Managing Variance to Reduce Proportion of ED Patients Undergoing CT that Fail Report-Turnaround Expectations

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No Disclosures
Learning Objectives

Exhibit reviewers should be able to apply available metrics to readily identify & effectively manage process improvements using

- Specific-cause variance management based upon
  - Shewhart case definition,
  - Fault Tree & Reliability analyses
- Deming/Shewhart Plan-Do-Study-Act cycles.
Background & Introduction

• Purpose
• Types of Variability
• Plan-Do-Study-Act
  • Defining, detecting & dealing with imperfect data
Purpose: Zero Defects

• SMC standard for ED CT ASAP RTAT: < 2 hrs
  – RTAT: Elapsed time between CT “order” & “signed” report
  – **Fail rate May 2012 ~12%** ED ASAP CT RTAT > 2hrs
  – Mean: 100 min; **STD: 647 min**

• Minimizing the time to correct diagnosis supports improved care quality (Voll K. Improving the utility of speech recognition through error detection. J Digit Imaging. 2008 Dec;21(4):371-377)
  – Earlier definitive treatment planning
  – Shorter patient times in ED
  – Increased ED capacity to see new patients

• Aligns with Institute of Medicine “Quality” goals (2001 IOM “Crossing the Quality Chasm”), eg:
  – Timely care: When it’s most effective
  – Efficient care: No waste
Shewhart & Variability: 
Chance-Cause vs. Assignable-Cause

• Chance-cause (Common-cause, Natural-cause):
  – Statistically predictable variation (eg, mean ± 2 STD)
  – “Noise” within system or process

• Assignable-cause (Special-cause)
  – Statistically unexpected (eg, > mean + 2 STD)
  – “Signal” from within system or process

• Control of special-cause events results in processes under statistical control (ie, only chance-cause variation), which reduces waste and improves quality
  (Shewhart WA. Economic control of quality of manufactured product. New York: Van Nostrand, 1931)
Defining, Detecting…

**Plan-Do**

- Assignable (special) cause = >3 STD from mean
  - Normal distribution, \(p(>3 \text{ std from mean}) = 0.3\%\)
  - Chebyshev's inequality: for any statistical distribution the probability of an event differing from the mean by more than \(n\) STD units diminishes as the square of \(n\) (ie, \(p(\text{event} > n \text{ STD from mean}) < 1/n^2\))
- Accumulate historical individual event data to determine mean & STD
  - Assignable-cause events: Filter individual event data for events differing from mean > 3 STD (Shewhart WA. Economic control of quality of manufactured product. New York: Van Nostrand, 1931)
  - Results in manageable number of cases for intense review
& Dealing Study-Act

• Evaluate assignable-cause events individually & collectively for point(s) & pattern(s) of process fault(s), respectively
  – Fault point(s): what, when, where, how, who
  – Reproducible current process-based classification scheme

• Develop & implement corrective measures
    • Models the causes of process faults, and highlights single-point failure (vulnerable) steps, as well as redundancy safeguards
    • Top-down approach using statistically identified assignable-cause events depicted graphically as causal links to prior events that contribute to the undesired “TOP” event (eg, the “undesired” event at top of fault tree: ED CT ASAP RTAT > 2 hrs).
    • Minimal cut set: least group of fault tree events that predict occurrence of TOP event
    • Guides nature of interventions: training vs. automation vs. redundancy

• Re-measure
  – RTAT
  – Reliability Analysis
Materials & Methods

- Setting
- RTAT data
- Classification scheme
- Identifying & classifying cases
- Fault Tree & Reliability Analyses
- Interventions
Setting

• Swedish Medical Centers, First Hill campus
  – 697 bed acute care tertiary referral hospital
• ED Visits – 40,000/year
  – Average ED stay – 160 minutes
• HIS & RIS: EPIC & Radiant (2010 IU6) (Epic Systems Corp; Verona, WI)
  – CPOE – ED 100%
• PACS: GE Centricity (Software 3.2) (GE Healthcare; Milwaukee, WI)
  – Priority-driven work lists (eg, STAT priority, ED location)
• CTs
  – GE Ultra 8 & Lightspeed16 (GE Healthcare; Waukesha, WI)
  – CT exam protocols assigned by ED MDs
    • Abdominopelvic exams: age & body habitus (small, medium, large)
• Speech/Voice recognition transcription: PowerScribe 360 (Nuance Communications; Burlington, VT)
  – Templates & macros: 99%
  – Self-edit: 100%
<table>
<thead>
<tr>
<th>Modali Pt Class</th>
<th>Desc A</th>
<th>Order Date</th>
<th>Checkin Time</th>
<th>Exam Begin Time</th>
<th>Exam End Time</th>
<th>Prelim Date/Time</th>
<th>Signing Date/Time</th>
<th>o2c</th>
<th>c2b</th>
<th>b2e</th>
<th>e2p</th>
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<td>4:02</td>
<td>4:22</td>
<td>4:18</td>
<td>4:38</td>
<td>20:48</td>
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## Monthly RTAT Dashboards

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<th>FH</th>
<th>ISQ</th>
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<td>ASAP</td>
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<td>46</td>
<td>39</td>
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<td>332</td>
<td>672</td>
<td>359</td>
<td>268</td>
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**Red dashboard light: OK, there’s a problem, but what is it & how are we going to fix it?**
## Cases (>3 STD) in Excel from EPIC CLARITY

<table>
<thead>
<tr>
<th>Modality</th>
<th>Description</th>
<th>Order</th>
<th>Check-in</th>
<th>Begin</th>
<th>End</th>
<th>Prelim</th>
<th>Signed</th>
<th>O2c min</th>
<th>c2b</th>
<th>b2e</th>
<th>e2p</th>
<th>e2s</th>
<th>o2s</th>
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<tbody>
<tr>
<td>CT</td>
<td>CT HEAD WITHOUT AND WITH CONTRAST</td>
<td>6/24/13</td>
<td>6/24/13</td>
<td>6/24/13</td>
<td>6/24/13</td>
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<td>14</td>
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<td>16</td>
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<td>45</td>
<td>320</td>
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<td>6/24/13</td>
<td>6/24/13</td>
<td>6/24/13</td>
<td>6/24/13</td>
<td>6/24/13</td>
<td>6/24/13</td>
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<td>14</td>
<td>0</td>
<td>53</td>
<td>326</td>
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<td>6/18/13</td>
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<td>6/18/13</td>
<td>6/18/13</td>
<td>6/18/13</td>
<td>6/18/13</td>
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<td>0</td>
<td>725</td>
<td>0</td>
<td>23</td>
<td>779</td>
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<td>6/20/13</td>
<td>6/20/13</td>
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<td>US ABDOMEN-LIMITED</td>
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<td>6/16/13</td>
<td>6/16/13</td>
<td>6/16/13</td>
<td>6/16/13</td>
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<td>0</td>
<td>750</td>
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<td>CTA CHEST WITHOUT AND WITH CONTRAST</td>
<td>6/29/13</td>
<td>6/29/13</td>
<td>6/30/13</td>
<td>6/30/13</td>
<td>6/30/13</td>
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<td>18</td>
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<td>6/21/13</td>
<td>6/21/13</td>
<td>6/21/13</td>
<td>6/21/13</td>
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<td>6/21/13</td>
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<td>737</td>
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<td>6/20/13</td>
<td>6/20/13</td>
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<td>6/20/13</td>
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<td>10</td>
<td>0</td>
<td>732</td>
<td>744</td>
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</tr>
</tbody>
</table>
EPIC-based Classification

**Order - Check-In (O-CI)**
- O1: Delay printing
- O2: Order for future date
- O3: Patient condition / Exam on hold

**Check-in - Begin (CI-B)**
- C1: Oral Contrast
- C2: Oral Contrast + Additional Delay
- C3: Patient condition / Exam on hold
- C4: Pre-Medicated
- C5: Patient Prioritization / Exam Delay
- C6: Routine Exam / Delay until next day

**Begin - End (B-E)**
- B1: Time Stamp
- B2: Not Verified
- B3: Exam Not Ended
- B4: Images not in PACS
- B5: Midnight Begin to End

**End - Sign (E-S)**
- E1: Prelim to Sign Delay
- E2: Marked Dictated - No Dictation
- E3: Delay in dictation
- E4: Patient to be called back
- E5: Radiologist specific exam
- E6: Locked to Radiologist
- E7: Research Exam
- E8: Other
# Case Classification Spreadsheets

<table>
<thead>
<tr>
<th>Day</th>
<th>Shift</th>
<th>O-Cl</th>
<th>Cl-B</th>
<th>B-E</th>
<th>E-S</th>
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<tbody>
<tr>
<td>Tuesday</td>
<td>3</td>
<td>1</td>
<td>Oral</td>
<td>1</td>
<td>1 hour Read Delay</td>
</tr>
<tr>
<td>Wednesday</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>Time Stamp</td>
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<tr>
<td>Monday</td>
<td>2</td>
<td>1</td>
<td>Oral + Add 1 hour delay</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>1</td>
<td></td>
<td>Patient Condition</td>
<td>Past Midnight begin to end</td>
<td>1 Locked in draft status</td>
</tr>
<tr>
<td>Wednesday</td>
<td>3</td>
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<td></td>
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<tr>
<td>Wednesday</td>
<td>2</td>
<td></td>
<td>Patient in TB Isolation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td>2</td>
<td>1</td>
<td>Oral Contrast 2 hour+ delay</td>
<td>1 Past Midnight begin to end</td>
<td></td>
</tr>
<tr>
<td>Saturday</td>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Saturday</td>
<td>3</td>
<td></td>
<td></td>
<td>1</td>
<td>Past Midnight begin to end</td>
</tr>
<tr>
<td>Friday</td>
<td>3</td>
<td></td>
<td>Oral Contrast 2 hour+ delay</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>1</td>
<td></td>
<td>Oral Contrast with unkown additional delay of 1 hour</td>
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<tr>
<td>Sunday</td>
<td>1</td>
<td></td>
<td>Oral Contrast Given+Patient vomiting delaying actual CT scan</td>
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<tr>
<td>Monday</td>
<td>1</td>
<td></td>
<td>Patient sent to the floor from the ED with orders for a CT. Patient prioritized with other in-patient and ED exams</td>
<td>1</td>
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</table>

Inter-reader (n=2) agreement “near perfect”: (Kappa = 0.94)
# All CT Subroutine Fault Distribution

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<th>Entry Event</th>
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<td>Delay in dictation</td>
<td>71</td>
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<td>BE1</td>
<td>Time Stamp</td>
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<tr>
<td>CB2</td>
<td>Conflicting Diagnostic Evaluations</td>
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<tr>
<td>CB1</td>
<td>Oral Contrast</td>
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<tr>
<td>BE5</td>
<td>Midnight Begin to End</td>
<td>10</td>
</tr>
<tr>
<td>BE2</td>
<td>Not Verified</td>
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<tr>
<td>ES5</td>
<td>Radiologist specific exam</td>
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<tr>
<td>ES8</td>
<td>Other</td>
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<td>CB3</td>
<td>Patient condition</td>
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<td>CB5</td>
<td>Excess Exam Volumes</td>
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<td>Exam Not Ended</td>
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<td>Prelim to Sign Delay</td>
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<td>Marked Dictated - No Dictation</td>
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<td>ES4</td>
<td>Patient to be called back</td>
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<td>OC1</td>
<td>Delay printing</td>
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<td>ES6</td>
<td>Locked to Radiologist</td>
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<td>OC3</td>
<td>Patient condition / Exam on hold</td>
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<td>CB4</td>
<td>Pre-Medicated</td>
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<td>CB6</td>
<td>Tranport Delay</td>
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</tr>
<tr>
<td>CB7</td>
<td>Routine Exam / Next Day Delay</td>
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<tr>
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<tr>
<td>ES7</td>
<td>Research Exam</td>
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</table>
Study

• Fault Tree Analysis
  – Graphical portrayal of “faults” based on 2 basic logic gates that define dependency between prior & subsequent events
    – “AND” requires every input event to occur for output event to occur
    – “OR” requires any of the input events to occur for the output event to occur
  – A hierarchical fault tree with single TOP event (CT ASAP RTAT > 2 hrs) as the inverted tree trunk, and the root causes of the error dangling as branches below

• Reliability Analysis
  – Reliability = p(ED CT ASAP RTAT < 2hrs)
Reliability Analysis
Failure Criticality Index (FCI)

RBD:

\[
I_{k}^{FCI}(t) = \frac{\text{Number of system failures caused by comp } k \text{ in } (0, t)}{\text{Number of system failures in } (0, t)}
\]

= Portion of TOP EVENTs caused by a specific \((k)\) entry event
Act

- Review data & “patterns” with departmental managers, technologists, & radiologists
  - “Brainstormed” for potential solutions
    - Piloted proposed interventions
      - Train, train, train…
        - Re-measured
Results

- Primary findings
  - Paredo graphs
  - Fault Tree
  - Minimal Cut Sets
  - Interventions
  - Variance
- Secondary findings
  - Non value-added steps
  - Cost of non value-added steps
## All CT Summary: Failed Entry Events

<table>
<thead>
<tr>
<th>Entry Event</th>
<th>Short Description</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES3</td>
<td>Delay in dictation</td>
<td>71</td>
</tr>
<tr>
<td>BE1</td>
<td>Time Stamp</td>
<td>14</td>
</tr>
<tr>
<td>CB2</td>
<td>Conflicting Diagnostic Evaluations</td>
<td>14</td>
</tr>
<tr>
<td>CB1</td>
<td>Oral Contrast</td>
<td>11</td>
</tr>
<tr>
<td>BE5</td>
<td>Midnight Begin to End</td>
<td>10</td>
</tr>
<tr>
<td>BE2</td>
<td>Not Verified</td>
<td>10</td>
</tr>
<tr>
<td>ES5</td>
<td>Radiologist specific exam</td>
<td>9</td>
</tr>
<tr>
<td>ES8</td>
<td>Other</td>
<td>8</td>
</tr>
<tr>
<td>CB3</td>
<td>Patient condition</td>
<td>8</td>
</tr>
<tr>
<td>CB5</td>
<td>Excess Exam Volumes</td>
<td>7</td>
</tr>
<tr>
<td>BE3</td>
<td>Exam Not Ended</td>
<td>4</td>
</tr>
<tr>
<td>ES1</td>
<td>Prelim to Sign Delay</td>
<td>2</td>
</tr>
<tr>
<td>ES2</td>
<td>Marked Dictated - No Dictation</td>
<td>2</td>
</tr>
<tr>
<td>ES4</td>
<td>Patient to be called back</td>
<td>2</td>
</tr>
<tr>
<td>OC1</td>
<td>Delay printing</td>
<td>1</td>
</tr>
<tr>
<td>ES6</td>
<td>Locked to Radiologist</td>
<td>1</td>
</tr>
<tr>
<td>OC3</td>
<td>Patient condition / Exam on hold</td>
<td>0</td>
</tr>
<tr>
<td>OC2</td>
<td>Order for future date</td>
<td>0</td>
</tr>
<tr>
<td>CB4</td>
<td>Pre-Medicated</td>
<td>0</td>
</tr>
<tr>
<td>CB6</td>
<td>Transport Delay</td>
<td>0</td>
</tr>
<tr>
<td>CB7</td>
<td>Routine Exam / Next Day Delay</td>
<td>0</td>
</tr>
<tr>
<td>BE4</td>
<td>Images not in PACS</td>
<td>0</td>
</tr>
<tr>
<td>ES7</td>
<td>Research Exam</td>
<td>0</td>
</tr>
</tbody>
</table>

**ED CT ASAP n = 4**
ED CT ASAP
Stable Patterns over Time

May 2012-Feb. 2013

May 2012-July 2013
Fault Tree
Minimal Event Cut Set

“Undesired” TOP event occurs if Entry event(s) in any row occur(s)
Interventions by Subroutine (% of case “faults”)

• Order – Check-in: (0.5%)
  – OC1 [Print Delay]: Increase redundancy
    • Add pager tied to technologists’ work list
• Check-in – Begin: (22.5%)
  – All: Increase Reliability
    • Train, train, train… (with timely & consistent feedback)
    • Formalize & standardize process steps (what, how, & when of documentation)
  – CB1&2 [Oral Contrast]: Revise Process
    • Marked reduction in use of alimentary contrast (eg, 0.5 cases/month)
  – CB3 [Patient Condition]: Increase Reliability
    • {CPOE pre-list checklist assuring patient availability}
  – CB5 [Prioritization, including consults & competing exams]:
    • {CPOE pre-list checklist establishing priorities}
• Begin – End: (6%)
  – BE2 [Not Verified in PACS]: Increase Reliability
    • Train, train, train…
    • Ultra-8 CT does not currently support “Auto-Verify” work flow
Interventions by Subroutine (% of case “faults”)

- End – Sign: (48.5%) WIP
  - ES1 [Preliminary Status]: Increase Reliability
    - Train, train, train… (with timely & consistent feedback)
  - ES2 [Marked Dictated without Report]: Increase Reliability
    - Train, train, train… (with timely & consistent feedback)
    - {Automate (Administratively “block” function)}
  - ES3 [Delay in Opening Exam in PACS]: Increase Redundancy
    - {Match radiologist staffing numbers to mirror demand}
  - ES5 [Subspecialty Requirement]: Increase Redundancy
    - {Coordinate specialty coverage across radiology groups within PH&S/SMC}
  - ES6 [Locked to Radiologist (Opened, Not reported)]:
    - {“Time-out” release for PowerScribe reports without text}
- Multiple: (22.5%)
  - As above
ED CT ASAP Variance

- FCT Std Dev
- FCT Mean
- FCT Variance
- 2 per. Mov. Avg. (FCT Mean)
Where to Focus Limited Resources? Reliability Block Diagram (RBD) & Failure Criticality Index (FCI)

ED CT ASAP RTAT > 2hr
Closely correlates with current dashboard failure rate of 6%, with mean 80 min, STD 129 min (albeit lower than starting 12%, with mean 100 min & STD 647 min)
Secondary Findings

• Hidden costs of non-value added “extra clicks” to end examinations in EPIC and verify in PACS – after ending exam on CT:
  – Personnel: ~$30K/CT scanner/year
  – Capacity: ~$150K/CT scanner/year

• Obvious & almost impossible to address within departmental budget
Discussion

• High Expectations
• Purpose before problems
• Strengths of main findings
• Limitations
• Future
High Expectations

• National focus on development of accountable healthcare systems that improve quality, contain costs, reduce waste, eliminate inefficiency, & enhance productivity  Boland GWL AJR 2010; 195:707–711

• Timely, effective & efficient provision of final diagnostic imaging reports is a critical task included in the ACR’s “Standard for Communication - Diagnostic Radiology”


• “…it has been found possible to set up limits within which the results of routine efforts must lie if they are to be economical. Deviations in the results of a routine process outside such limits indicate that the routine has broken down and will no longer be economical until the cause of trouble is removed.”  Shewhart WA. Economic control of quality of manufactured product. New York: Van Nostrand, 1931.
“Focus on your purpose before focusing on your problems”

• Provision of patient- & referral-centered “quality” necessitates more holistic focus on continual improvement of processes by which provided services meet or exceed customer expectations (Ondategui-Parra S. Survey of the Use of Quality Indicators in Academic Radiology Departments AJR 2006; 187:W451–W455)

• “Quality management, a fact-based management concept used intensively by industry to improve quality while lowering costs, requires the regular measurement of indicators and comparisons with standards to identify opportunities for improvement.” (Ondategui-Parra S. Survey of the Use of Quality Indicators in Academic Radiology Departments AJR 2006; 187:W451–W455)

• “…the primary purpose of monitoring should be quality improvement… by identifying unusual (special cause) variation, investigating, and learning from such a process.” (Tom Marshall in Comment: Guthrie B. Routine mortality monitoring for detecting mass murder in UK general practice: test of effectiveness using modelling Brit J Gen Pract 2008; 58: 311–317)
Significance of Main Findings

• Enterprise dashboard data can guide, but, by itself, does not inform development of nuanced interventions

• Use of “assignable cause” variations as cases allows
  – Reproducible basis for fault classification
  – Modest reduction on portion of ED CT ASAP cases failing institutional standards, although interventions to eliminate “assignable cause” variation substantially reduced variance variability.
    • Provides “best case” estimate of current process capabilities

• FTA & Reliability analyses showed our processes lack redundancy, & subroutine reliability is too low to achieve “zero defects”
  – “Zero defects” will likely require many small redesigns

• Hidden costs are not inconsequential
Limitations

• Single “volunteer physician” institution within multi-facility healthcare organization (eg, command & control)

• Incomplete evaluation of all process subroutines, eg:
  – Volume-independent variations in work habits among radiologists have substantial impact on overall RTAT (Krishnaraj A. Voice Recognition Software: Effect on Radiology Report Turnaround Time at an Academic Medical Center AJR 2010; 195:194–197)

• IT technologies
  – Not uniformly IHE-compliant (eg, modest interoperability)
  – Limited ability to increase automation & redundancy ($$)
    • Differing technical capabilities of imaging platforms across system
    • Internal politics, re: lack of consensus among competing radiology groups

• Process & methodology differences among RTAT studies hampers direct comparisons
  – None-the-less, fully-implemented VR reduces mean RTAT & SD by >85%.
Future

• End – Sign subroutines
  – Radiologists work flow
    • Effective?
    • Efficient?
  – Stay tuned!
• IT platforms
  – IHE compliant
  – Fully implemented
• Downtime Procedures
• Disaster Procedures
one only becomes real
at the point of action...

Thank-you