Effect of Monitoring System Design on Response Time to Cardiac Arrhythmias

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Raleigh

2nd Easiest City to Find a Job (Forbes 2016)
2nd in America's Hottest Spots For Tech Jobs (Forbes 2016)
3rd in Best Cities for Young Families (Value Penguin 2016)
North Carolina is No. 1 “Growth State” (Triangle Business J 2016)

NC State: Largest University in the North Carolina University System

- > $1.4B expenditures
- > $400M research
- 35,479 students
- 2,201 Faculty
- 6,547 S taff

- US national ranking in innovation
  - Licenses: #1
  - Startup companies: #5
  - Industry research: #7
  - Patents: #7

NC State Among the Best

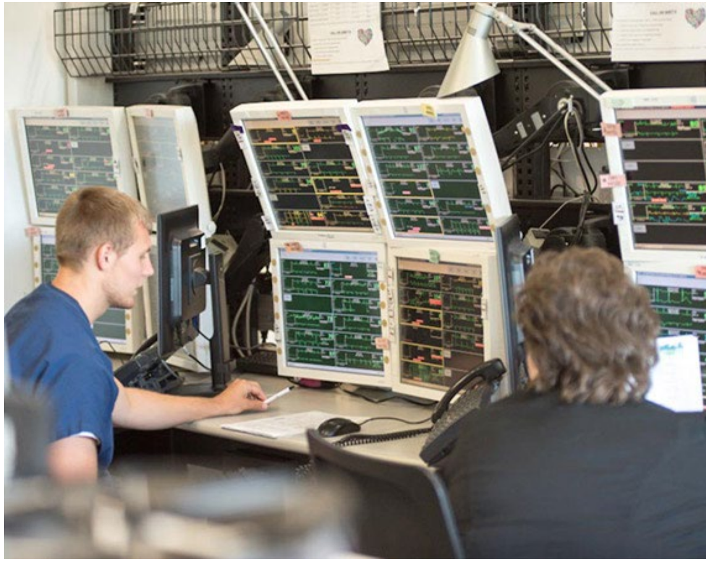
#1 best college in North Carolina
#4 vet med nationally
#6 best value among public univ. nationally
#6 nationally in online grad. computer and IT prog
#7 best value for out-of-state studs among public univ.
#8 in MBA programs with best return on investment
#8 online graduate engineering program nationally
#9 best value for in-state students among public univ.
#11 in undergraduate entrepreneurship nationally
#11 online MBA nationally
#12 grad. engineering prog. among public univ.
#15 online grad. prog. in education nationally
#16 graduate statistics program nationally

Motivation

Potential Issues: Nearly 500,000 people die each year in the US from in-hospital cardiac arrest

Question: How does the monitoring system design effect the response time to cardiac arrhythmias?

Purpose: Increase Performance of Hospital Operation



https://consultqd.clevelandclinic.org/centralized-cardiac-telemetry-monitoring-slashes-alarm-fatigue-saves-lives/

National Institute of Health (NIH) Grant

Participants: Duke University Health System (Two Hospitals)
Saint Alphonsus Regional Medical Center, Boise, Idaho
NC State University

Specific Aim 1: Identify candidate monitoring configurations

Specific Aim 2: Determine which monitoring configuration leads to the shortest response time to lethal arrhythmias

Specific Aim 3: Test the most efficient monitoring configuration

Types of Monitoring System

Duke University Hospital: Telemetry station is off-unit detect cardiac events

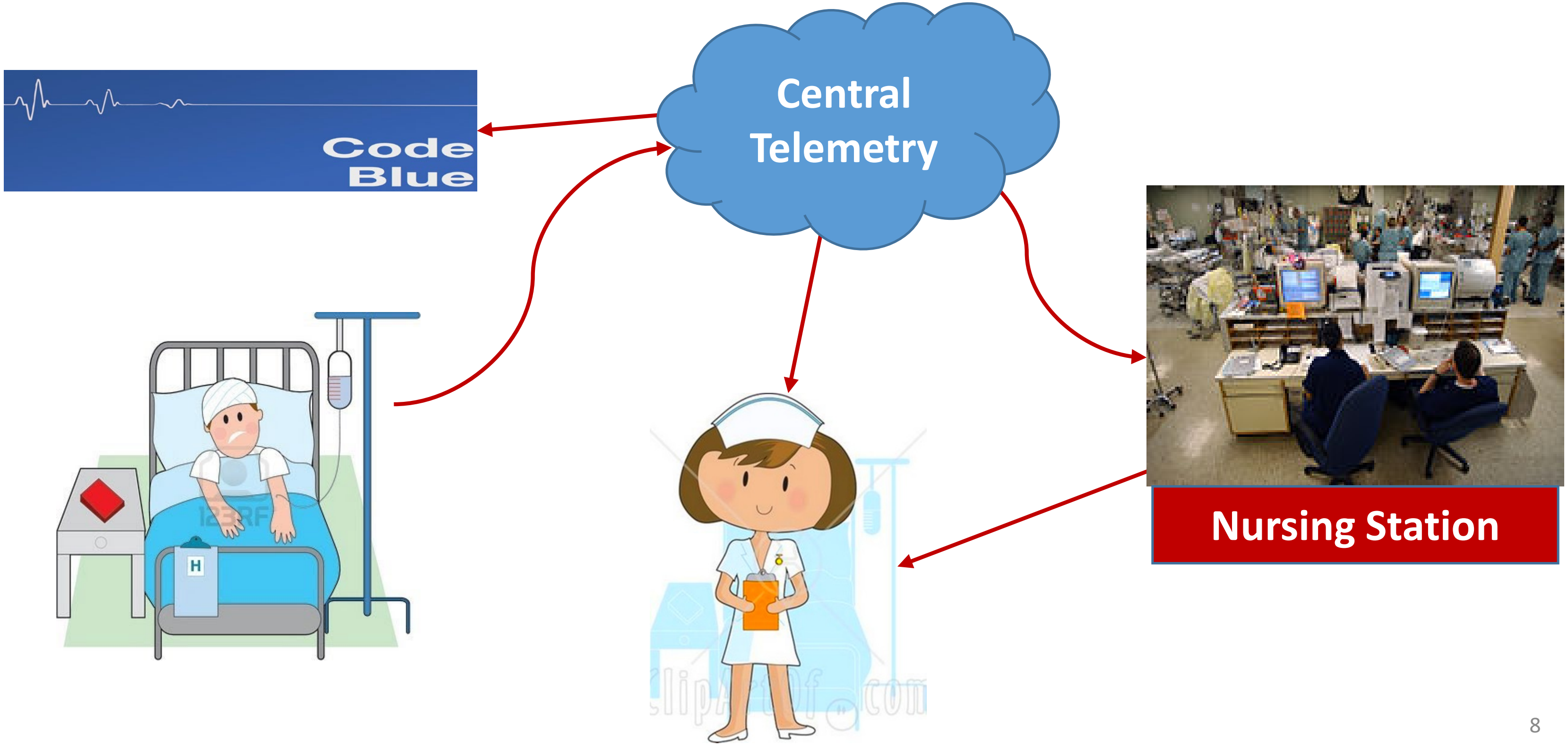
Duke Raleigh Hospital: Telemetry station is on-unit to detect cardiac events

Boise: Telemetry station is positions strategically on floor

Other Key factors

- Patient Flow
- Workload of Nurses
- Central Telemetry and Nurse Response Time
- Number patients being watched
- Patient to Nurse Ratio

Conceptual Model



Data Collection

Data Driven Models

Most of the modeling is often easy

Data collection often difficult part

- Resolution/Format
- Use rough cut models to plan collection
- Can lead to breakthroughs

Distribution-Selection Hierarchy

1. Use recent/historical data to fit the distribution
2. Use raw data and load discrete points into a custom distribution (i.e., Empirical CDF) using a table
3. Use the distribution suggested by the nature of the process or underlying physics
4. Assume a simple distribution and apply reasonable limits when lacking data

Sources of Data

IT systems

Pulled data from the Hospital Database to give insight on patients.

Observational Data

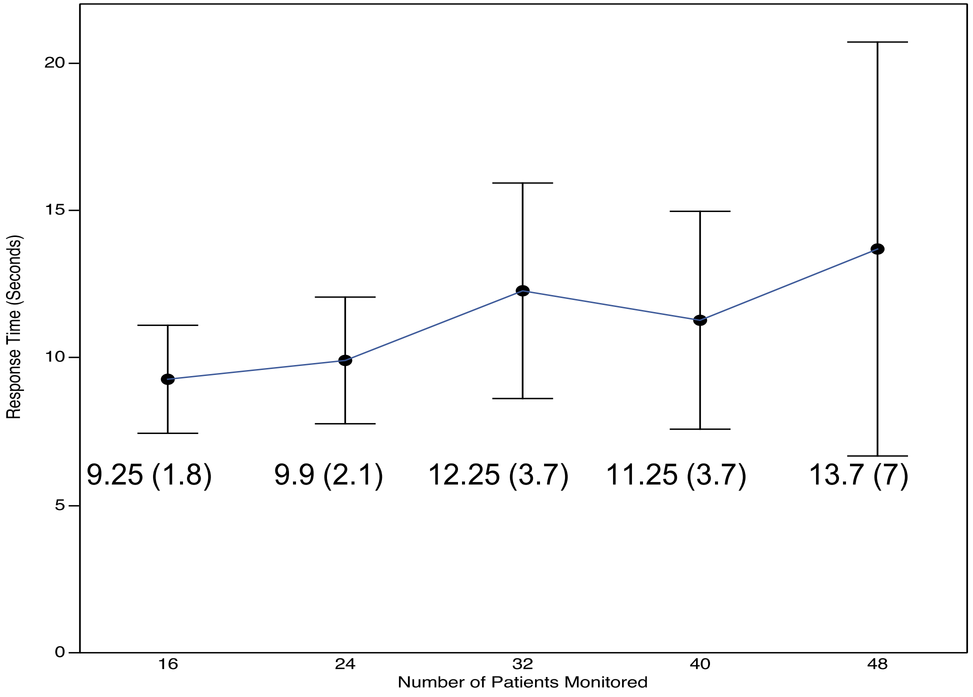
Data collected and recorded by the nurses on the day-to-day task during a specific time period.

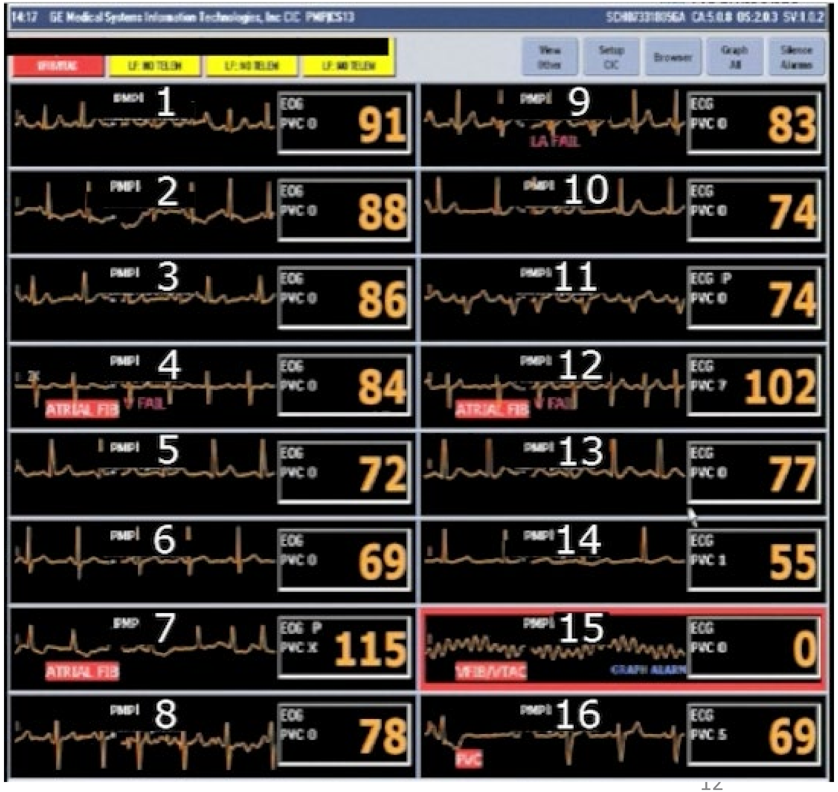
Data collected and recorded observing the telemetry technicians

Physical Simulated Data

Contains fictionalized hospital data developed to mirror a cardiac event and simulate the response time of the nurse and central telemetry

Technician Response Time on Simulated Data





Collected Data

Name Of Data	Data Type	Description
Arrivals → Arrival Rate	IT Systems	The count of patients admissions and transfer into units per day.
Length of Stay	IT Systems	The total amount of time the patient spends in the unit
Event Inter arrival Time	Observational Data	The time between successive events (i.e. cardiac)
Event Processing Time	Observational Data	The time it takes a nurse to treat an event (i.e. cardiac)
Response Time	Simulated Data	The time between an event occurring and the nurse reaction
Census	IT Systems	Count of patients in the unit per day
Patient Percentage	IT Systems	Count of patients on telemetry in the unit annually in reference to the total population of patients

Distribution Fitting Process

Step 1: Organize data (Clean, structure, format, etc.)

Step 2: Specify Input Data to Analyze in EasyFit

Step 3: Identify Best-fitting Distribution
(Anderson Darling-Goodness to Fit Test)

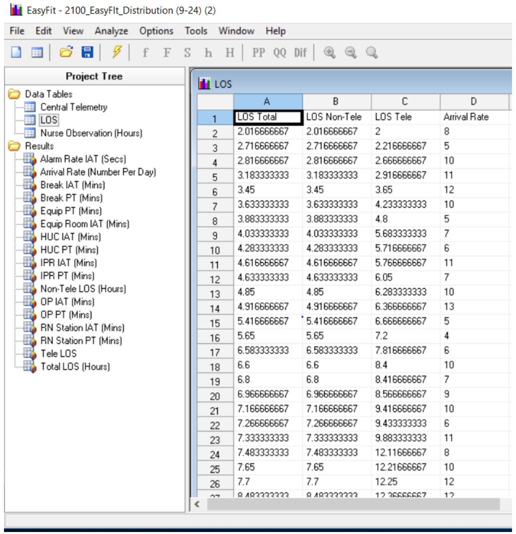
Might need to use empirical distributions

Step 4: Compare Distribution to Histogram (Visual)

Step 5: Write Distribution in terms of SIMIO
(i.e. Random.PearsonVI (2.5165, 2.6867, 72.481)

Step 6: Reanalyze data

Identify Best Fit

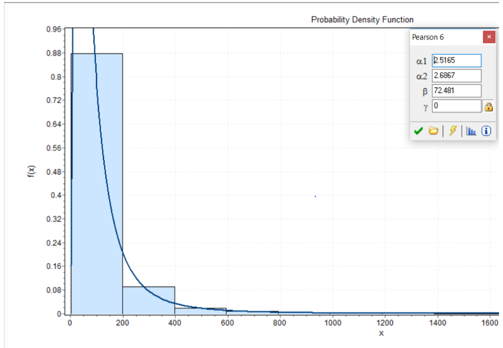


Sort and Specify Input Data

Goodness of Fit - Summary

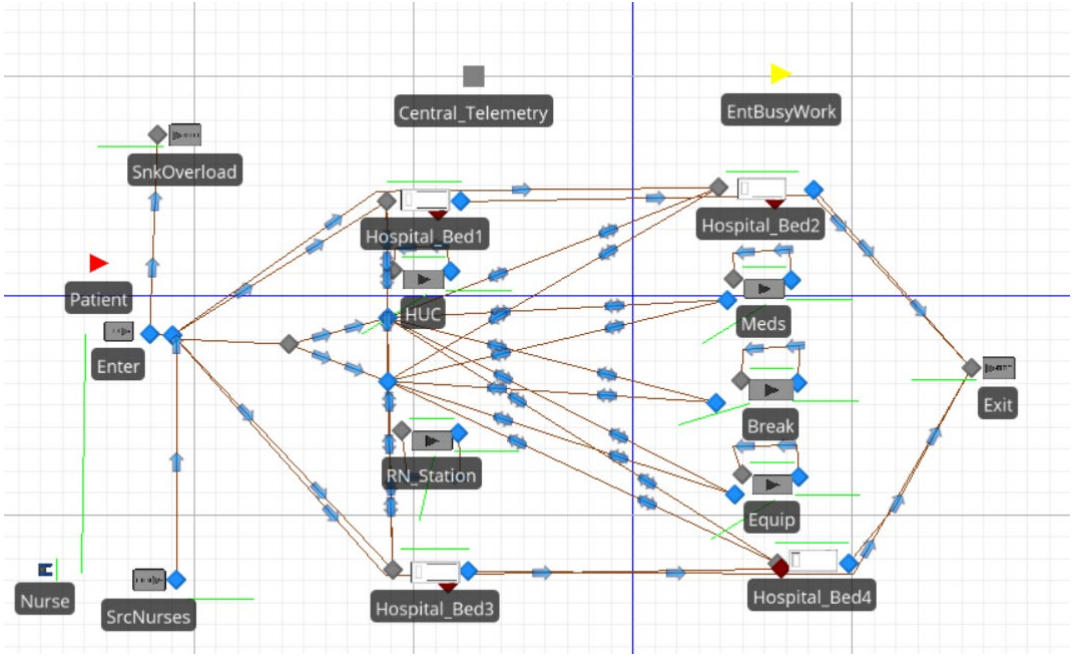
#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
37	Log-Pearson 3	0.04375	6	6.3813	1	221.1	3
40	Lognormal (3P)	0.04442	9	6.4643	2	230.93	4
39	Lognormal	0.0438	7	6.4995	3	216.57	2
21	Gen. Gamma (4P)	0.0366	2	6.6561	4	292.55	13
28	Inv. Gaussian (3P)	0.04061	5	6.9769	5	211.21	1
3	Burr (4P)	0.04692	10	7.426	6	339.46	15
46	Pearson 6	0.05021	11	7.7692	7	249.89	7
2	Burr	0.05041	12	8.8586	8	332.33	14
14	Fatigue Life (3P)	0.03868	4	8.8704	9	249.36	6
13	Fatigue Life	0.04387	8	9.5114	10	260.02	9
36	Log-Logistic (3P)	0.05404	14	10.048	11	263.39	10
7	Dagum	0.05495	16	10.414	12	273.13	11
47	Pearson 6 (4P)	0.05547	17	12.033	13	245.89	5
19	Gen. Extreme Value	0.05108	13	12.138	14	417.38	20
35	Log-Logistic	0.05986	19	12.996	15	275.53	12
16	Frechet (3P)	0.05705	18	13.81	16	256.64	8
22	Gen. Logistic	0.05417	15	15.56	17	418.43	21
27	Inv. Gaussian	0.07035	21	17.188	18	413.63	19
34	Log-Gamma	0.06501	20	18.164	19	367.11	17

Goodness to Fit Test



Compare Distribution

Testing/Validations Distributions



Example of Smaller Model

Created a smaller model to replicate the larger unit to run test on the data.

Checked for errors

- Averages
- Outliers
- Distributions

Data Analysis Issues

Outliers in Data

Cause long tails in Fitted Distributions

Changes the output of the simulation

Data Structure is structured differently

Reformatted for consistency

Resolve redundancy issues

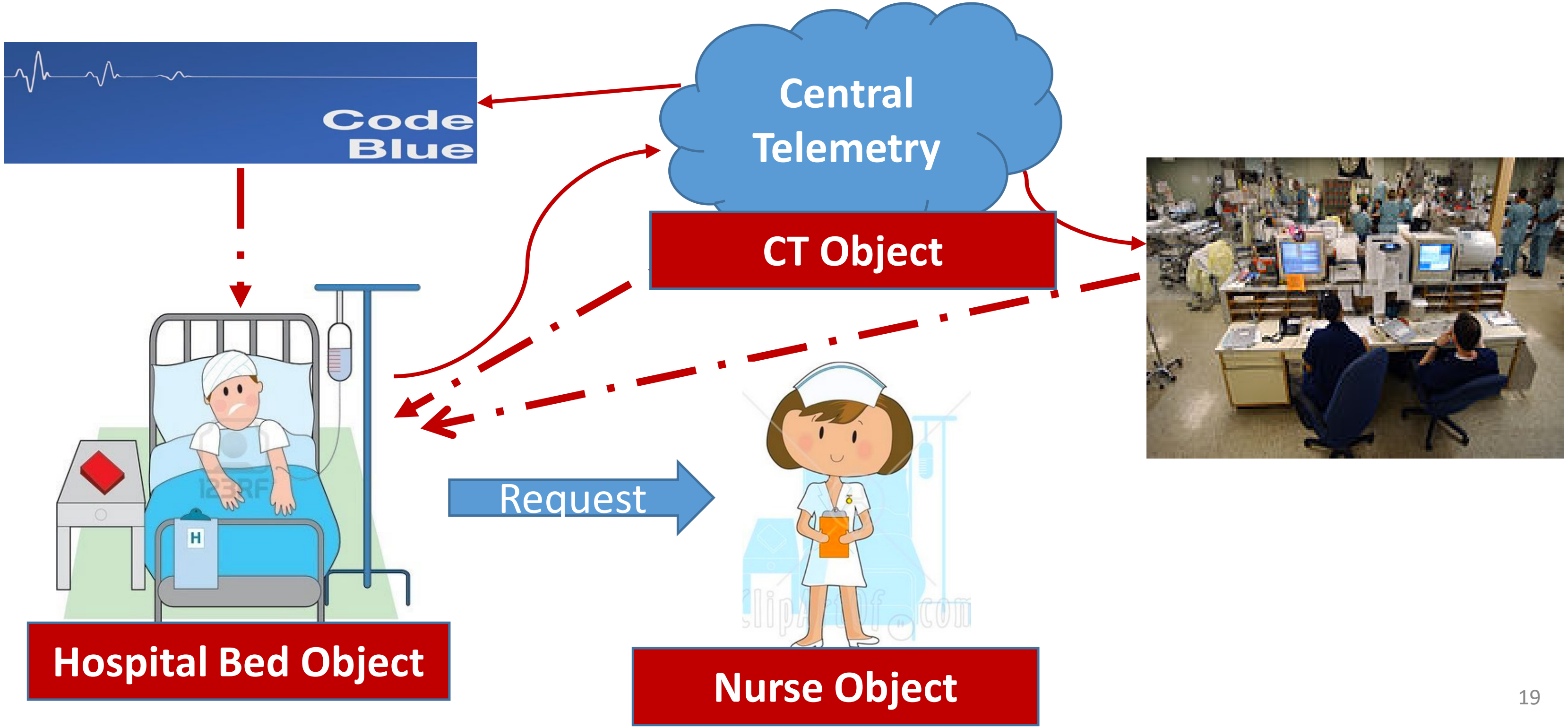
Examples of Outliers

ID	UNIT	StartTime	EndTime	PT(Hours)
5236	DUH N2100	9/19/2017 16:18	12/27/2017 13:20	2373.033333
3743	DUH N2100	8/15/2016 7:43	11/3/2016 10:37	1922.9
1971	DUH N2100	3/2/2017 14:21	5/6/2017 11:35	1557.233333

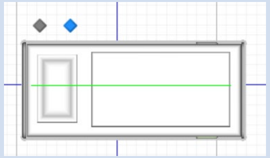
1922.9 seemed to be an outlier because of the large processing times

3743	DUH N2100	791	Transfer In	15-Aug-16	8/15/16 8:00	10	N	14014964	3101001502	Intermediate	15-Aug-16	8/15/16 7:43
3743	DUH N2100	791	Transfer Out	15-Aug-16	8/15/16 10:49	12	N	14016372	3101001502	Intermediate	15-Aug-16	8/15/16 10:48
3743	DUH N2100	791	Transfer In	15-Aug-16	8/15/16 15:36	15	N	14019041	3101001502	Intermediate	15-Aug-16	8/15/16 15:36
3743	DUH N2100	791	Transfer Out	1-Sep-16	9/1/16 6:56	33	N	14250147	3101001502	Intermediate	1-Sep-16	9/1/16 6:04
3743	DUH N2100	791	Transfer In	1-Sep-16	9/1/16 15:10	36	N	14254145	3101001502	Intermediate	1-Sep-16	9/1/16 15:10
3743	DUH N2100	791	Transfer Out	7-Sep-16	9/7/16 22:39	43	N	14332989	3101001502	Intermediate	7-Sep-16	9/7/16 22:38
3743	DUH N2100	791	Transfer In	7-Sep-16	9/7/16 22:39	44	N	14332990	3101002402	Intermediate	7-Sep-16	9/7/16 22:38
3743	DUH N2100	791	Discharge	3-Nov-16	11/3/16 10:38	102	N	15107485	3101002402	Intermediate	3-Nov-16	11/3/16 10:37

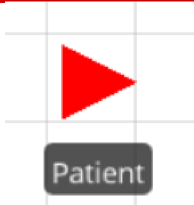
Modeling Approach

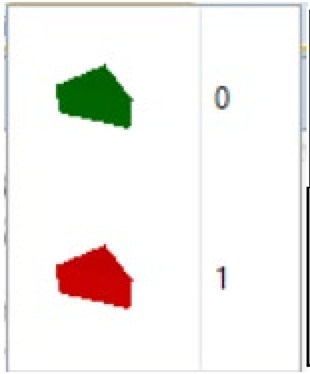


Objects Created/Modified

Object	Type	Picture/
Entity	Modified	
Worker	Modified	
Hospital Bed	Created	
Central Telemetry	Created	

Entity: *Patient*





Non-Telemetry Patients

Telemetry Patients

Entities *(Patients)* arrive in the system *(Hospital)* based on an arrival rate

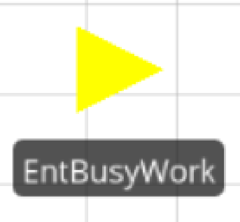
Assigned rows in Data tables

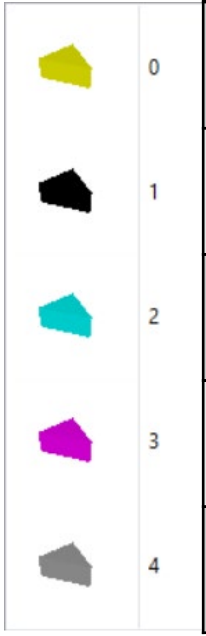
Takes on specific values, such as Length of Stay in hours, Telemetry Patient

Entity LOS Assumptions

Patient Type	Length of Stay Distribution *(Hours)* *(ShapeA, ShapeB, Scale)*
Regular (Non-Tele.)	Random.PearsonVI (2.6835, 2.6208, 63.72)
Telemetry	Random.PearsonVI (2.216, 2.8791, 96.382)

Entity: *Busy Work*





Busy-Work Location
O/P(Meds)
HUC (Health Unit Coordinator)
Break Room
Equip/Utility
RN Station

Entities created to give nurses specific tasks while waiting on patient-based events.

Busy Work Entities Created at the beginning of the simulation sent to appropriate server

Each "Busy Work" Entity is assigned to a specific nurse

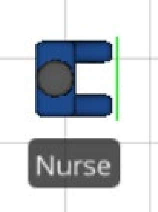
Take on specific values, such as Processing and Inter-Event, and Work Location Node

Busy Work Entity: *Key State Variables*

Name	Description
EStaBusyWorkID	An Unique Integer State Variable that is assigned to the Busy Work Entity to match the Worker unique ID
EStaBusyWorkName	String State variable that evaluates to name of the Busy Work Type

Busy Work ID	Busy Work Type	Processing Time	Inter Arrival Time	Percentage	Busy Work Node Name
0	O/P(Meds)	InpNurseTable_OP_ProcessingTime	InpNurseTable_OP_IAT	1	TableBedAssignments.Op
1	HUC	InpNurseTable_HUC_ProcessingTime	InpNurseTable_HUC_IAT	1	Input@SrvHUC
2	Break Room	InpNurseTable_Break_ProcessingTime	InpNurseTable_Break_IAT	1	Input@SrvBreakRoom
3	Equip/Utility	InpNurseTable_Equip_ProcessingTime	InpNurseTable_Equip_IAT	1	Input@SrvEquipRoom
4	RN Station	InpNurseTable_RNStation_ProcessingTime	InpNurseTable_RNStation_IAT	1	TableBedAssignments.Documen

Modified Worker: *Nurse*



Handle rounds at certain time interval (Added Timer)

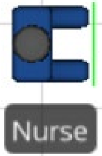
Serve only a certain list of beds (i.e., nurse to bed ratio).

- 8 workers (Nurses) are created for unit 2100
- 1:4 nurse to bed ratio

Assigned row Table Busy Work

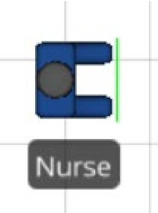
Assigned row Table Bed Assignments and Location

Worker: *Table Bed Assignments*



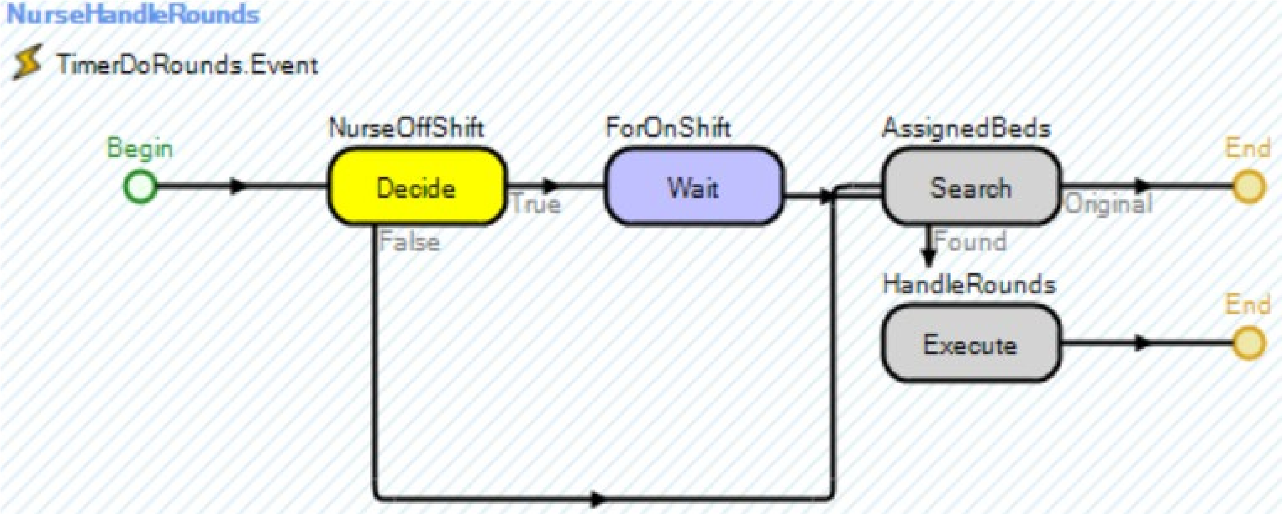
Nurse ID	Start Bed	Last Bed	Home Node	Op	Documentation
1	1	4	NurseStation1	Input@SrvO_P1	Input@SrvDocumentation_H1
2	5	8	NurseStation1	Input@SrvO_P1	Input@SrvDocumentation_H1
3	9	12	NurseStation1	Input@SrvO_P1	Input@SrvDocumentation_H1
4	13	16	NurseStation2	Input@SrvO_P2	Input@SrvDocumentation_H2
5	17	20	NurseStation2	Input@SrvO_P2	Input@SrvDocumentation_H2
6	21	24	NurseStation2	Input@SrvO_P2	Input@SrvDocumentation_H2
7	25	28	NodeHUC	Input@SrvO_P1	Input@SrvHUC
8	29	32	NodeHUC	Input@SrvO_P2	Input@SrvHUC

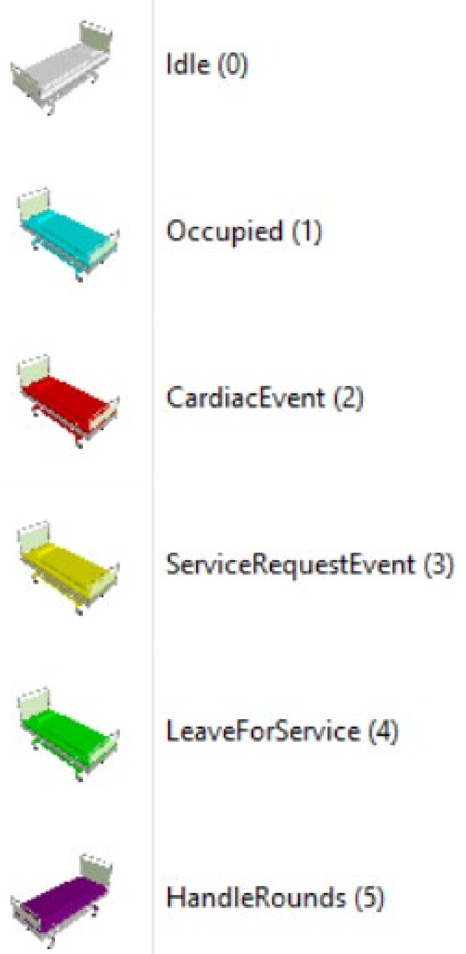
Worker: *Subclass*



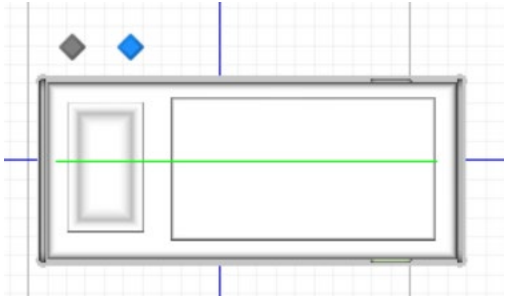
Create busy work entities that are linked to an individual worker

Nurses need to do periodic rounds





Hospital Bed (New Fixed Object)



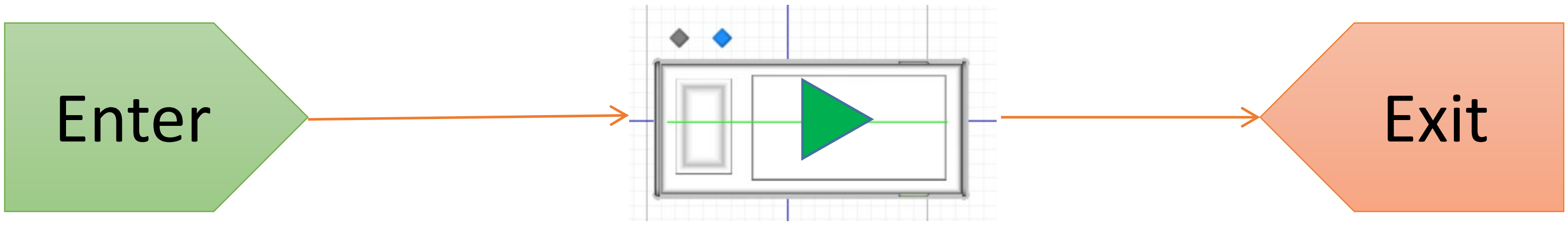
Modeling Decisions

- Patient Centric
- Bed Centric (Failures in Server)

Bed Centric Approach

- Cardiac Event
- Service Request (i.e., Call Button)
- Leave for a service (e.g., MRI)
- Handle Rounds

Patient Flow Process of Service



Entering

- Enable Timers
- Update CT if Telemetry

Exiting

- Disable Timers
- Update CT if Telemetry
- Remove Nurse Requests

Central Telemetry (New Fixed Object)

Portrays one Telemetry Technician

Responds to all cardiac events on-floor (i.e., Unit 2100) and off-floor

Properties:

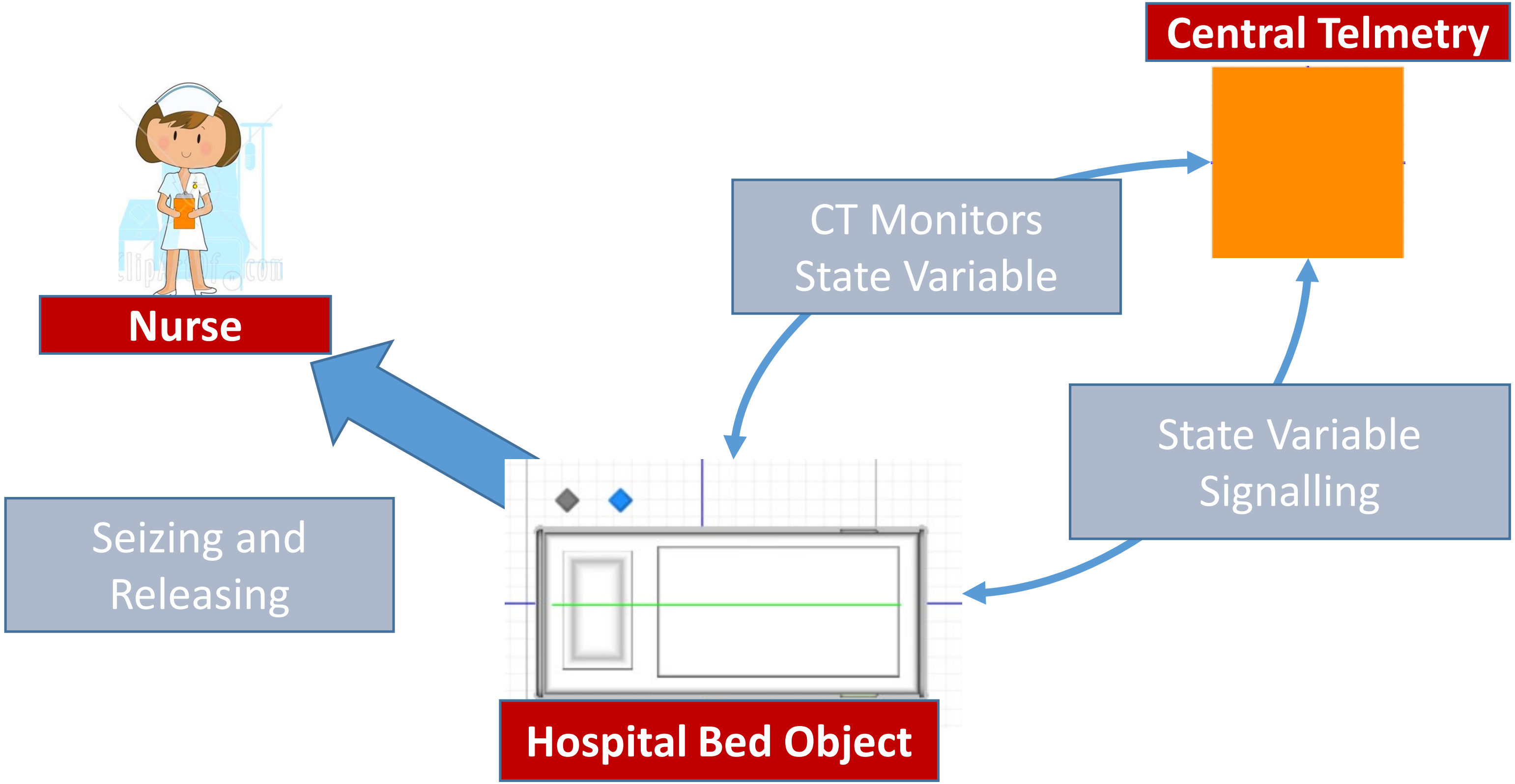
Maximum number of patients to be monitoring (e.g., 16, 32, 48)

Typically number they monitor

Time intervals busy work and off floor

Delay to check and make phone calls

Communication Between Objects



Central Telemetry: *Processes*

Mon Patient	Which Patient
Monitor 1	1
Monitor 2	2
Monitor 3	3
Monitor 4	4
Monitor 5	5
Monitor 6	6
Monitor 7	7
Monitor 8	8
Monitor 9	9
Monitor 10	10

Process Generic

Handles when a cardiac event

Process Other Events

Simulates off unit/floor events

Flow Process of Telemetry Event

Step 1: Hospital Bed triggers Cardiac Event

Step 2: Central Telemetry is triggered by Bed Signaling CT via state variable assignment

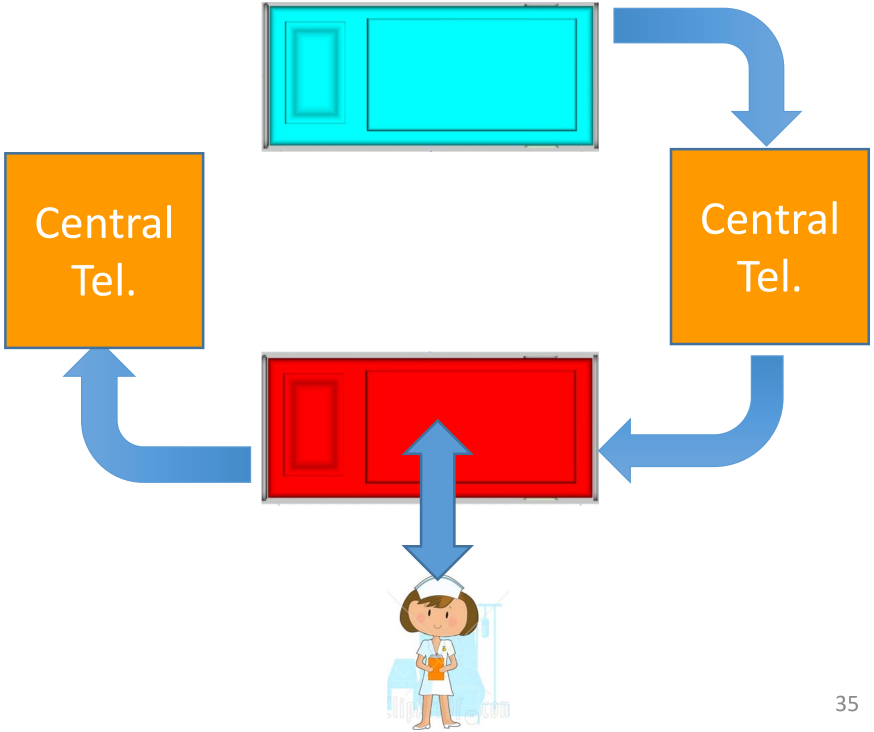
Step 3: Central Telemetry is than delayed to respond the event type

Step 4: Hospital Bed is the signaled by CT through monitored state variable

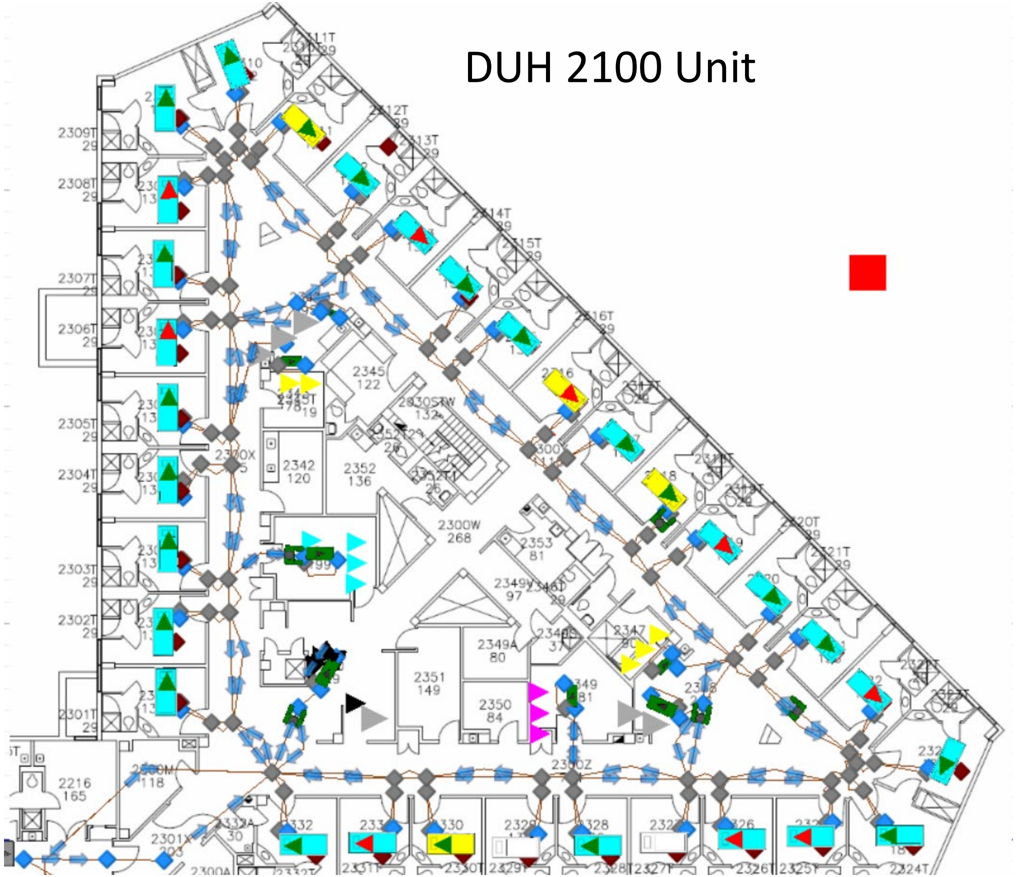
Step 5: Then, the nurse (specific/any) is seized and released by the Hospital Bed to handle event

Step 6: Finally Central Telemetry trigger is updated to bring state down

Conceptual Signal between Hospital Bed and Telemetry Model



Validation



Arrival Rates

Number of Patients in unit daily

Response of times (Compared to Simulated Data)

Results

Output Attributes

Average

Drop Column Fields Here

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
Model_DukeMedFloor	Model_DukeMedFloor	TallRegTimeInSystem	Time In System	Regular Patients Time	Average (Hours)	99.1993
					Maximum (Hours)	1,349.3227
					Minimum (Hours)	2.2073
					Observations	1,730.0000
		TallTelmPercent	Telemetry Data	Percentage of Telemetry	Average	0.2886
					Maximum	0.5625
					Observations	365.0000
		TallTelmTimeInSystem	Time In System	Telemetry Patients Time	Average (Hours)	102.9079
					Maximum (Hours)	1,377.9758
					Minimum (Hours)	2.9314
					Observations	615.0000
		TallyNumArrivalperDay	Census Data	Arrival Per Day	Average	8.4000
					Maximum	24.0000
					Observations	365.0000
		TallyNumberInSystem	Census Data	Number In System	Average	29.4691
					Maximum	40.0000
					Observations	2,377.0000
		TallyNumCensusper...	Census Data	Census	Average	28.5014
					Maximum	37.0000
					Observations	365.0000
		TallyNumDepartureP...	Census Data	Departure Per Day	Average	6.4247
					Maximum	14.0000
					Observations	365.0000

Key Properties of DUH Model

Simulation Results that replicate Actual Data

Key Factors

Factors	Description
Number of Nurses	Nurse-to-Bed Ratio
Percentage of Telemetry	Number of Telemetry Patients in Unit
Number Patients Watching (Tech)	Number of Patients Telemetry Tech is Watching
Nurse Response Time (Cardiac)	Time Nurse Responds to Cardiac Events
Nurse Response Time (Service Request)	Time Nurse Responds to “Regular” Events

Any Questions