Improving Care and Efficiency through Analytics: **Automating Patient Triage in Radiology**

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Collaborative work with Mark Halsted, MD and Neil Johnson, MD of CCHMC

The Setting

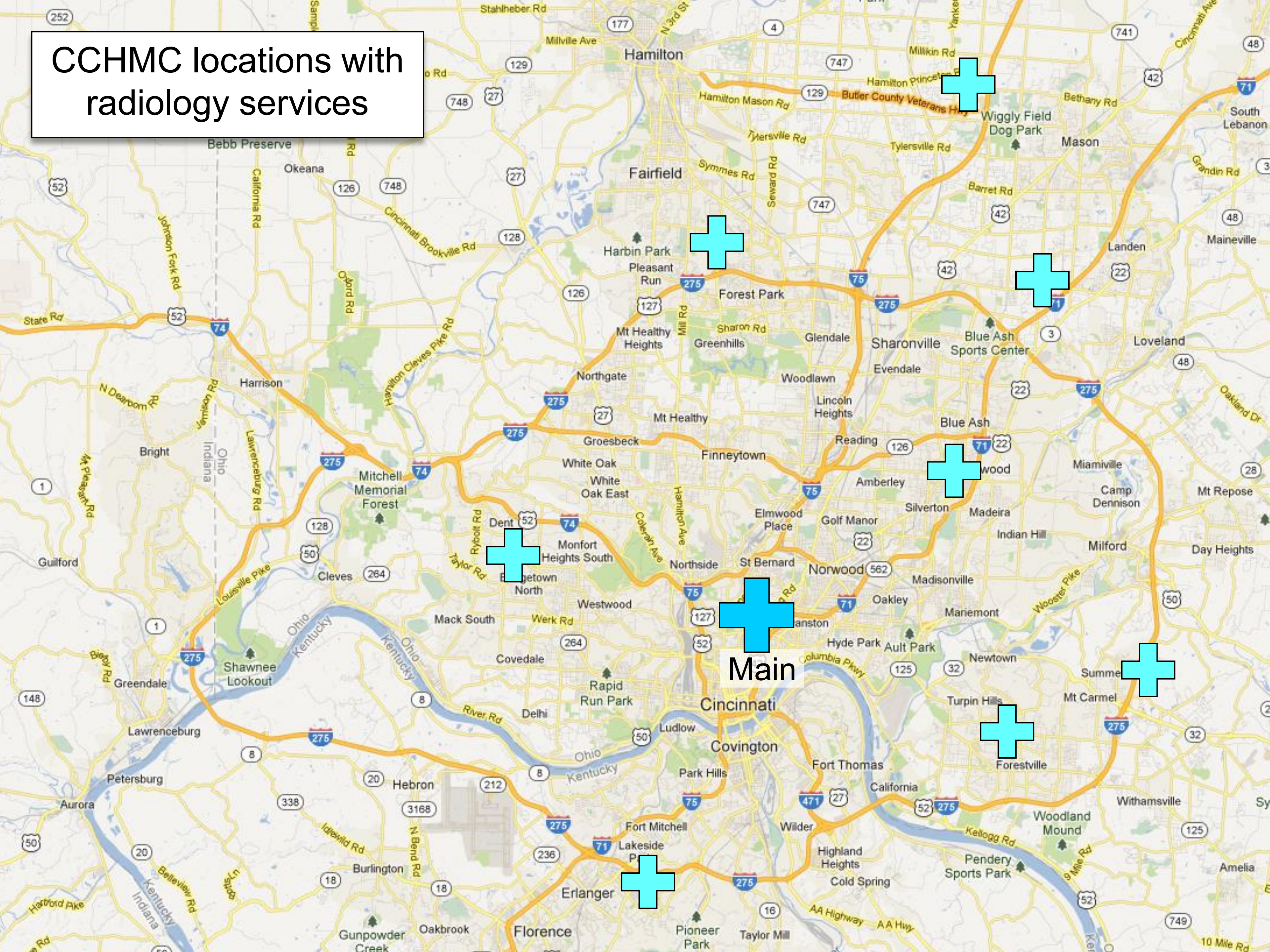
Cincinnati Children’s Hospital

- 587-bed private teaching pediatrics hospital
- Over 1.1 million patient encounters last year
- 16 patient care sites
- Consistently ranked in top 3 institutions

Children’s Radiology services

- Main hospital + 8 neighborhood locations
- Operate from a centralized “stat box” after hours
  - Staffed by 1-2 radiologists (attendings, fellows, residents)

CCHMC locations with radiology services



UNIVERSITY OF Cincinnati

Cincinnati Children's Hospital Medical Center

Cases Arrive Randomly

Different imaging modalities

- X-ray
- Ultrasound
- MRI
- CT

Different requisition-delivery mechanisms

- Faxed from remote locations
- Brought by hand from on-site staff

Overall Goals:

- Ensure most critical patients are served first
- Reduce duration and variability of patient waiting

Approach:

Develop automated workflow management system

Two functions:

1) Automatic triage of waiting cases
2) Automatic case routing and documentation of flow through the process

Measuring Baseline Performance

Overall	55
Emergency	23
Outpatient	57
Inpatient	103

Median (minutes)

Key performance metric

How can we improve this?

Baseline Sample:
6,093 exams, spanning 14 days

Automating Triage

Automating Triage

- Radiologists use internal heuristics to select their next case
- Can we develop an algorithm to emulate their decision-making?
  - Using easily obtainable data
  - Simple to program

9 Potentially Influential Variables

- Patient Age
- Exam Type
  - 20 exam categories
- Subjective Acuity
  - Extreme, Mod., Mild
- Medical Acuity
  - 5 categories (Airway, Trauma, Fracture, Pneum., Routine)
- Patient Anxiety
  - High, Low
- Referring MD Anxiety
  - High, Low
- Additional View?
  - Yes, No
- Patient Waiting?
  - Yes, No
- History
  - Brief background

Data Collection

- Constructed 25 sets of 20 hypothetical cases
  - Randomly generated
  - Validated for OK medicine
- For each case, asked radiologists to ***rate*** (1-100) the urgency of the case
- Then asked to ***rank*** the 5 most urgent cases
- 22 radiologists (88%) participated

<table>
<tr><th colspan="10">Patient/Case Information</th><th colspan="2">Please Provide the Following:</th></tr>
<tr><th>Case #</th><th>Patient Age</th><th>Type</th><th>Subjective Acuity</th><th>Medical Acuity</th><th>Patient Waiting</th><th>Patient Anxiety</th><th>Ref'g MD Anxiety</th><th>Add'l View?</th><th>History</th><th>Urgency Score (100 = Extreme 1 = None)</th><th>Rank 5 Most Urgent</th></tr>
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<tr><td>10</td><td>12 yr</td><td>Knee</td><td>Moderate</td><td>Routine</td><td>Yes</td><td>High</td><td>High</td><td>No</td><td>Knee pain</td><td></td><td></td></tr>
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14	18 mo	Chest	Mild	Pneum	No	Low	High	No	cough		
15	17 yr	Skull	Mild	Trauma	Yes	Low	High	Yes	Bike accident		
16	7 yr	Chest	Mild	Trauma	Yes	Low	High	No	Near drowning		
17	6 yr	Femur	Mild	Trauma	Yes	High	High	No	Fall from tree		
18	15 mo	Airway	Extreme	Airway	Yes	Low	Low	Yes	Severe stridor		
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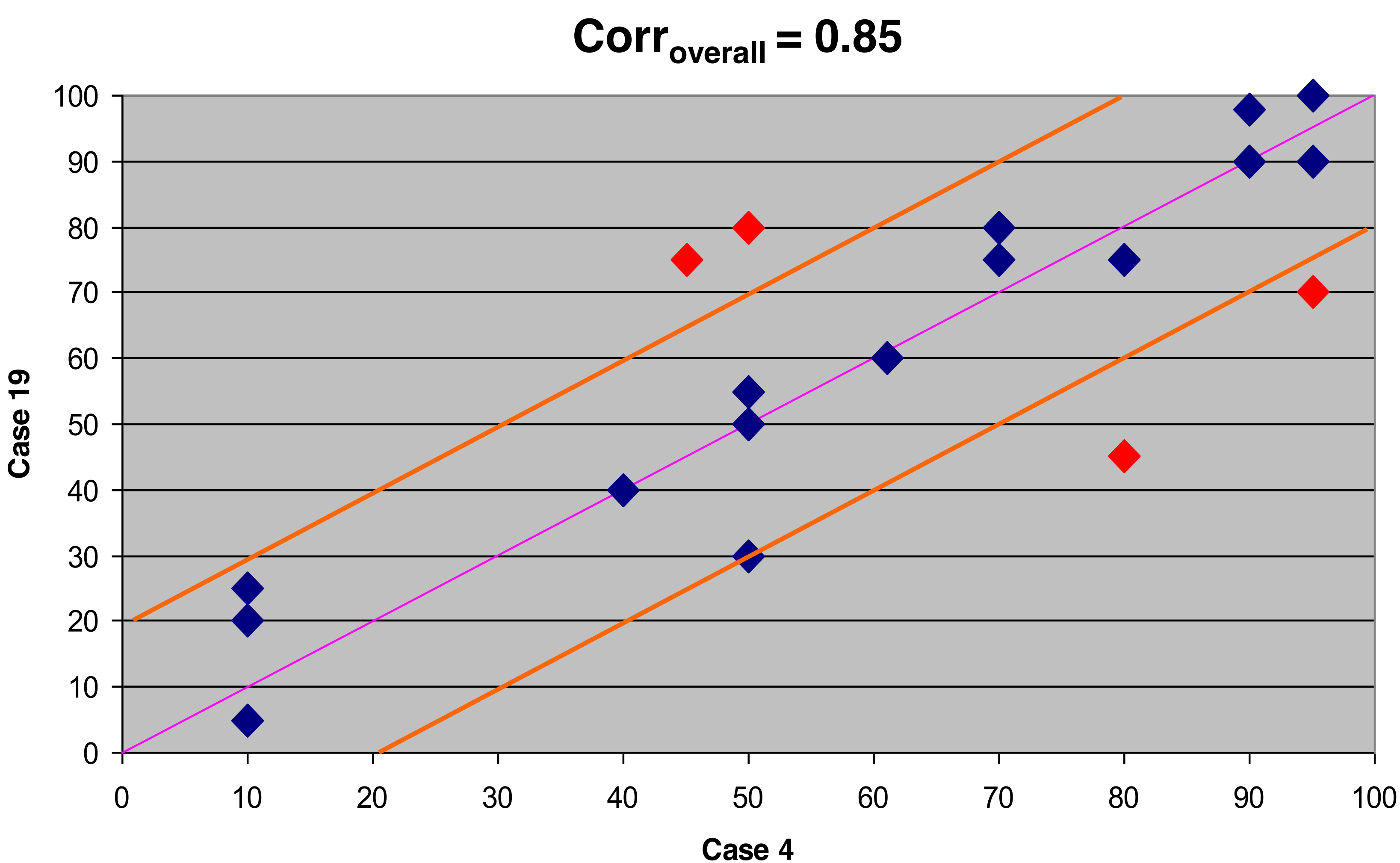
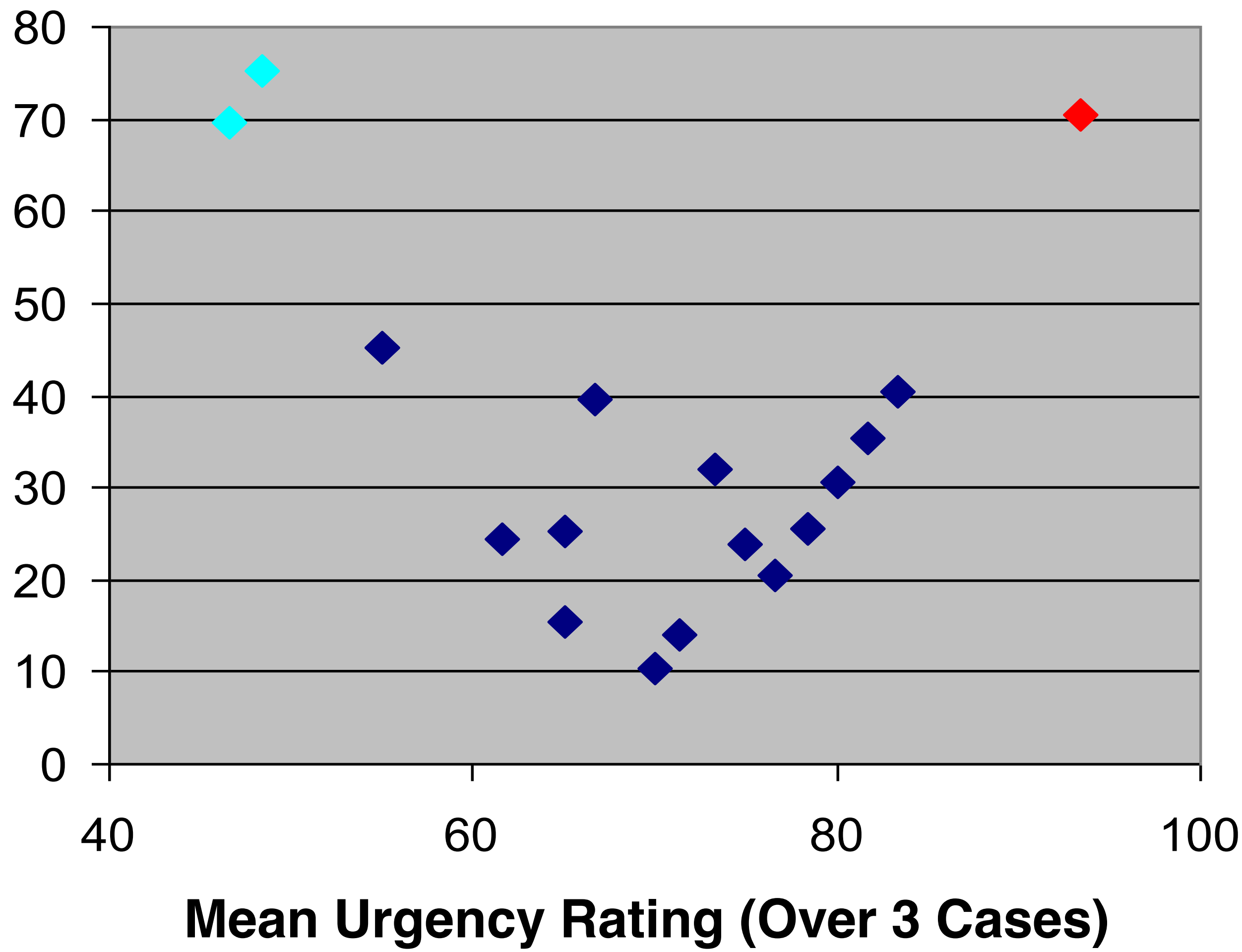
Test #1: Intra-Physician Consistency



Test #2: Inter-Physician Consistency

$$\sum_{c=1}^{3} | u_{pc} - \bar{u}_c |$$

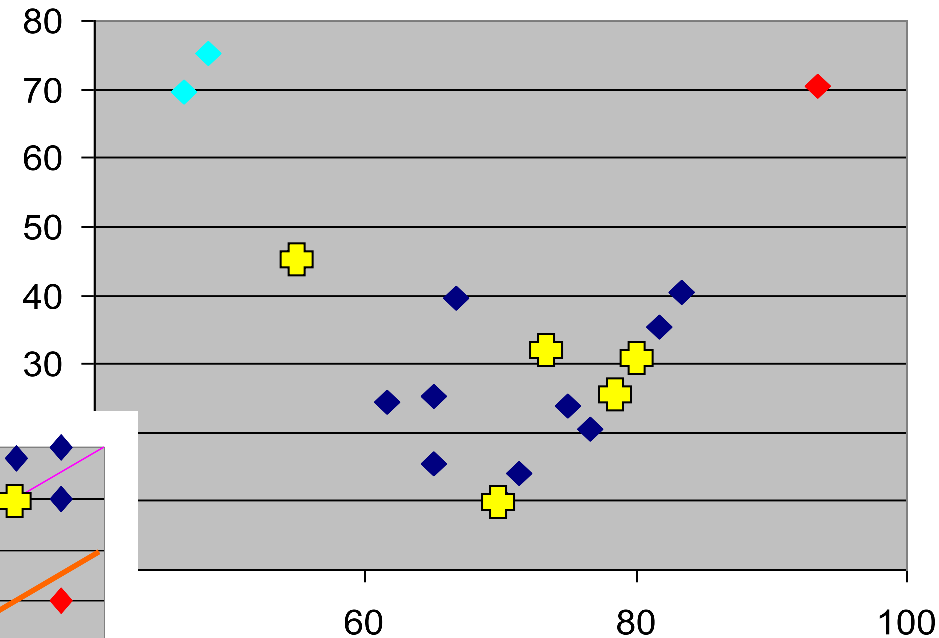
Sum of Absolute Deviations from Group Mean Urgency Rating (Over 3 Cases)

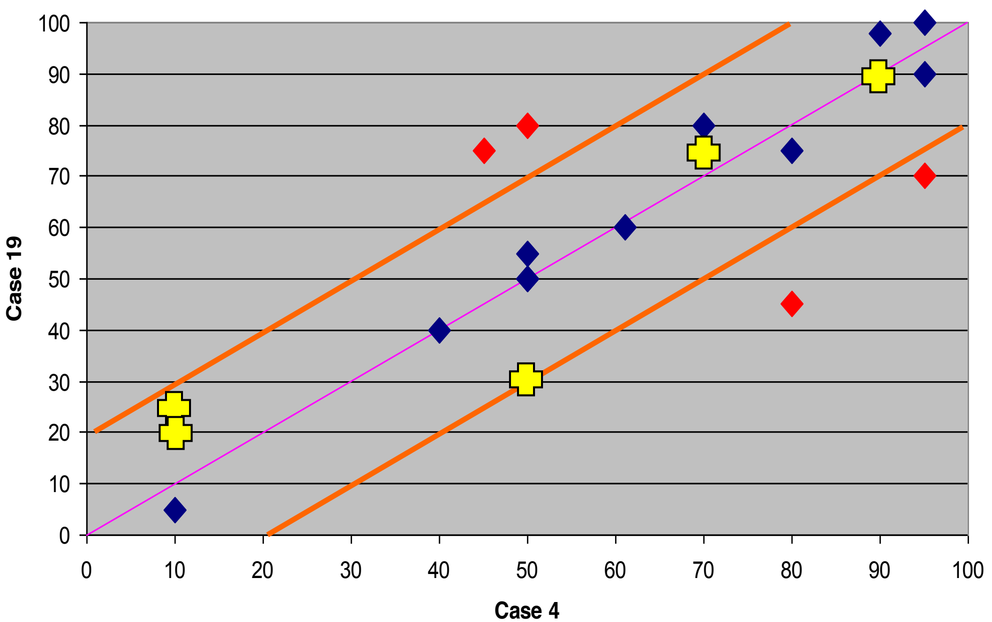


Physician Selection

Identified 5 representative docs:

- Consistent decision-making
- Within range of the majority
- Highly experienced

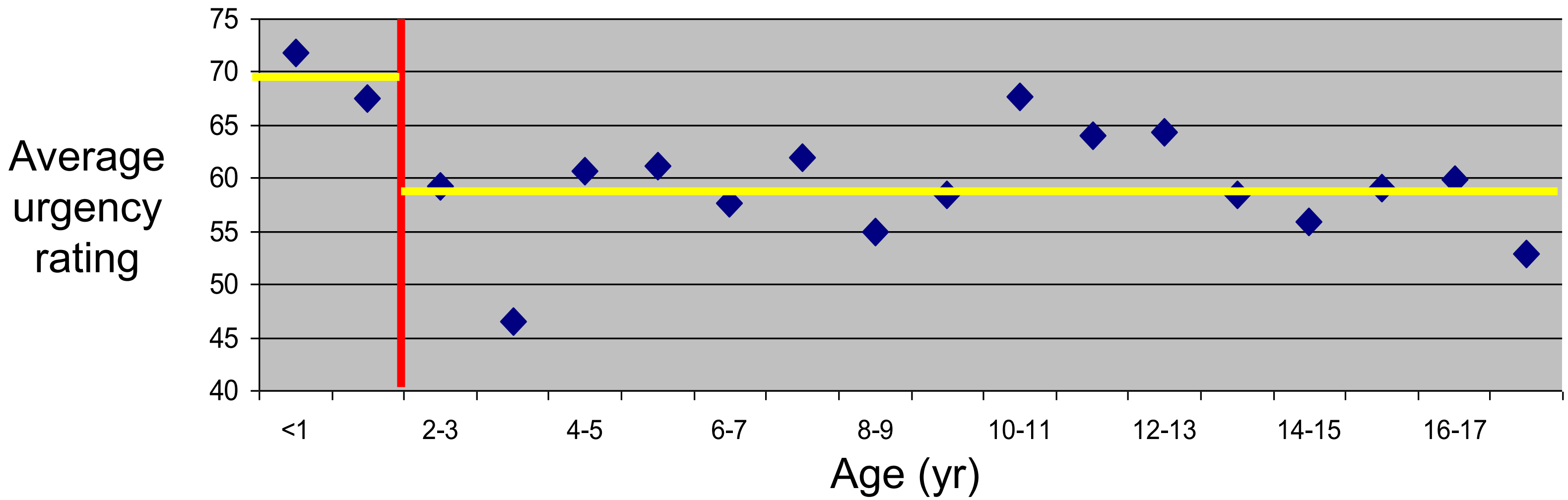




These 5 radiologists' responses were then used for the algorithm development step

Variable Management

- Compared urgency means and distributions across categories; some were combined:
  - Exam Type: 20 categories reduced to 2
  - Medical Acuity: 5 categories reduced to 2
  - Age: continuous variable dichotomized (<2, 2+)



Constructing the Triage Algorithm

- Stepwise OLS regression using 5 radiologists' responses:

URGENCY =

	12.31 * SUBJACU	(.36)
+	25.94 * PATWAIT	(.13)
+	15.98 * REFANX	(.08)
+	15.35 * PATANX	(.05)
+	28.45 * DUMTYPE	(.05)
+	9.70 * DUMYOUNG	(.01)

F=35.52 (P<.0001)

R^2 = .70

Not included:
DUMMEDAC
ADDVIEW

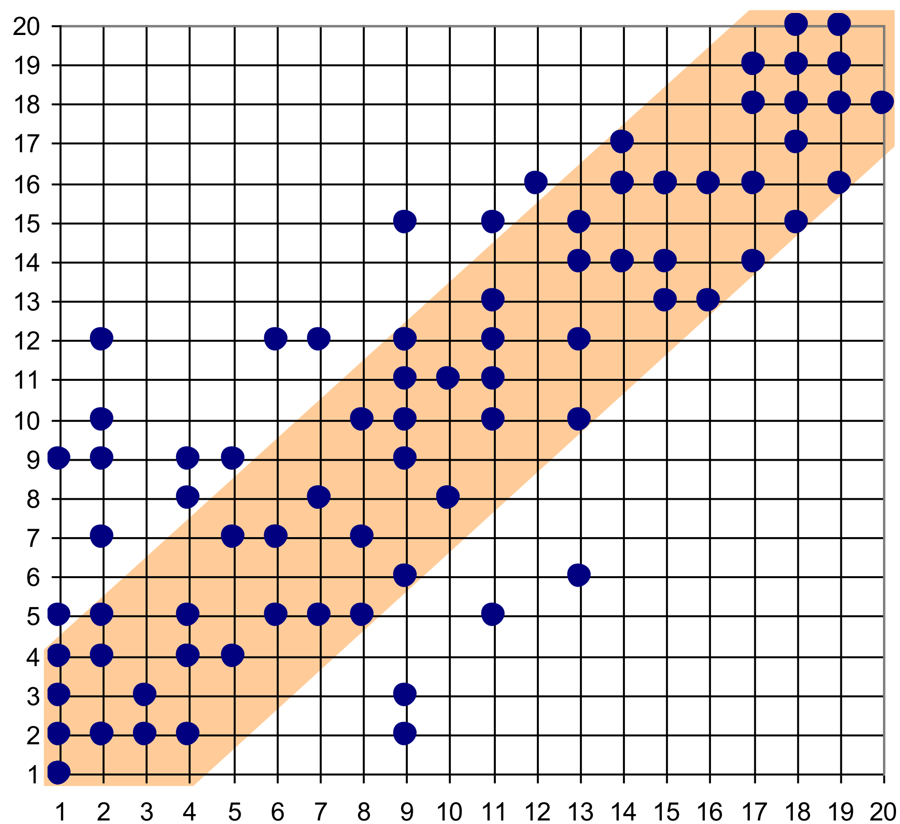
But how well did it match our radiologists' heuristics?

Testing the Triage Algorithm

- Prediction of rankings is primary metric:

Corr = .87

Predicted ranking (algorithm)



Actual ranking (radiologists)

|Act-Pre|	#	%
0	22	22
1	29	51
2	17	68
3	14	82
4	5	87
5	3	90
6	4	94
7	3	97
8	2	99
9	0	99
10	1	100

Validation Survey

Patient/Case Information										This is how your colleague ranked these cases:	Please note here any changes *you* would make to the rankings:
Case #	**Patient Age**	**Type**	**Subjective Acuity**	**Medical Acuity**	**Patient Waiting**	**Patient Anxiety**	**Ref'g MD Anxiety**	**Add'l View?**	**History**		
1	4 mo	Chest	Extreme	Trauma	Yes	High	High	No	MVA 1 hour ago	**1**	
2	2 yr	Ankle	Moderate	Fracture	Yes	High	High	No	Fell	**2**	
3	11 mo	Chest	Extreme	Pneum	No	Low	High	Yes	Cough, fever	**3**	
4	10 yr	CSpine	Mild	Trauma	Yes	High	Low	No	MVA	**4**	
5	9 yr	Abd	Moderate	Routine	No	High	High	No	Abdominal pain	**5**	
6	12 yr	Femur	Mild	Fracture	Yes	High	High	No	Fell	**6**	
7	16 yr	Chest	Mild	Pneum	Yes	Low	High	Yes	Cough	**7**	
8	18 wk	Chest	Mild	Pneum	No	Low	High	No	Shortness of breath for 2 days	**8**	
9	9 yr	Foot	Moderate	Fracture	No	Low	Low	No	Bike accident	**9**	
10	5 yr	Abd	Mild	Routine	No	High	Low	No	Abdominal pain	**10**	

1. Overall, how well do you feel the list of cases is ordered in a way that has the most medically urgent cases (those needing to be read sooner) higher on the list with less urgent cases nearer the bottom (circle one)?

Completely acceptable   Mostly acceptable   Mostly unacceptable   Completely unacceptable

2. What changes would you make to the ranked list (in terms of how the cases are ordered)? Make any revisions in the right-most column in the table and describe below (continue on the back if necessary) why you made those changes.

Validating the Triage Algorithm

Provided each of the 5 radiologists with a set of 10 randomly generated, pre-ranked cases…

Found that:

- 3 of 5 docs made <u>no</u> changes or only swapped a <u>single</u> pair of *adjacent* cases (e.g., 3rd $\leftrightarrow$ 4th)
- 87% of all suggested changes were 1 or 2 places
- Only two “large” changes: -4 and +5 (same doc)
- Often used histories to substantiate changes

We’re still missing a key operational component…

How to include patients' waiting time?

Physician and department beliefs:

- "Stat" patients:
  - Should not wait >1 hour
  - A short (~10 minutes) initial wait should not affect queue position
- "Nonstat" patients:
  - Should generally be served after stat patients
  - Can "get lost" among fast-moving stat cases

Incorporating Wait Times

Started with the Standard Normal CDF

Scale Factor

Stat Cases
t in minutes

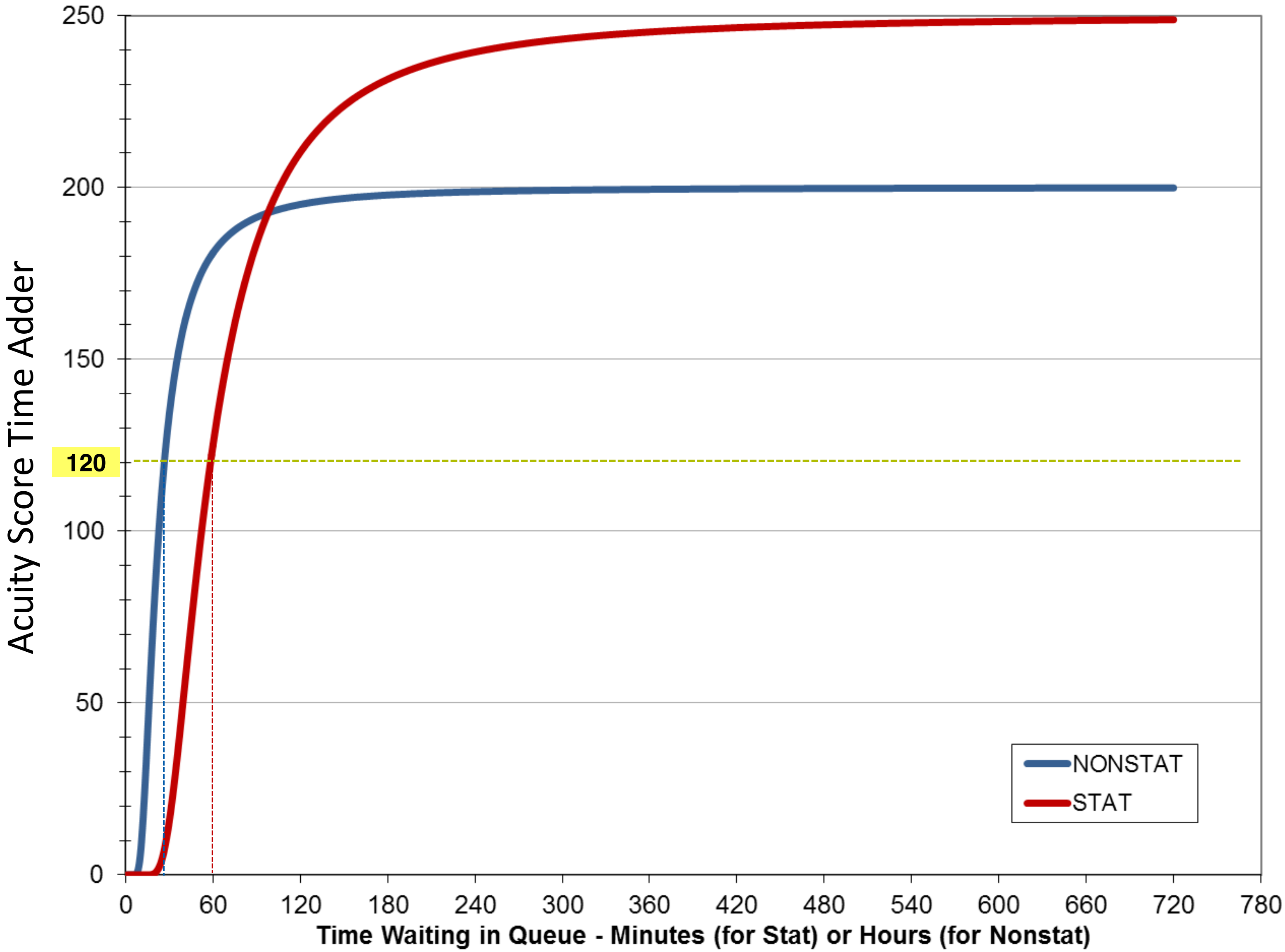
Time adder = $250e^{-.7\left(\frac{60}{t}\right)^2}$

Shape Factor

Nonstat Cases
t in hours

Time adder = $200e^{-.1\left(\frac{60}{t}\right)^2}$

Wait Time Adder



The Final Triage Algorithm

URGENCY =

12.31 * SUBJACU [*3 levels*]

\+ 25.94 * PATWAIT

\+ 15.98 * REFANX

\+ 15.35 * PATANX

\+ 28.45 * DUMTYPE

\+ 9.70 * DUMYOUNG

\+ Wait Time Adder {Stat or Nonstat}

Urgency scores range 0 – 370.04 for "stat" and 0 – 320.04 for "nonstat"

Implementation

RadStream: Radiology Workflow Management

User: LAURIE PERRY,Tech_Base   Services   shows: 18 exams   Feedback   News   Hide

Patient Name | MR# | Accession | Service: All | Modality: All | Location: All | Priority: All | Exam Type: All | Radiologist: All | Arts Status: All | RIS Status: All | Search

ARTS RADIOLOGY TECHNOLOGIST WORKLIST

Enter — Service: ICU

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
Pending: 11/3 1:32 PM	CHEST (1V)	RAD	5202302		Ordered: 11/3 1:32 PM			Inpt

Enter — Service: RAD

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
Pending: 11/3 3:03 PM	CLAVICLE R	RAD	5202388		Ordered: 11/3 3:03 PM			OP
Pending: 11/3 3:03 PM	CHEST (2V)	RAD	5202387		Ordered: 11/3 3:03 PM			OP

Enter — Service: RAD

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
Pending: 11/3 2:42 PM	ABDOMEN (1V)	RAD	5202370		Ordered: 11/3 2:42 PM			OP

Enter — Service: RAD

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
Pending: 11/3 2:31 PM	GASTROINTESTINAL TUBE (GJ)	RAD	5202357		Ordered: 11/3 2:31 PM			OP

Enter — Service: RAD

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
Pending: 11/3 11:34 AM	CYSTOURETHROGRAPHY (VOIDING)	RAD	5202202		Ordered: 11/3 11:34 AM			OP

Enter — Service: PMR

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
Pending: 11/3 3:11 PM	CHEST (1V)	RAD	5202396		Ordered: 11/3 3:11 PM			Inpt

Enter — Service: SUR

Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type

Radiologists Sign in to Services

- √ **Main Reading Room**
  - √ MSK (Pod 1)
  - √ Chest (Pod 2)
  - √ Abdomen (Pod 3)
  - √ Cardiac
  - √ Fluoro at Base
- ☐ **Outpatient Satellites**
  - ☐ Anderson
  - ☐ East
  - ☐ Fairfield
  - ☐ Kentucky
  - ☐ Mason
  - ☐ Harrison
  - ☐ West Chester
- ☐ **Neuro Imaging**
  - ☐ Neuro Base
  - ☐ Neuro OPM/Kenwood
- ☐ **Body Imaging**
  - ☐ CT Body - Chest
  - ☐ CT Body - Abdomen
  - ☐ CT Body - MSK
  - ☐ MRI Body
- ☐ **Fetal Imaging**
  - ☐ Fetal Imaging
- ☐ **Vascular / Interventional**
  - ☐ Vascular Interventional

Radiologists Select, Assign, & Review Cases

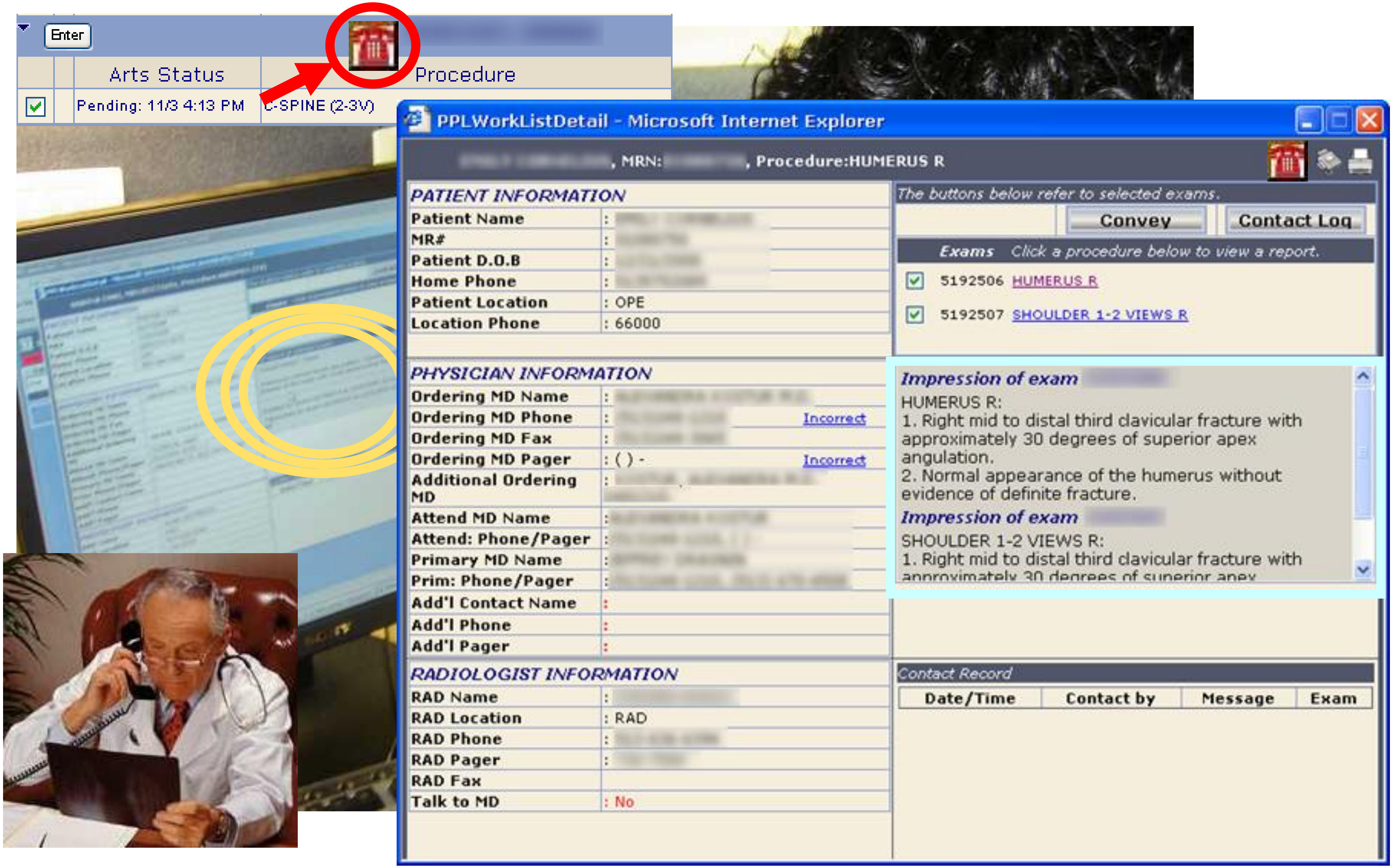
- Cases are pre-sorted per the triage algorithm
- Physicians may still select any case in their service

		Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
☑	!	Assigned: 11/3 3:57 PM	BONE AGE (SPECIFY)	RAD	5202401	Anderson	Completed: 11/3 3:19 PM	LAURIE PERRY		Op_PPL
☑	!	Assigned: 11/3 3:57 PM	SINUSES 3V+	RAD	5202402	Anderson	Completed: 11/3 3:19 PM	LAURIE PERRY		Op_PPL

		Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type
☑		Entered: 11/3 3:09 PM	CYSTOURETHROGRAPHY (VOIDING)	RAD	5202097	Fluoro at Base	Completed: 11/3 9:50 AM			OP

		Arts Status	Procedure	Mod.	Accession	Service	RIS Status	Radiologist	Ordering MD	Type

Completed Cases Automatically Routed to Call Center



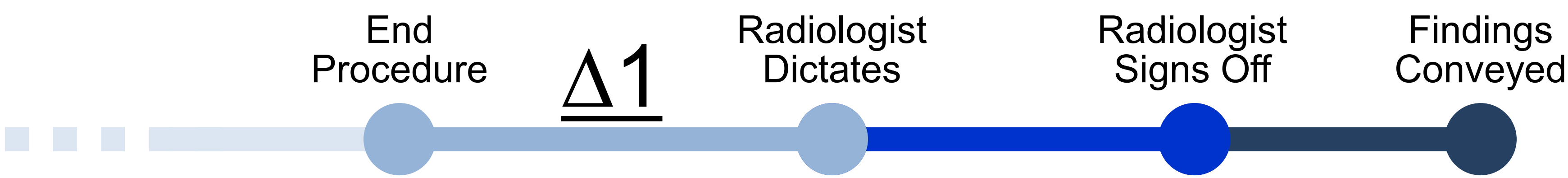
Results

Changes to Workflow

- Tech answers 5 questions during imaging session
- Paper requisitions eliminated
- Waiting exams automatically triaged (sorted)
- Enhanced visibility and coordination
  - Improved load-leveling across radiologists
- Expanded documentation of communications

Overall Goals:

- Ensure most critical patients are handled first
- Reduce duration and variability of patient waiting



Overall	55
Emergency	23
Outpatient	57
Inpatient	103

Median (minutes)

Baseline Sample:
6,093 exams, spanning 14 days

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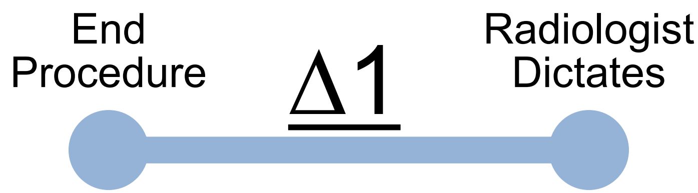


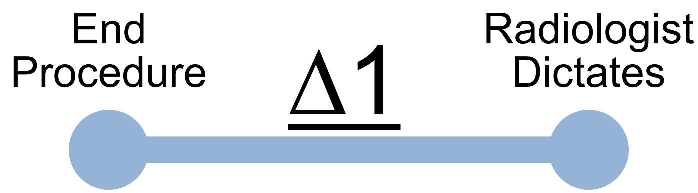
Overall	55	**34**
Emergency	23	**23**
Outpatient	57	**35**
Inpatient	103	**60**

Median (minutes)

Post-implementation Sample:
7,493 exams, spanning 15 days

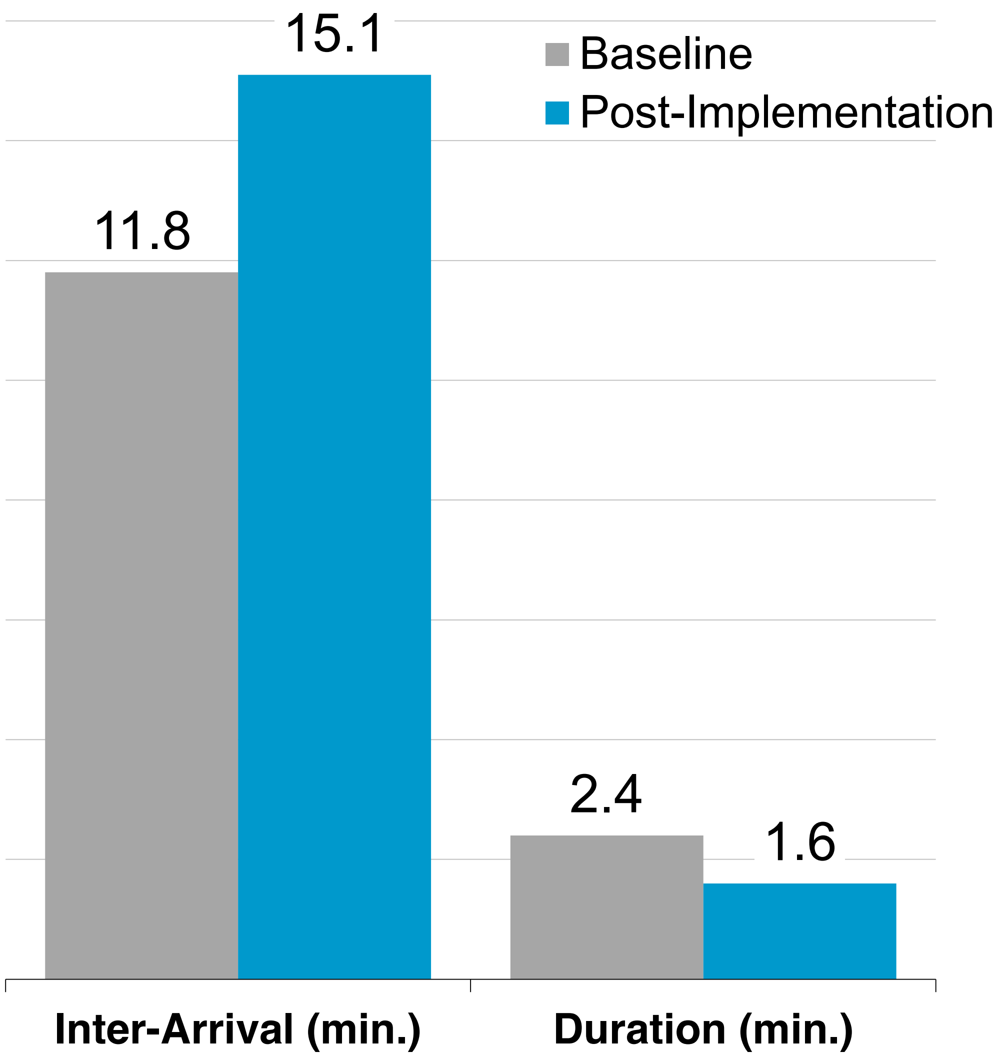
Overall Goals:

- Ensure most critical patients are handled first
- Reduce duration and variability of patient waiting



	Median (minutes)		Std. Dev. (minutes)	
Overall	55	**34**	430	**356**
Emergency	23	**23**	233	**185**
Outpatient	57	**35**	485	**350**
Inpatient	103	**60**	381	**490**

Physician Interruptions Decreased



Significantly different at P<.05

PRODUCTION AND OPERATIONS MANAGEMENT

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Interruption and Forgetting in Knowledge-Intensive Service Environments

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An increasing barrier to productivity in knowledge-intensive work environments is interruptions. Interruptions stop the current job and can induce forgetting in the worker. The induced forgetting can cause re-work; to complete the interrupted job, additional effort and time is required to return to the same level of job-specific knowledge the worker had attained prior to the interruption. This research employs primary observational and process data gathered from a hospital radiology department as inputs into a discrete-event simulation model to estimate the effect of interruptions, forgetting, and re-work. To help mitigate the effects of interruption-induced re-work, we introduce and test the operational policy of *sequestering*, where some service resources are protected from interruptions. We find that sequestering can improve the overall productivity and cost performance of the system under certain circumstances. We conclude that research examining knowledge-intensive operations should explicitly consider interruptions and the forgetting rate of the system's human workers, or models will overestimate the system's productivity and underestimate its costs.

Key words: health care; services; interruptions; simulation
History: Received: September 2011; Accepted: April 2013 by Michael Pinedo, after 3 revisions.

AMICAS RadStream™

PROVEN RESULTS

Research conducted at Cincinnati Children's Hospital Medical Center about the use of RadStream determined the following:

56% improvement in report turnaround time

25% reduction in radiologist interruptions

5 to 10% savings in full time radiologist staffing

MERGE Healthcare

Managing critical results and reducing interruptions

AMICAS RadStream is a next generation software product designed to mitigate the risks associated with communicating critical results to referring physicians. RadStream helps broker the communication of positive results to help meet the ever increasing scrutiny surrounding The Joint Commission on Accreditation of Healthcare's (JCAHO) national patient safety goals. Using a sophisticated prioritization algorithm, RadStream can dramatically improve radiologists' reading productivity because of reduced interruptions.

Discover True Workflow

RadStream focuses on improving three critical aspects of radiology workflow, which include:

- **Conveying Results.** The RadStream communications worklist facilitates the communication of positive results to referring physicians. This communications mechanism ensures that patients get the best care while your facility reduces the legal risk associated with not communicating positive results.
- **Reducing Interruptions.** With RadStream, technologists complement clinical data with subjective patient observations to create an objective clinical acuity score. This acuity score prioritizes the most acute cases (those most likely to interrupt radiologists) for radiologists in real time.
- **Brokering Communications.** With its patent-pending communications concept for automating and brokering interactions between clinicians, RadStream ensures that radiologists can easily be put in contact with referring physicians to discuss patients' cases. With RadStream, an administrative employee can track down referring physicians, which means that radiologists can focus on reading cases — and this saves time and money.

Integrated Critical Results Distribution

JCAHO has noted the importance of critical results communications in their national patient safety goals. A critical results communication solution fully integrated with AMICAS PACS™ offers the following benefits:

- Critical results communication fully integrated in the radiologists' workflow — no third-party applications or disruptions
- Patient data automatically included with critical results — no need to re-enter any data
- Radiologists dictating results to a single location — no need to duplicate radiologists' efforts in multiple locations
- A robust audit trail fully integrated with AMICAS PACS
- Allows radiologists to focus on reading cases and creates a mechanism for administrative employees to track down referring physicians

US008484048B2

(12) **United States Patent**
Halsted et al.

(10) **Patent No.: US 8,484,048 B2**
(45) **Date of Patent: Jul. 9, 2013**

(54) **AUTOMATED SYSTEM AND METHOD FOR PRIORITIZATION OF WAITING PATIENTS**

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(73) Assignee: **Cincinnati Children's Hospital Medical Center**, Cincinnati, OH (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 701 days.

(21) Appl. No.: **11/603,911**

(22) Filed: **Nov. 22, 2006**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(60) Provisional application No. 60/664,517, filed on Mar. 23, 2005.

(51) **Int. Cl.**
G06Q 10/00 (2012.01)

(52) **U.S. Cl.**
USPC **705/3**; 235/385

(58) **Field of Classification Search**
USPC 705/3
See application file for complete search history.

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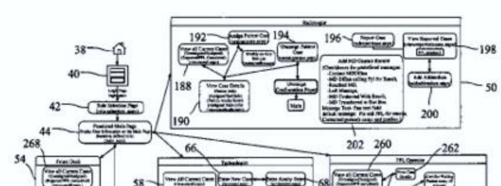
Primary Examiner — Hiep V Nguyen
(74) *Attorney, Agent, or Firm* — Baker & Hostetler LLP

(57) **ABSTRACT**

The present invention provides an automated triage system performs a computerized method that includes the steps of: (1) for plurality of patients, gathering medical factor(s) associated with each patient's medical condition, where the medical condition may be (a) a type of injury, (b) a symptom, (c) a condition of a patient, and/or (d) a demographic statistic of the patient; (2) for the same plurality of patients, gathering subjective perception(s) associated with each patient's medical condition, which may be (a) the anxiety of the patient, (b) the anxiety/concern of the referring physician, and/or (c) the anxiety of the reviewing attendee; and (3) ordering, by a computerized algorithm, the plurality of patients for medical treatment and/or medical assessment, based upon the medical factors and subjective perceptions gathered for each of the plurality of patients. The method may also include the step of gathering operational aspect(s), such as (a) waiting time of the patient, (b) medical treatment facilities availability, (c) medical treatment staff availability, (d) medical assessment facilities availability, and/or (e) medical assessment staff availability; where the ordering step includes the step of ordering, by the computer algorithm, the plurality of patients for medical treatment and/or medical assessment, based at least upon the medical factors, subjective perceptions and operational aspects gathered for each of the plurality of patients.

49 Claims, 17 Drawing Sheets



Conclusions for Care Delivery

- Decision-making in healthcare settings isn't always objective or rational
- Automating operational decision-making can be powerful
  - But sometimes the data you need don't exist
- The benefits of efficiency are multiplicative

“Fast is good, when you’re sitting in pain.”

Dr. Todd Guth, an intake physician in the new emergency department at University of Colorado Hospital, looks at 10-month-old Marcel’s ears for signs of infection while his mother, Monique Duran, holds him. Nurse Wendy Wilson, left, holds Marcel’s twin, Micah, while scribe Sarah Anderson takes notes. *Helen H. Richardson, The Denver Post*

Improving Care and Efficiency through Analytics: **Automating Patient Triage in Radiology**

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