Technical Appendix:

Formalizing Theoretical Insights from Ethnographic Evidence:

Revisiting Barley's Study of CT-Scanning Implementations

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For more information on the research program that generated this paper, visit
http://web.mit.edu/nelsonr/www/.

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Appendix

List of Model Equations in VENSIM

The model is written using the VENSIM simulation software produced by Ventana systems (more information available at www.vensim.com. The syntax of each entry is as follows:

VARIABLE X = f(VARIABLE A,…,VARIABLE Z)
~ Units of Measure
~ Comments |

A simulating version of the model in the written in the VENSIM software is available at <web.mit.edu/nelsonr/www>.

****
.Scanning Activity
**********~
|

Fraction of Operating Decisions by Doctors=
Indicated Fraction of Operating Decisions by Doctors
*Doctor Participation in Scanning
~ dimensionless
~ The actual fraction of operating decisions that doctors make, suggesting that while technicians may be present (they do not have autonomy to leave the scanning area), only doctors operate the CT machine
|

Indicated Fraction of Operating Decisions by Doctors=
(Doctor Operating Knowledge*(1-Technologist Operating Knowledge)
+(1-Technologist Operating Knowledge)
*(1-Doctor Operating Knowledge)
*Fraction of New Operating Decisions by Doctors)
~ dimensionless
~ The fraction of operating decisions made by doctors indicated by the relative balance of operating knowledge.
|

Fraction of New Operating Decisions by Doctors=
Doctors Knowledge Relative to Technologists^Doctors Knowledge Bias/(1+Doctors Knowledge Relative to Technologists)
^Doctors Knowledge Bias)

~ dimensionless
~ The percentage of operating decisions for which neither groups has the appropriate knowledge that doctors make. Doctors make new decisions when they possess operating knowledge that technologists do not have.
|

Doctors Knowledge Relative to Technologists=
Doctor Operating Knowledge/Technologist Operating Knowledge

~ dimensionless
~ The ratio of doctors' operating knowledge to technologists. This variable is used as a measure of the relative distribution of expertise between the two groups.
|

Doctors Knowledge Bias= 2

~ dimensionless
~ The knowledge bias determines the shape of the function relating the relative balance of knowledge to who gets to make the new decisions.
|

Fraction of Operating Decisions by Technologists=
Indicated Fraction of Operating Decisions by Technologists*Doctor Participation in Scanning + (1-Doctor Participation in Scanning)

~ dimensionless
~ The actual fraction of decisions about how to use the CT machine to produce a scan made by technologists. Technologists make decisions only when the doctors present delegate decisions to them.
|

Indicated Fraction of Operating Decisions by Technologists=
Technologist Operating Knowledge+(1-Technologist Operating Knowledge)
*(1-Doctor Operating Knowledge)
*(1-Fraction of New Operating Decisions by Doctors)
~ dimensionless
~ The fraction of operating decisions made by technologists indicated by the relative balance of operating knowledge.

|

Fraction of Operating Decisions by Technologists with Doctor Supervision=
Fraction of Operating Decisions by Technologists
-(1-Doctor Participation in Scanning)

~ dimensionless
~ The percentage of decisions about how to conduct scans that technologists make while doctors are present in the CT area, suggesting that technologists and doctors can discuss options and the rationale for trying different things to produce a scan useful to diagnosis, although only technologists operate the CT machine
|

****
.Technologist Operating Knowledge
**********~
|

Technologist Operating Knowledge=
INTEG (Technologist Operational Learning
+Increase in Technologist Operating Knowledge from Staff Transfers,
Initial Technologist Operating Knowledge)

~ dimensionless
~ The accumulation of expertise technologists have about how to operate the CT machine to produce a scan useful to diagnosis, increased by experience using the machine when doctors are present to provide rationale for trying certain maneuvers
|

Initial Technologist Operating Knowledge= 0.1

~ dimensionless
~ The amount of expertise about how to operate the CT machine that technologists staffing the CT area have when the machine is initially deployed (this expertise would have been accumulated from experiences outside the CT unit under study).
|

Technologist Operational Learning= MAX(0,
(Fraction of Operating Decisions by Technologists with Doctor Supervision
-Technologist Operating Knowledge)
/Time to Accumulate Operating Knowledge)

~ 1/Day
~ The rate at which technologists learn about how to use the CT machine to produce scans that aid diagnosis (technologists gain operating knowledge by using the machine and exercising discretion in how to conduct the scans)
|

Time to Accumulate Operating Knowledge= 28
~ Days
~ The amount of on-the-job time it takes to learn from on-the-job experiences using the CT machine to produce scans useful to dianosis (it is assumed that technologists and doctors learn at about the same rate, given the same experiences)
|

Increase in Technologist Operating Knowledge from Staff Transfers=
(Technologist Operating Knowledge
*Fraction Increase in Technologist Experience/TIME STEP)
*PULSE(Day of Staffing Change,TIME STEP)

~ 1/Day
~ The rate at which technologists collectively gain knowledge about using the CT machine from having experienced technologists transferred into the unit or inexperienced technologists transferred out of the unit
|

Fraction Increase in Technologist Experience= 0

~ dimensionless
~ The collective knowledge gained when technologists least experienced in CT scanning are transferred out of the CT area or when technologists more experienced with CT scanning are transferred into the CT area
|

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********************************************************
        .Doctor Operating Knowledge
********************************************************~
        |

Doctor Operating Knowledge= INTEG (Doctor Operational Learning
        -Decrease in Doctor Operating Knowledge from Rotation,
                initial doctor operating knowledge)

        ~       dimensionless
        ~       The accumulated expertise that doctors have about how to use the CT
                machine to produce a scan
                |

Initial Doctor Operating Knowledge= 0.5

        ~       dimensionless
        ~       The amount of expertise about how to operate the new CT machine that
                doctors staffing the CT area have when it is initially deployed (knowledge
                accumulated from experiences preceding the period of the CT unit under
                study)
                |

Doctor Operational Learning= MAX(0,(Fraction of Operating Decisions by Doctors
        -Doctor Operating Knowledge)/Time to Accumulate Operating Knowledge)

        ~       1/Day
        ~       The rate at which doctors learn about how to use the CT machine to
                produce scans (doctors learn by using the machine to produce scans)
                |

Decrease in Doctor Operating Knowledge from Rotation=
        ((Doctor Operating Knowledge*Fraction Experienced Doctors Leaving)
        /TIME STEP)*PULSE(Day of Staffing Change,TIME STEP)

        ~       1/Day
        ~       The collective decrease in doctors' understanding  of how to produce scans
                using the CT machine, which results from experienced radiologists leaving
                and inexperienced doctors entering  the area when there is a staffing
                change
                |
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********************************************************
        .Switch to Change to Extended Model
********************************************************~
        |

Participation Switch=1

        ~       dimensionless
        ~       Switch to change formulation initially presented in the paper to the full
                mode.  Set participation switch =0 for initial model and equal to 1 for
                extended model.
                |

********************************************************
        .Doctor Participation and Role Reversals
********************************************************~
        |

Doctor Participation in Scanning=
        Smooth(Indicated Doctor Participation in Scanning,
        Time to Adjust to Role Reversal)*Participation Switch
        +(1-Participation Switch)

        ~       dimensionless
        ~       The fraction of time doctors are in the CT scanning room while scans are
                being produced.  Doctors' decision to participate is determine by the recent
                instances of role reversals. The SMOOTH function captures the delay in
                reacting role reversals.
                |

Time to Adjust to Role Reversal= 4

        ~       Week
        ~       Average time required for doctors to recognize role reversals and take
                action to avoid them.
                |

Indicated Doctor Participation in Scanning=
        function for effect of technologists' diagnostic knowledge on doctor
        participation(Threat of Role Reversal)
                ~       dimensionless
                ~       Non-linear function relating the threat of role reversals to doctors' \
                        participation in the scan.
                |
```

function for effect of technologists' diagnostic knowledge on doctor participation(
[(0,0)-(0.1,1)],
(0,1),(0.015,0.98),(0.025,0.93),(0.03,0.75),(0.0382759,0.528736),(0.05,0.2),
(0.06,0.065),(0.075,0),(0.1,0),(0.5,0),(1,0))

~ dimensionless
~ A function capturing the nonlinear effects that technologists' possession of diagnostic knowledge has on doctors' willingness to be around technologists who seem to possess expertise that doctors should have but do not.
|

Threat of Role Reversal=
Technologist Diagnostic Knowledge*(1-Total Doctor Diagnostic Knowledge)

~ dimensionless
~ The probability that technologists possess CT-specific diagnostic knowledge that doctors do not and so by interpreting scans may up-end the hierarchical and social norm that doctors should know more than technologists
|

****
.Doctor Diagnostic Knowledge
**********~
|

Total Doctor Diagnostic Knowledge=
MIN(1,Doctor Diagnostic Knowledge from Experience
+Doctor Diagnostic Knowledge from Schooling)

~ dimensionless
~ The total diagnostic expertise that doctors bring to bear in interpreting a CT scan (the sum of diagnostic knowledge gained from medical training and experience using other technologies and the diagnostic experience gained from on-the-job experience using the new CT technology
|

Doctor Diagnostic Knowledge from Schooling= 0.5

~ dimensionless
~ The general diagnostic knowledge that doctors possess, regardless of whether they have had experience with the CT scanner
|

Doctor Diagnostic Knowledge from Experience= INTEG (Doctor Diagnostic Learning-
Decrease in Doctor Diagnostic Knowledge from Rotation,
initial doctor diagnostic knowledge from experience)

~ dimensionless
~ The CT-specific knowledge that doctors have about how to interpret a CT scan, acquired from on-the-job experience in this unit or from a previous rotation
|

Initial Doctor Diagnostic Knowledge from Experience=0.4

~ dimensionless
~ The amount of CT-specific expertise in interpreting scans that doctors (staffing the CT area when the new machine is deployed) have accumulated from on-the-job experience outside the CT unit under study
|

Doctor Diagnostic Learning=
MAX(0,(Attainable Diagnostic Knowledge From Experience
-Doctor Diagnostic Knowledge from Experience)
/Time for Doctors to Accumulate Diagnostic Knowledge)

~ 1/Day
~ The rate at which doctors learn about interpreting CT scans from on-the-job experience
|

Attainable Diagnostic Knowledge From Experience=
Potential Doctor Diagnostic Knowledge from Experience
*Doctor Participation in Scanning

~ dimensionless
~ The CT-specific knowledge that doctors can acquire by observing how to use the CT machine to produce scans whose interpretation aids diagnosis of pathology. Doctors can only gain additional knowledge from experience when they participate in scanning.
|

Time for Doctors to Accumulate Diagnostic Knowledge=28

~ Days
~ The amount of on-the-job time needed for doctors to learn from on the job experiences interpreting CT scans
|

Potential Doctor Diagnostic Knowledge from Experience=
1-Doctor Diagnostic Knowledge from Schooling

~ dimensionless
~ The percentage of total diagnostic knowledge that doctors must learn from on-the-job experience using particular technologies, rather than from medical training
|

Decrease in Doctor Diagnostic Knowledge from Rotation=
((Doctor Diagnostic Knowledge from Experience
*Fraction Experienced Doctors Leaving)/TIME STEP)
*PULSE(Day of Staffing Change, TIME STEP)

~ 1/Day
~ The collective decrease in doctors' understanding of how to interpret CT scans, which results from experienced radiologists leaving and inexperienced doctors entering the area when there is a staffing change
|

Day of Staffing Change=1000

~ Days
~ Day on which radiologists inexperienced with CT begin rotating through the CT unit
|

Fraction Experienced Doctors Leaving=
0
~ dimensionless
~ The fraction of the radiologists leaving the CT unit when there is a staffing change
|

****
.Technologist Diagnostic Knowledge
**********~
|

Technologist Diagnostic Knowledge= INTEG (
Technologist Diagnostic Learning, Initial Technologist Diagnostic Knowledge)

~ dimensionless
~ The accumulated expertise about how to read CT scans to diagnose pathology that technologists gain from on-the-job experiences of operating the CT machine while talking with doctors about what they're doing and why
|

Initial Technologist Diagnostic Knowledge=0

~ dimensionless
~ The knowledge about how to interpret CT scans to diagnose pathology that technologists staffing the CT area when the machine is first deployed have (accumulated from experiences outside the CT unit under study)
|

Technologist Diagnostic Learning=
MAX(0,(Maximum Technologist Diagnostic Knowledge
*Fraction of Operating Decisions by Technologists with Doctor Supervision
-Technologist Diagnostic Knowledge)
/Time for Technologists to Accumulate Diagnostic Knowledge)

~ 1/Day
~ The rate at which technologists learn about how to interpret CT scans (technologists gain diagnostic knowledge when doctors talk to them about the scans and provide rationale for conducting the scans in certain ways; there is a limit to how much technologists can learn about diagnosis, since they lack the rigorous and extended training of medical school and residency, so technologists can never gain as much diagnostic knowledge as doctors)
|

Maximum Technologist Diagnostic Knowledge=0.4

~ dimensionless
~ The most CT-specific diagnostic knowledge that technologists can accumulate from on-the-job experience (considerably less than 1, since they have little formal medical training and probably very little diagnostic experience using other tools)
|

Time for Technologists to Accumulate Diagnostic Knowledge=56

~ Days
~ The amount of on-the-job time needed for technologists to learn from on-the-job experiences of producing and reading scans to diagnose pathology (because technologists have little formal medical training, it is assumed they take at least twice as long as doctors to learn diagnostic skills from looking at CT scans)
|

****
.Practical Knowledge
**********~

Practical Knowledge= (Technologist Operating Knowledge
+Total Doctor Diagnostic Knowledge)/2
|

****
.Control
**********~
Simulation Control Parameters
|

FINAL TIME =260

~ Days
~ The final time for the simulation.
|

INITIAL TIME = 0
~ Week
~ The initial time for the simulation.
|

SAVEPER =

TIME STEP
~ Month [0,?]
~ The frequency with which output is stored.
|

TIME STEP =0.25
~ Month [0,?]
~ The time step for the simulation.
|

Instructions for replicating the simulations in the paper:

To replicate the Suburban run in the simple model, set:

Participation Switch=0
Initial Technologist Operating Knowledge=.3
Initial Doctor Operating Knowledge=.5

To replicated the Urban run in the simple model, set:

Participation Switch=0
Initial Technologist Operating Knowledge=.1
Initial Doctor Operating Knowledge=.5

To replicate the Suburban run in the extended model, set:

Participation Switch=1
Initial Technician Operating Knowledge=.3
Initial Doctor Operating Knowledge=.5
Initial Technician Diagnostic Knowledge=00
Initial Doctor Diagnostic Knowledge from Experience=.4
Day of Staffing Change=21
Fraction Experienced Doctors Leaving=.83
Fraction Increase in Technologist Experience=0

To replicate the Suburban run in the extended model, set:

Participation Switch=1
Initial Technologist Operating Knowledge=.1
Initial Doctor Operating Knowledge=.5
Initial Technologist Diagnostic Knowledge=0
Initial Doctor Diagnostic Knowledge from Experience=.4
Day of Staffing Change=105
Fraction Experienced Doctors Leaving=.8
Fraction Increase in Technologist Experience=.5