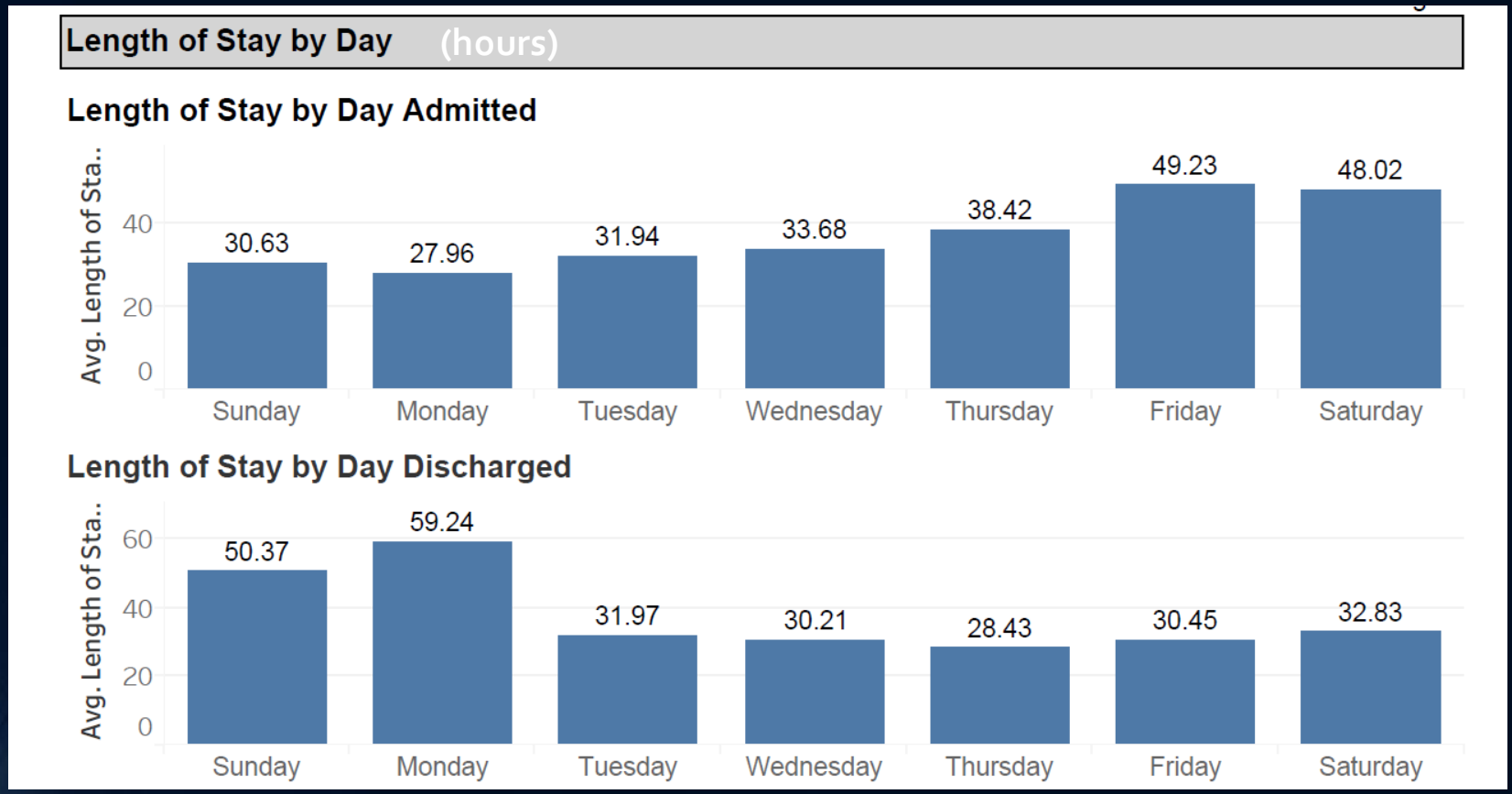
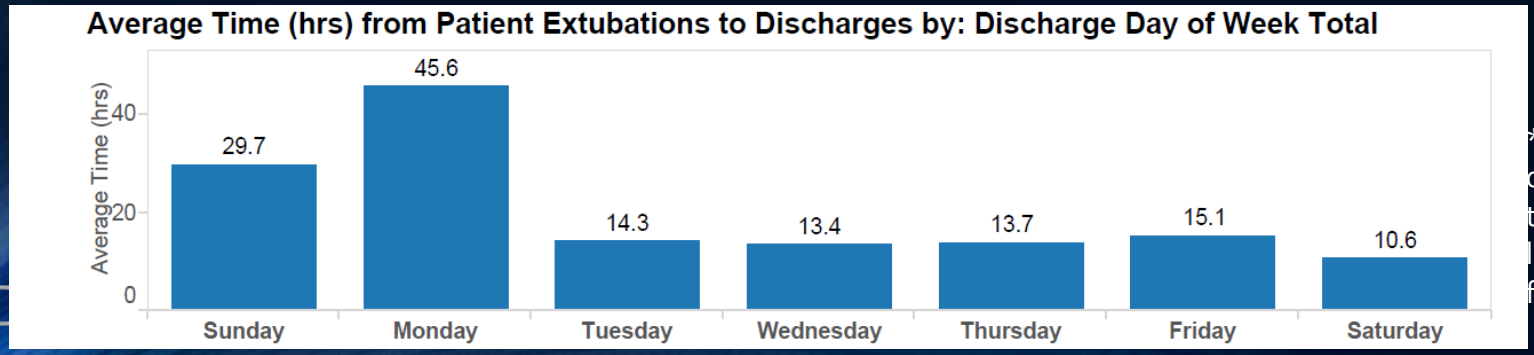
Length of Stay Analysis



Why are Sunday and Monday discharges so much longer?



*extubation is determined by when tidal volume is no longer available from ventilator

Interpret Results

Analyze Data

A Problem of Interest

Assemble Relevant Data

Decision to Study

Research article

Open Access

Exploring if day and time of admission is associated with average length of stay among inpatients from a tertiary hospital in Singapore: an analytic study based on routine admission data

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Published: 22 January 2006

BMC Health Services Research 2006, 6:6 doi:10.1186/1472-6963-6-6

Received: 22 June 2005

Accepted: 22 January 2006

Bed stays increase if you are in hospital over the weekend → Publish Paper → no way to deploy solution

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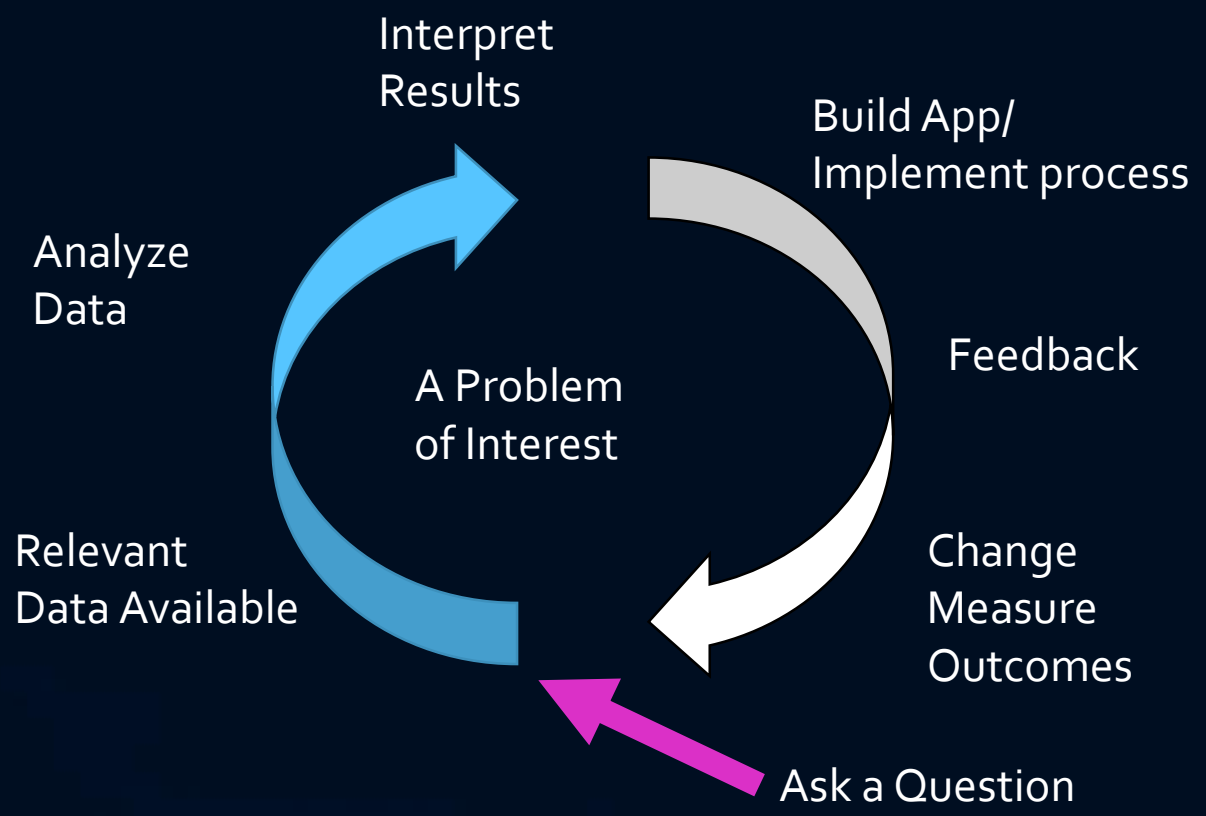
Closing the Loop

- New solutions can be deployed
- Data is collected continuously
- Improvements are continuous based on data
- Innovation is enabled
- Scale with new Apps on platform



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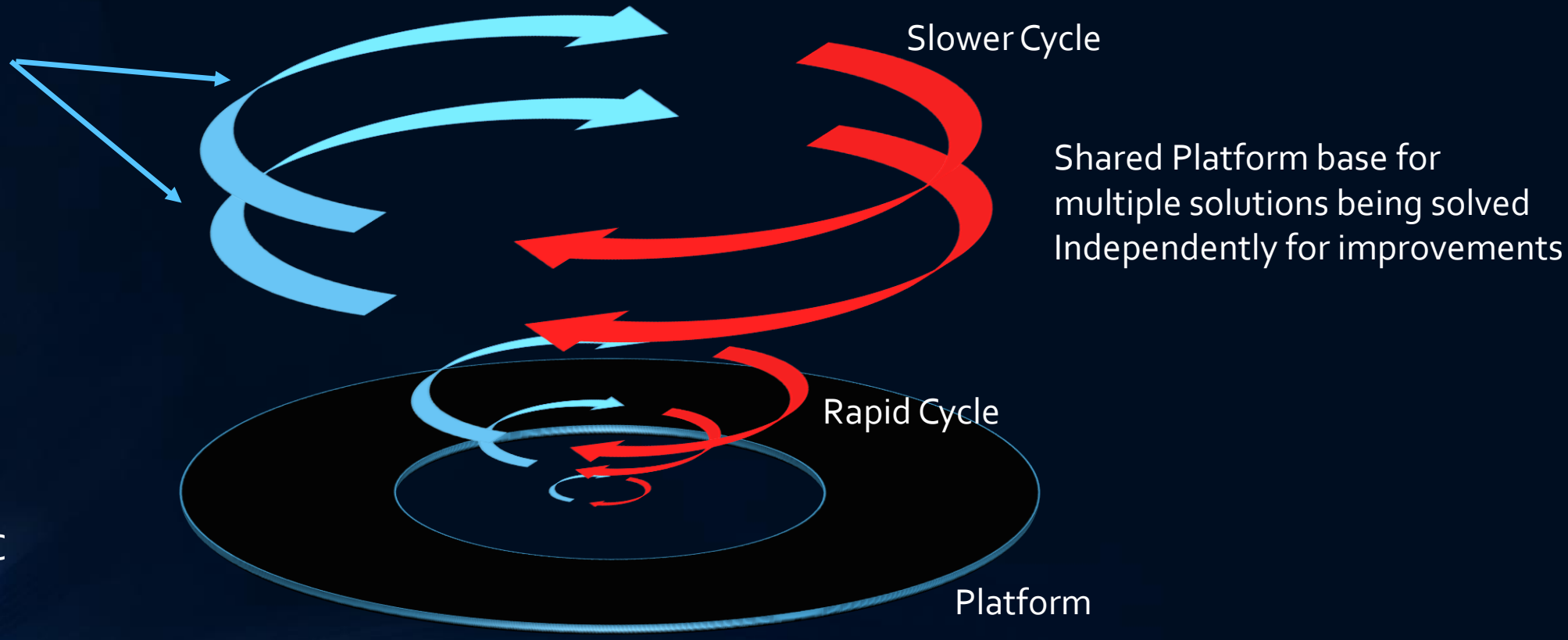
Medical Internet of Things Creates Platform



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W81XWH17C0013

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