Bringing Data to the Provider: Remote Monitoring

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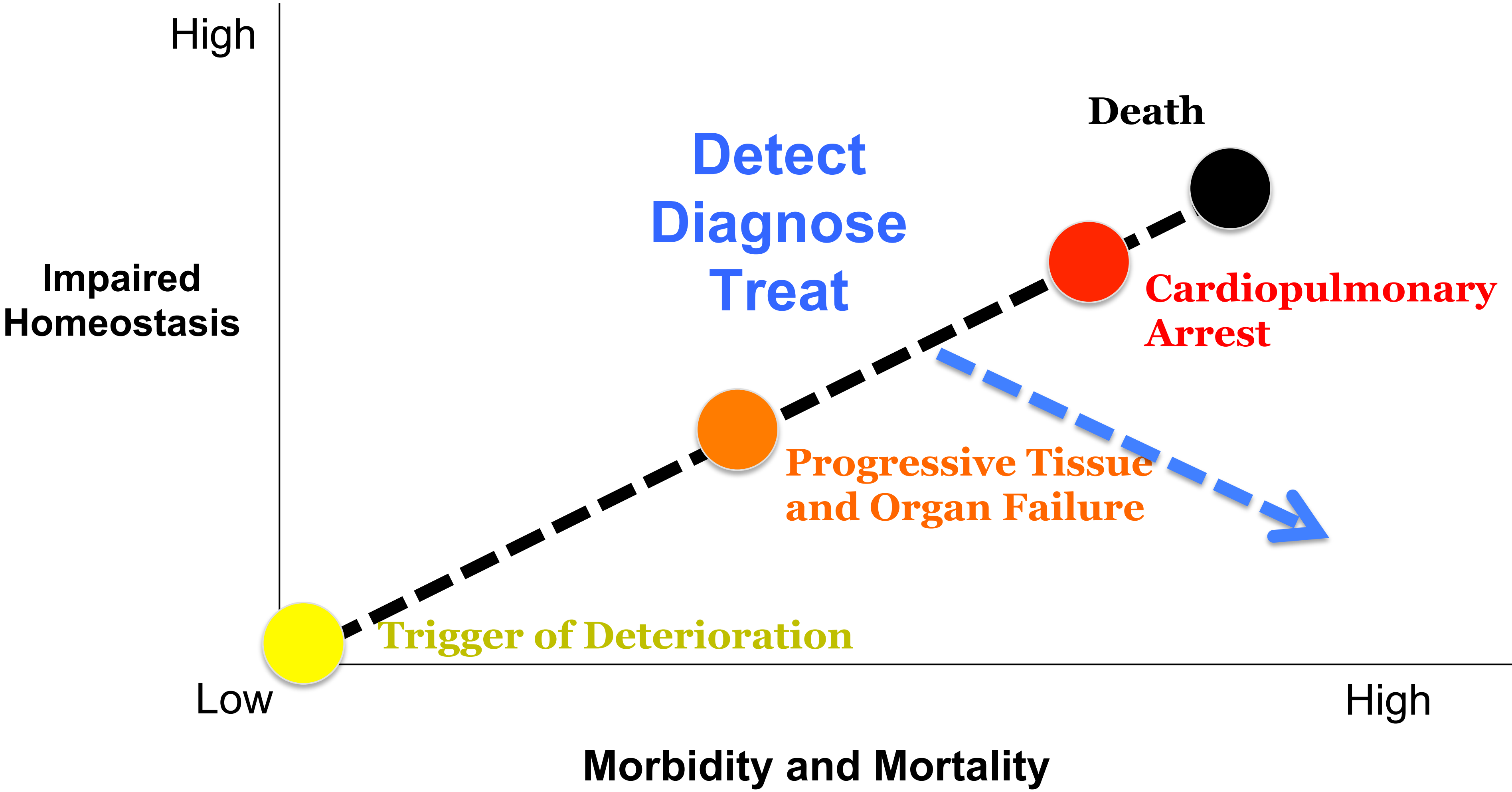
Dartmouth-Hitchcock

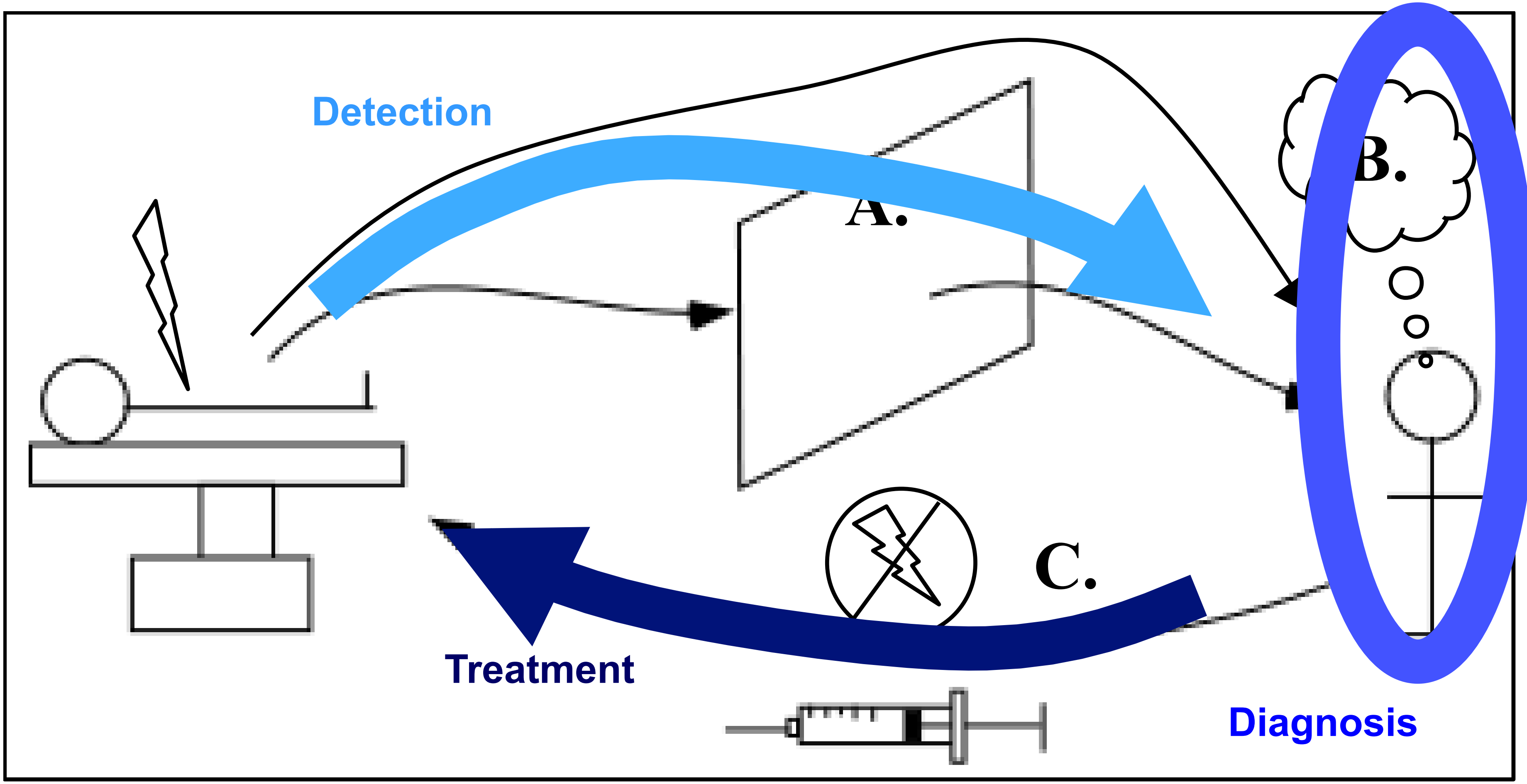
Agenda

- **Control Basics**
  - *Review some basics of Control Theory and Control Systems*
- **Problem**
  - *Single parameter vs multiparameter*
  - *Single patient vs. population*
- **Automated Remote Triage**
  - *Combat Casualty Care*
  - *Post-surgical Care*
- **Conclusions**

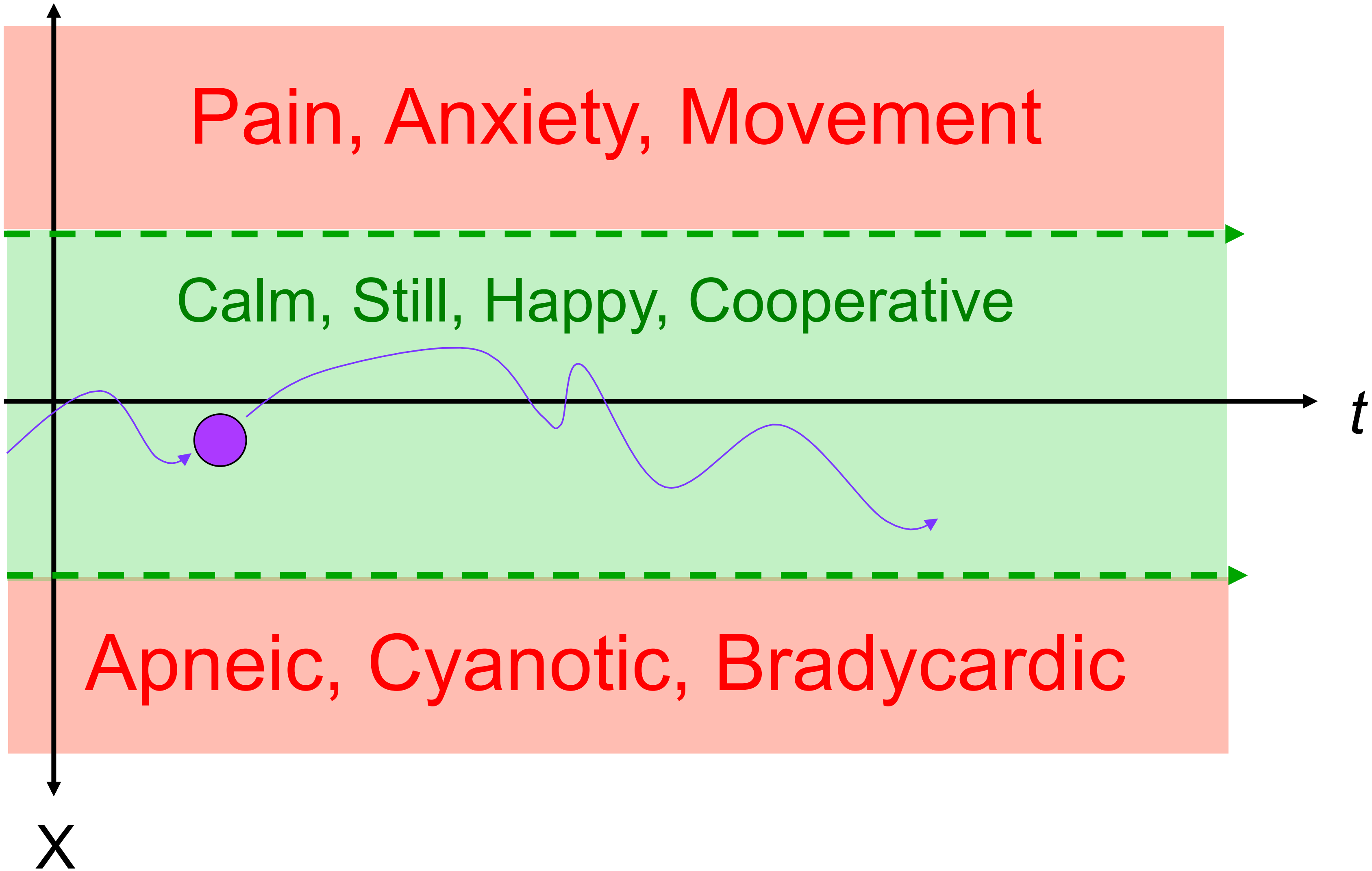
Deterioration

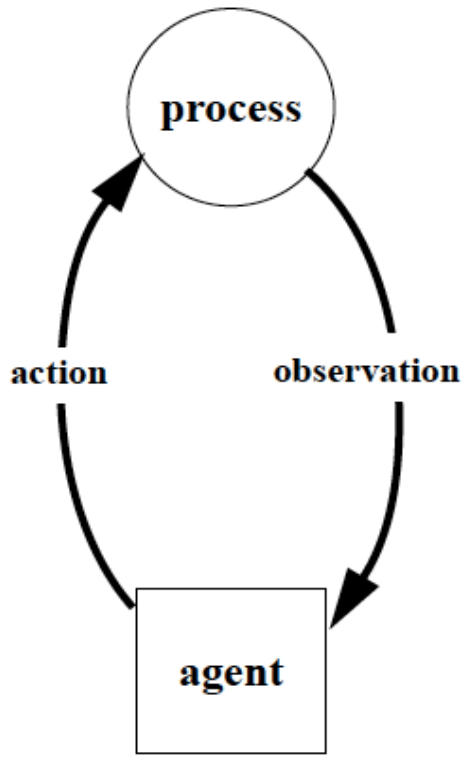


Patient State Control



Pediatric Sedation Example





(a)

Figure 1.2. Generic monitoring task.

An agent is responsible for managing an ongoing process. In (a), the agent attends to the process at all times. In (b), an alarm attends to the process continuously, alerting the agent whenever the process needs the agent's active intervention.

Cecil Huang MD, PhD; Intelligent Alarms: Allocating Attention Among Concurrent Processes; Thesis in Support of PhD, March, 1999.

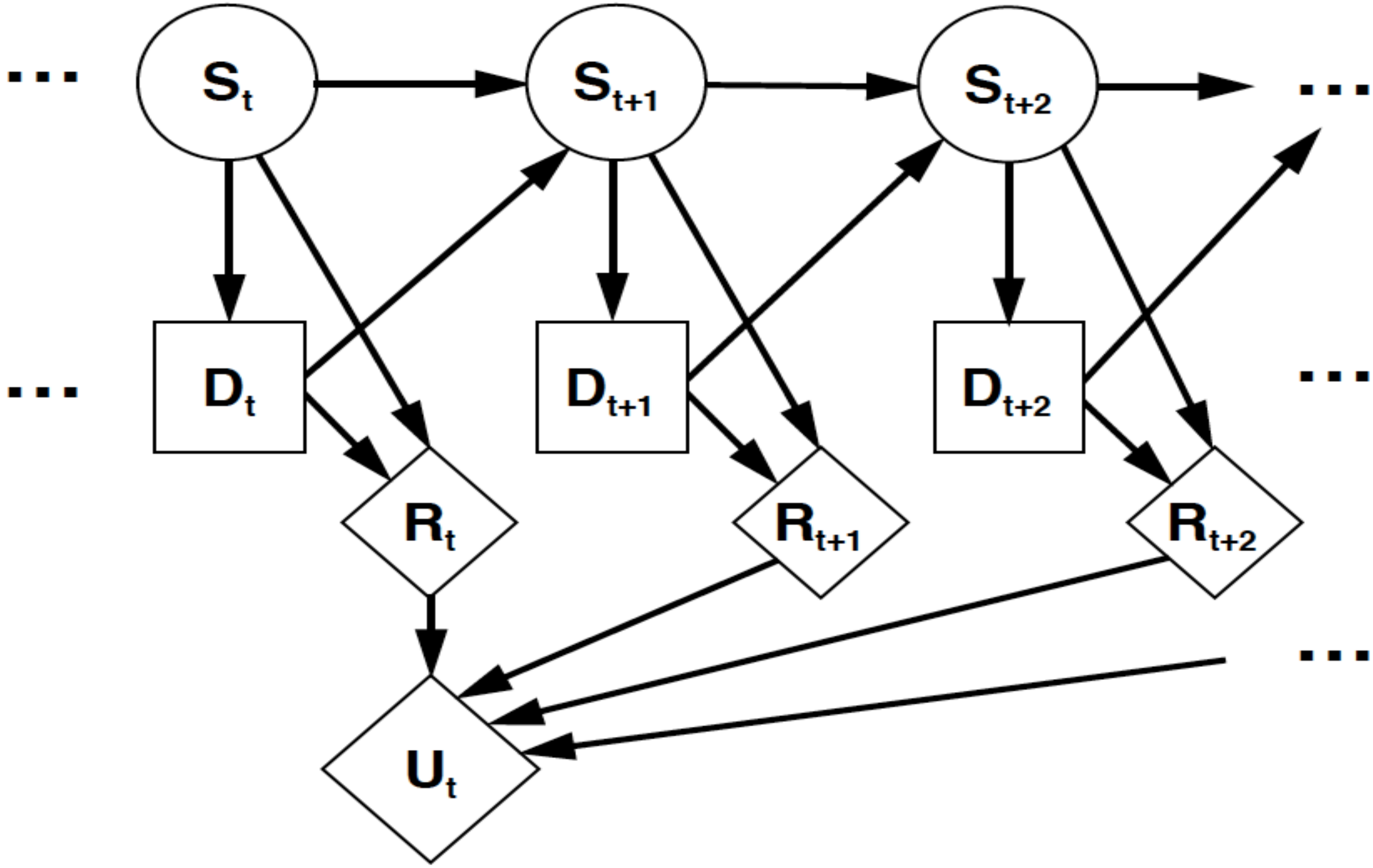
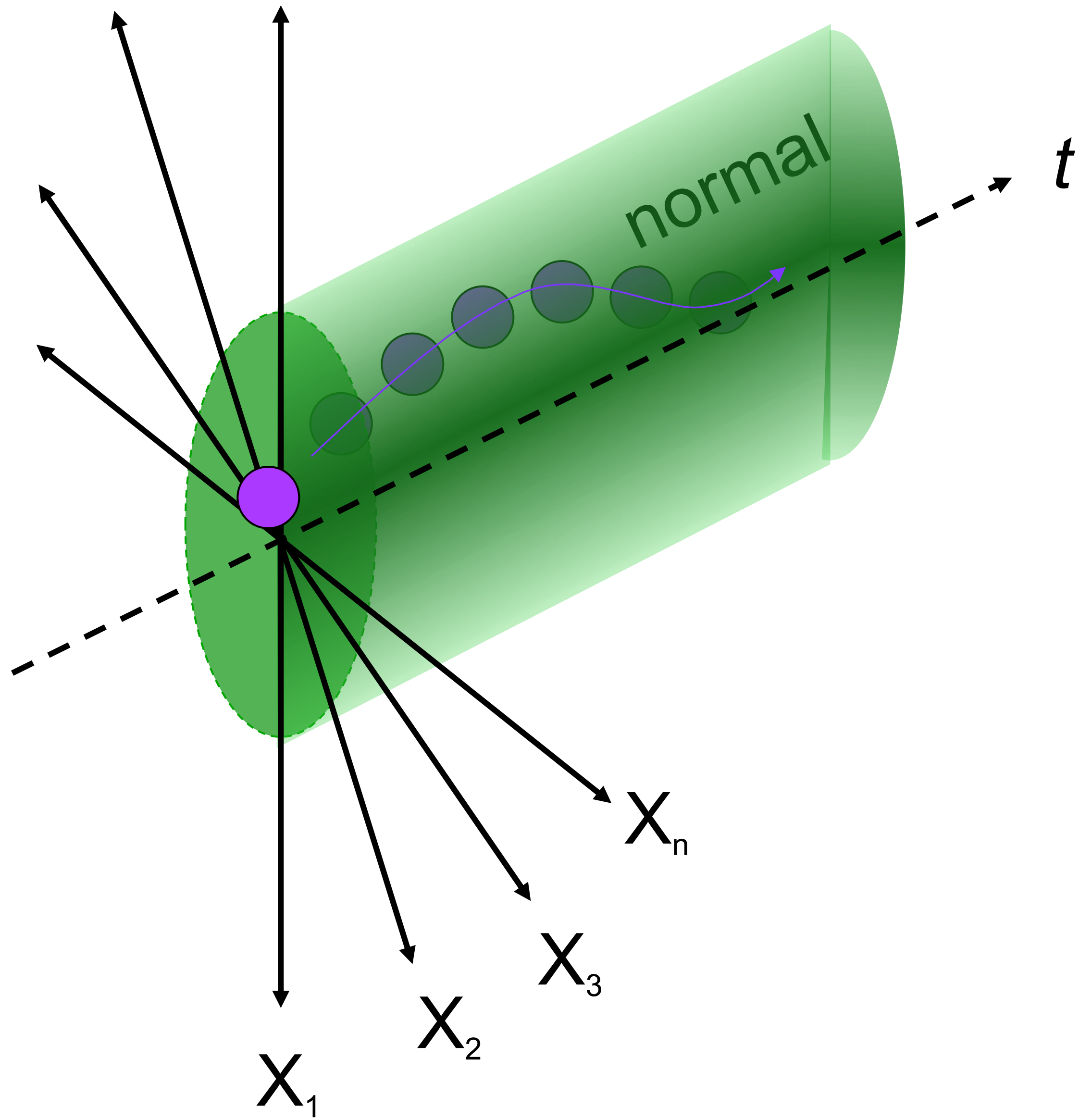


Figure 2.4. Markov decision process.

In this influence diagram of a generic Markov decision process (MDP), circles denote states of the world, squares denote actions to be decided on, and diamonds denote value parameters. Time is divided into discrete epochs, indexed by integers in this figure. Suppose that t denotes the present epoch. The instantaneous reward R_t is influenced by the current state S_t and the current action D_t; the latter two quantities influence the next state S_{t+1}. The total value at time t, U_t, is a discounted sum of the instantaneous rewards from

Cecil Huang MD, PhD; Intelligent Alarms: Allocating Attention Among Concurrent Processes; Thesis in Support of PhD, March, 1999.


normal
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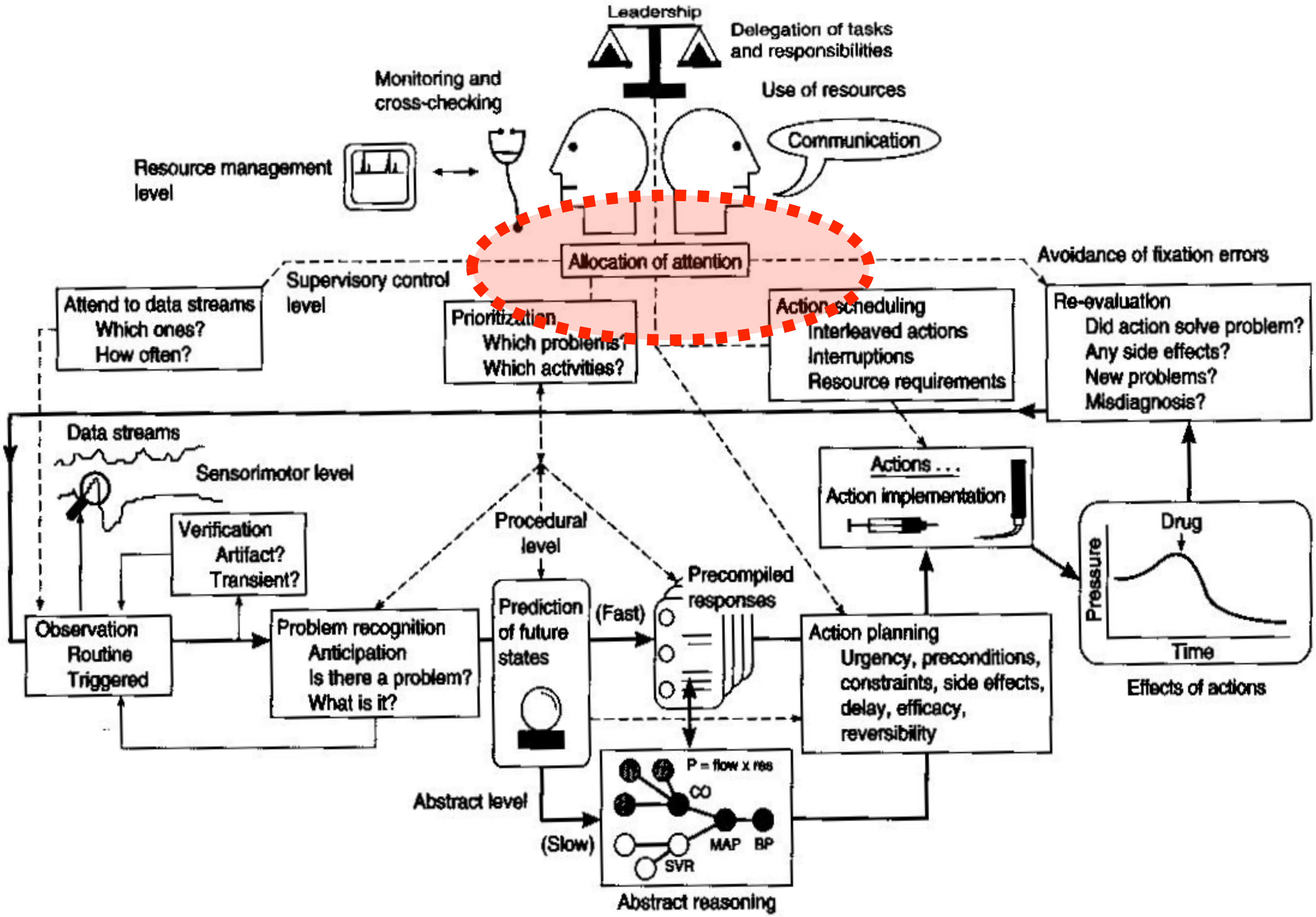
Xn
X3
X2
X1



Leadership
Delegation of tasks and responsibilities
Use of resources
Monitoring and cross-checking
Communication
Resource management level
Allocation of attention
Avoidance of fixation errors
Supervisory control level
Attend to data streams
Which ones?
How often?
Prioritization
Which problems?
Which activities?
Action scheduling
Interleaved actions
Interruptions
Resource requirements
Re-evaluation
Did action solve problem?
Any side effects?
New problems?
Misdiagnosis?
Data streams
Sensorimotor level
Verification
Artifact?
Transient?
Procedural level
Actions . . .
Action implementation
Precompiled responses
Observation
Routine
Triggered
Problem recognition
Anticipation
Is there a problem?
What is it?
Prediction of future states
(Fast)
Action planning
Urgency, preconditions, constraints, side effects, delay, efficacy, reversibility
Drug
Pressure
Time
Effects of actions
Abstract level
(Slow)
P = flow x res
CO
MAP
BP
SVR
Abstract reasoning

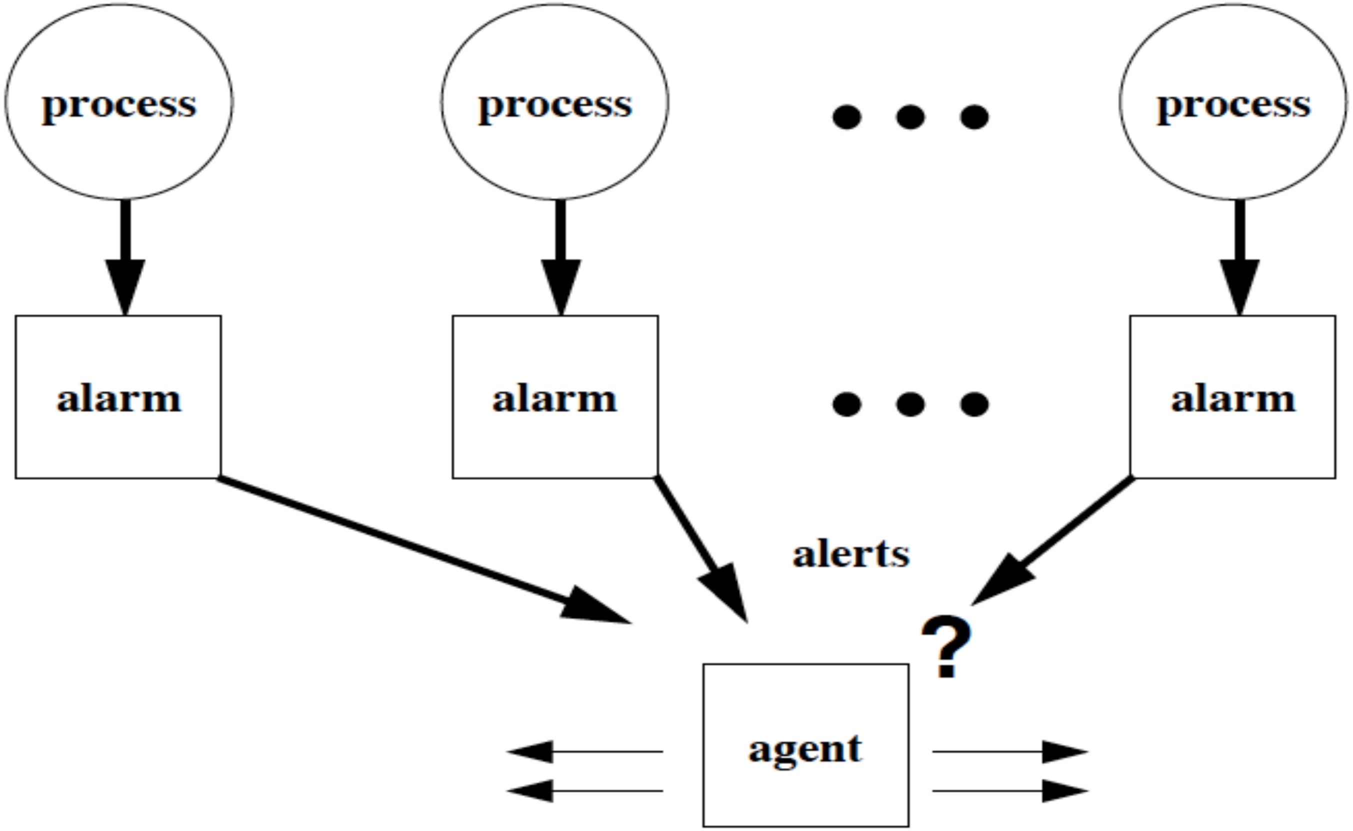


Figure 1.4. The problem of multiple, independent alerts.
An agent is confronted by simultaneous alerts that originate independently from multiple processes. Although each alert may result from a sophisticated inference procedure, the alerts, taken together, do not help the agent to allocate her attention among the processes.

Cecil Huang MD, PhD; Intelligent Alarms: Allocating Attention Among Concurrent Processes; Thesis in Support of PhD, March, 1999.

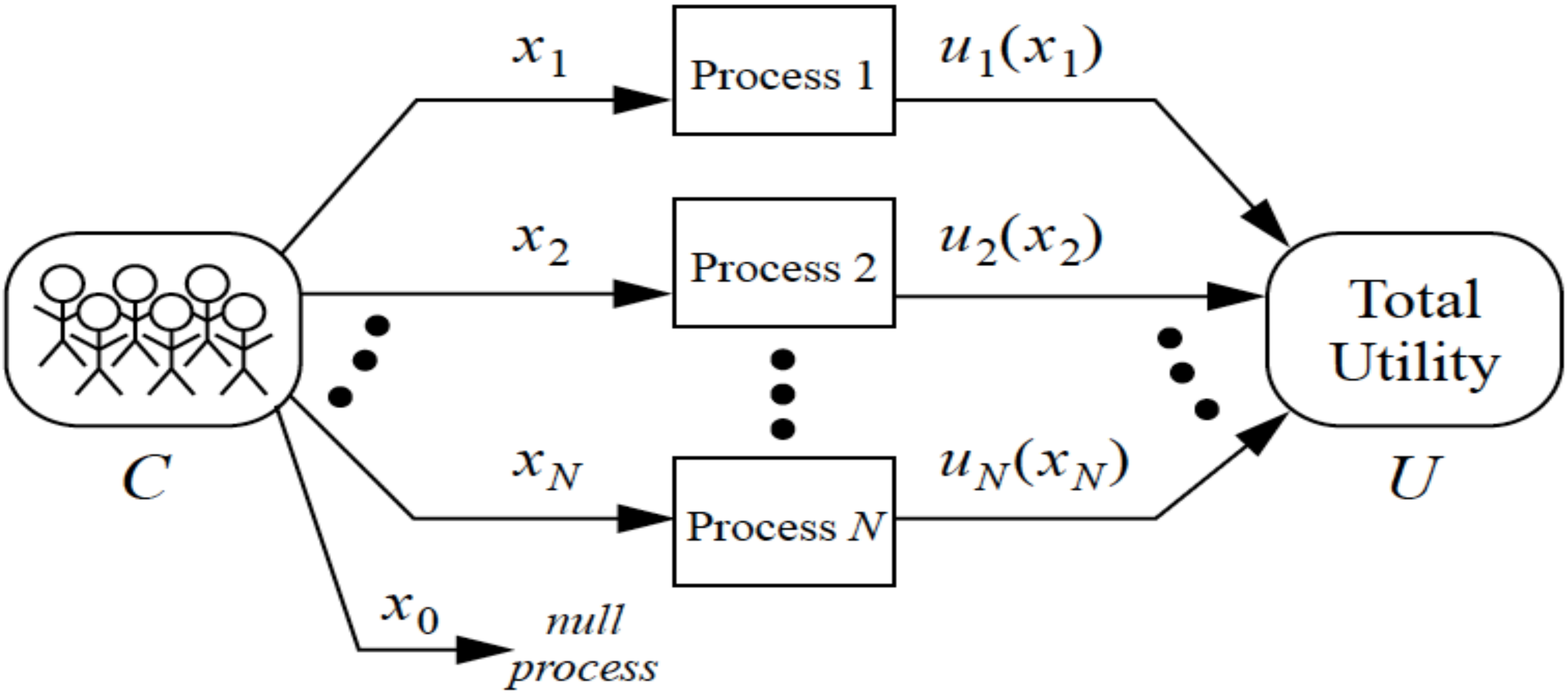
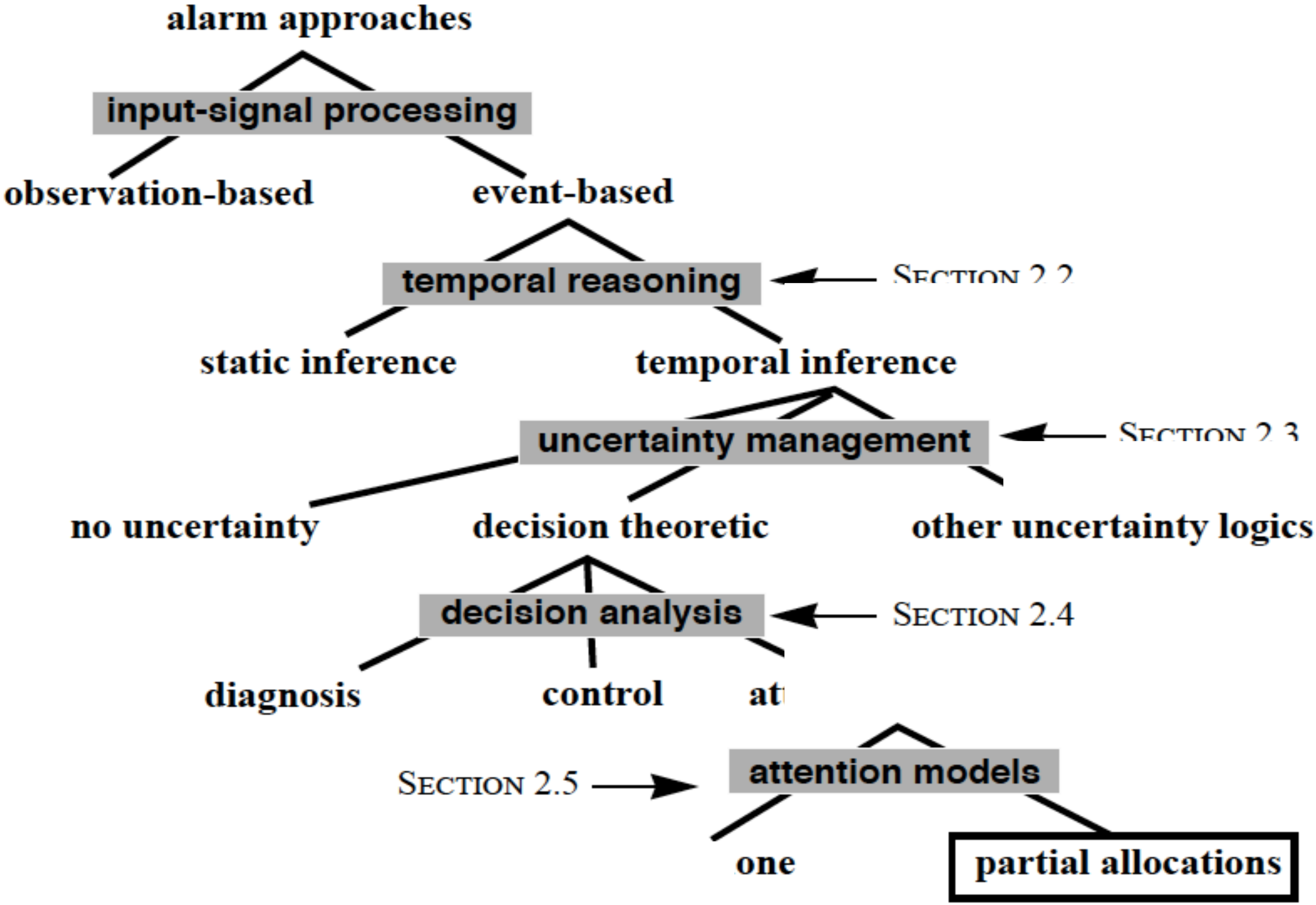


Figure 4.3. Distribution of attention among concurrent processes.

A limited amount of attention C is to be distributed among N processes. When process j receives an attention amount x_j, it yields an expected utility $u_j(x_j)$. The total utility U depends on the values assigned to $x_1, \ldots, x_N$, and is equal to the sum of the process utilities $u_j(x_j)$ for $j = 1, \ldots, N$. Unused attention resources are incorporated into the special variable x_0, where $0 \le x_0 \le C$. The x_js must add up to C.

Cecil Huang MD, PhD; Intelligent Alarms: Allocating Attention Among Concurrent Processes; Thesis in Support of PhD, March, 1999.



Cecil Huang MD, PhD; Intelligent Alarms: Allocating Attention Among Concurrent Processes; Thesis in Support of PhD, March, 1999.

ARTEMIS: A Vision for Remote Triage and Emergency Management Information Integration

Susan P. McGrath, Eliot Grigg, Suzanne Wendelken, George Blike, Michael De Rosa, Aaron Fiske and Robert Gray

***Abstract-* This paper describes the design of an automated triage and emergency management information system. The prototype system is capable of monitoring and assessing physiological parameters of individuals, transmitting pertinent medical data to and from multiple echelons of medical service, and providing filtered data for command and control applications. The system employs wireless networking, portable computing devices, and reliable messaging technology as a framework for information analysis, information movement, and decision support capabilities. The embedded medical model and physiological status assessment are based on input from humans and a pulse oximetry device. The physiological status determination methodology follows NATO defined guidelines for remote triage and is implemented using an approach based on fuzzy logic. The approach described can be used in both military and civilian settings.**

Battlefield Casualties

The overarching premise of the military version of the ARTEMIS system is that the survivability of our soldiers and mission success can be improved by expanding the flow of medical information on the battlefield and throughout the chain of command. Our aim is to provide a degree of medical situational awareness at all levels of command that has never existed before. In our view, the most critical stage of this process begins by monitoring individual soldiers and providing relevant information to the medic—the first line of care in the battlefield. Our primary target population is the 25% of soldiers killed in action who die between 5 minutes and 6 hours of injury [1]. These soldiers live long enough to be rescued but die quickly enough to be affected by the suboptimal

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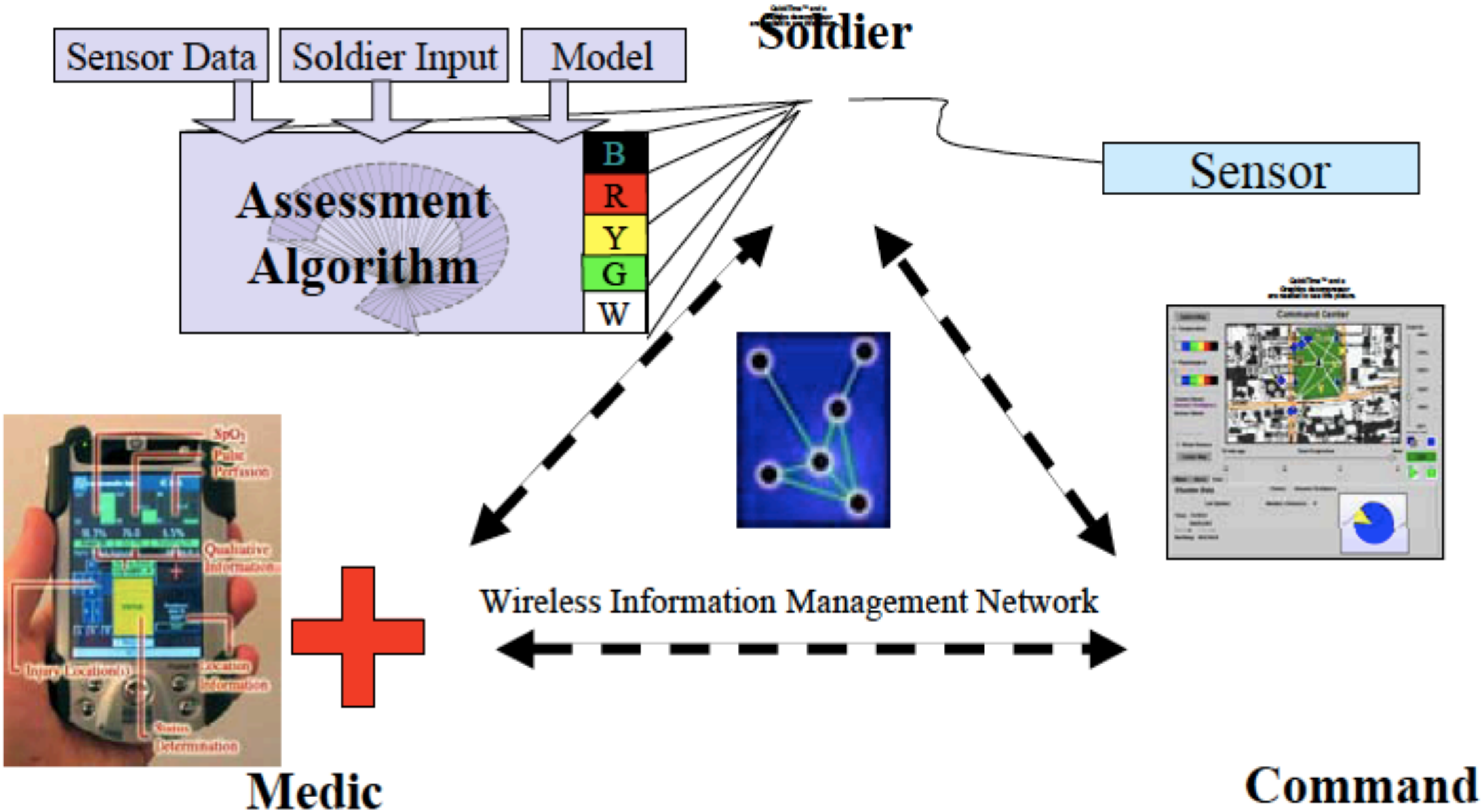
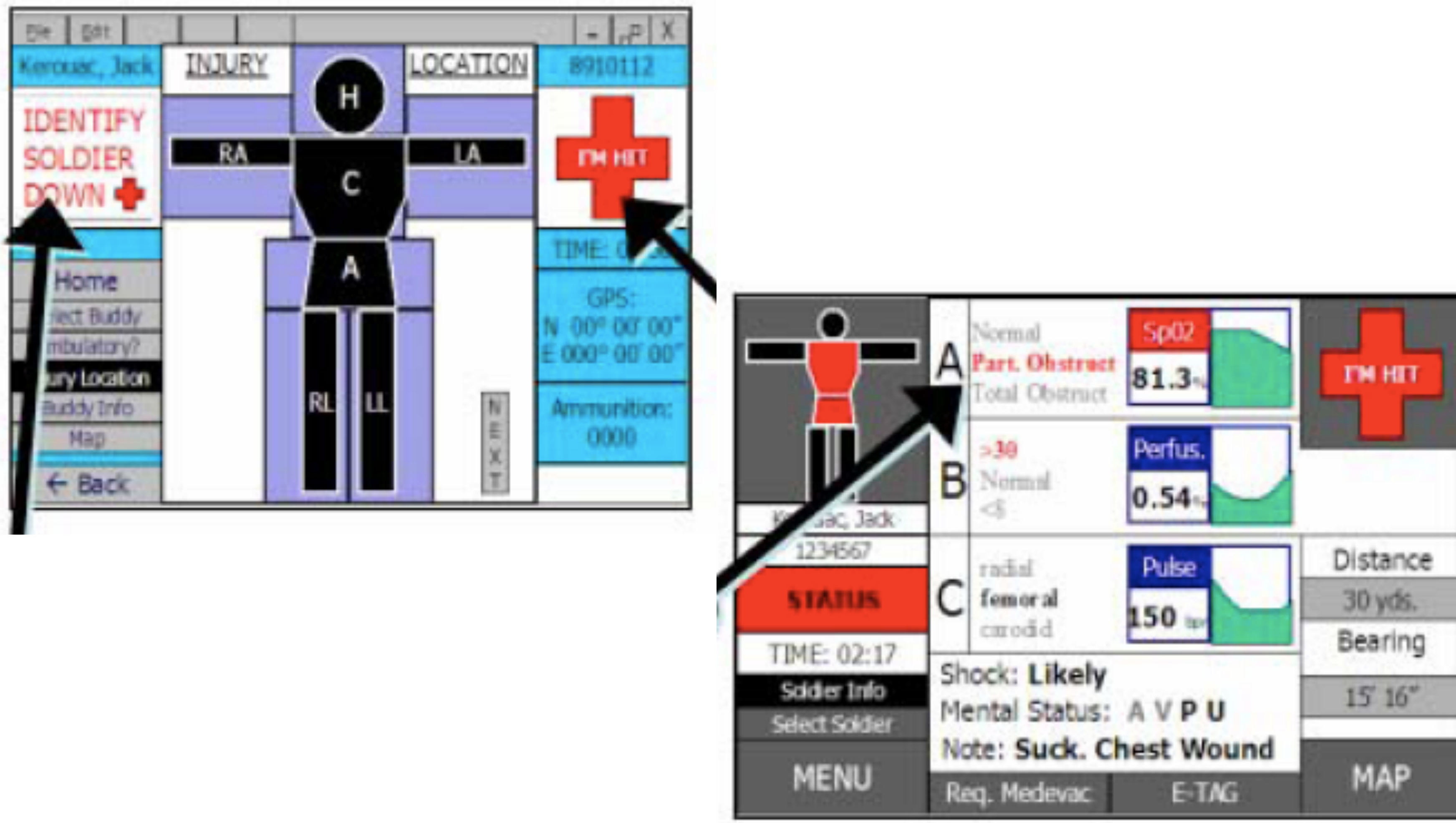
2003


Sensor Data
Soldier Input
Model
Assessment Algorithm
B
R
Y
G
W
Soldier
Sensor
SpO2
Pulse
Perfusion
Qualitative Information
Injury Location(s)
Location Information
Status Determination
Wireless Information Management Network
Medic
Command


Kerouac, Jack
INJURY
LOCATION
8910112
IDENTIFY SOLDIER DOWN
H
RA
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A
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I'M HIT
Home
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Map
GPS:
Ammunition:
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NEXT
A
Normal
Part. Obstruct
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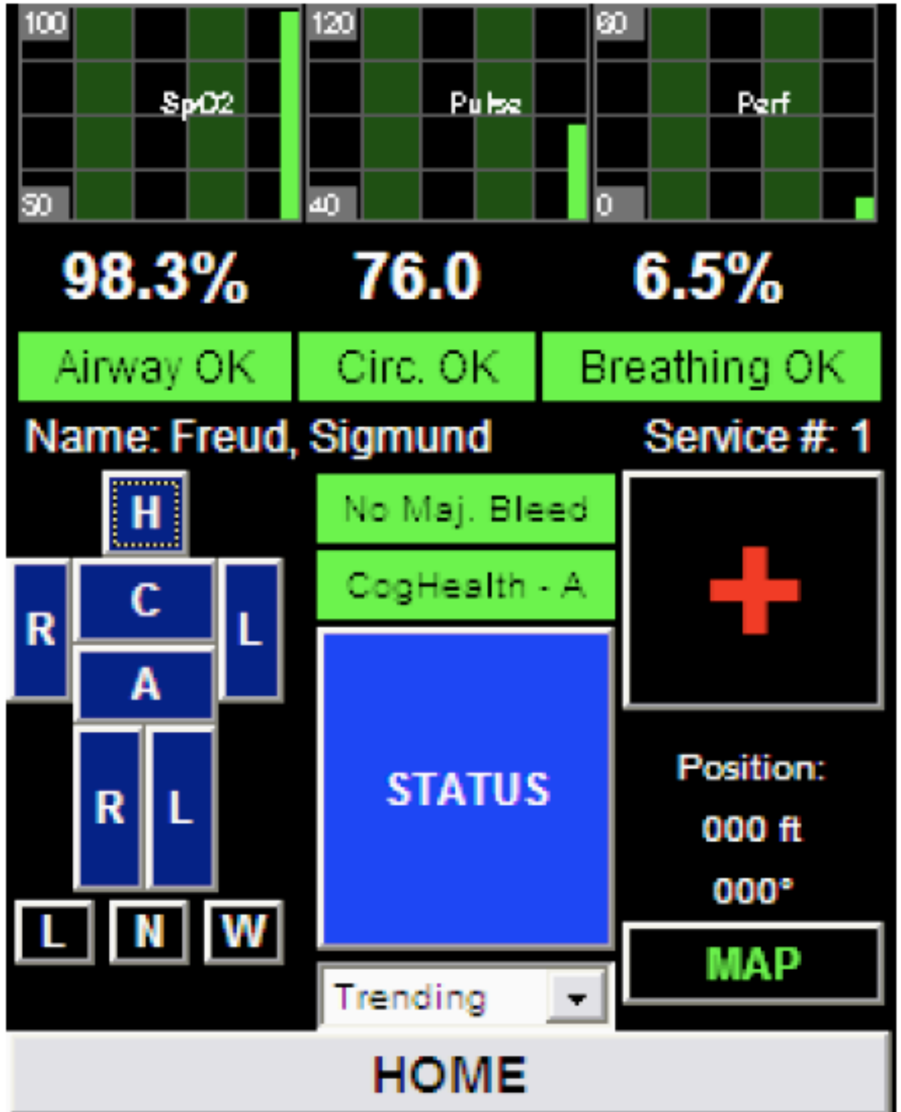
Sp02
81.3
B
>30
Normal
<8
Perfus.
0.54
C
radial
femoral
carotid
Pulse
150
I'M HIT
Distance
30 yds.
Bearing
15' 16"
1234567
STATUS
TIME: 02:17
Soldier Info
Select Soldier
Shock: Likely
Mental Status: A V P U
Note: Suck. Chest Wound
MENU
Req. Medevac
E-TAG
MAP


100
SpO2
50
120
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40
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76.0
6.5%
Airway OK
Circ. OK
Breathing OK
Name: Freud, Sigmund
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STATUS
Position:
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MAP
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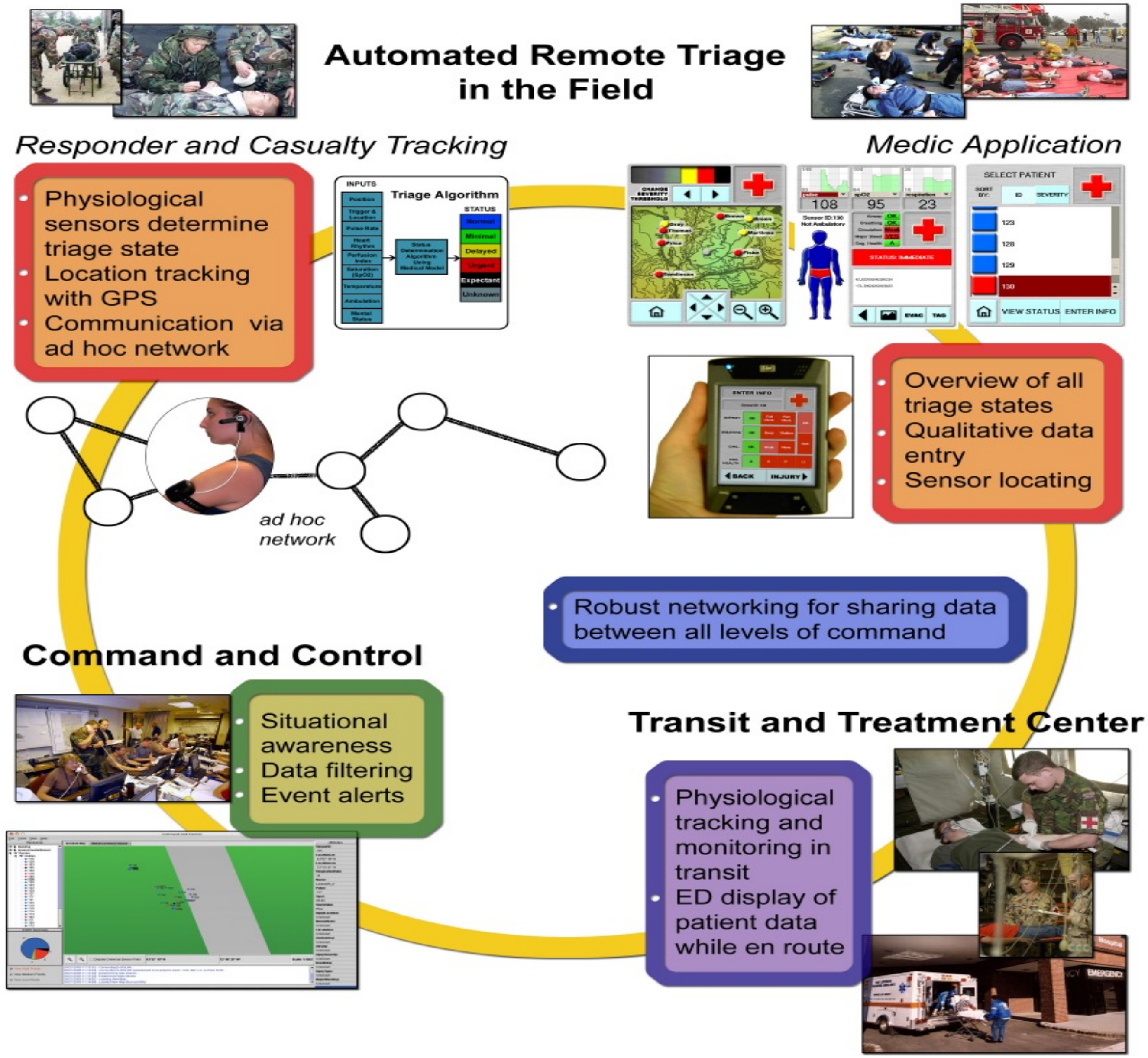
HOME

ARTEMIS

Automated
Remote
Triage and
Emergency
Management
Information
System



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Automated Remo
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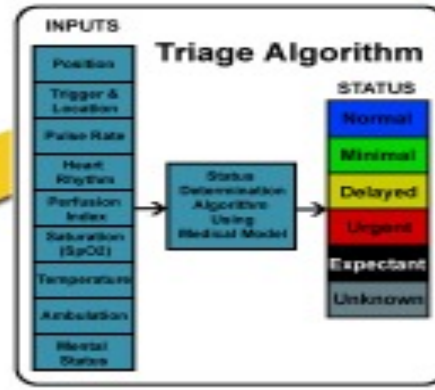
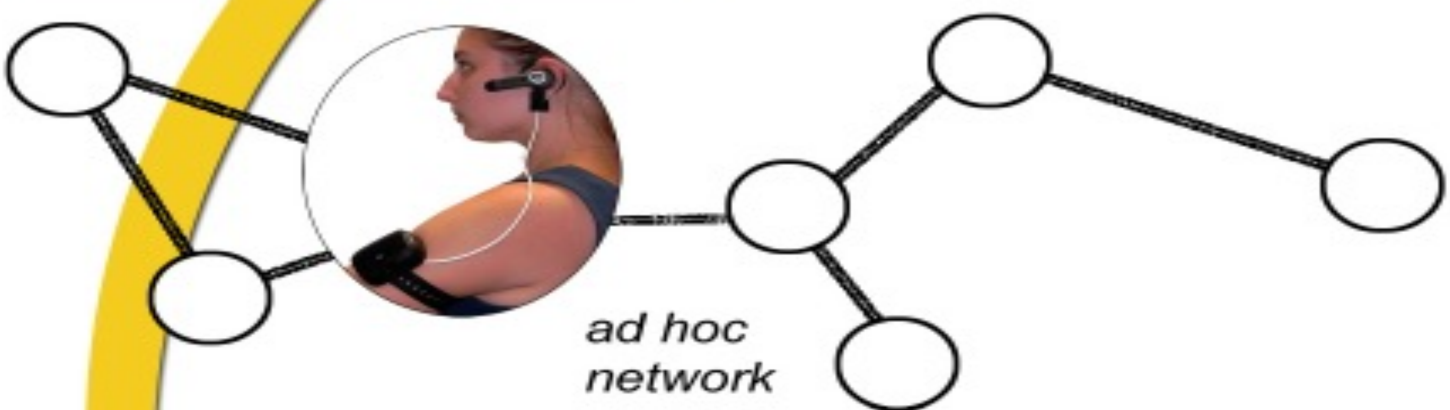
Responder and Casualty Tracking

- Physiological sensors determine triage state
- Location tracking with GPS
- Communication via ad hoc network





ote Triage
eld

Medic Application

- Overview of all triage states
- Qualitative data entry
- Sensor locating

- Robust networking for sharing data between all levels of command

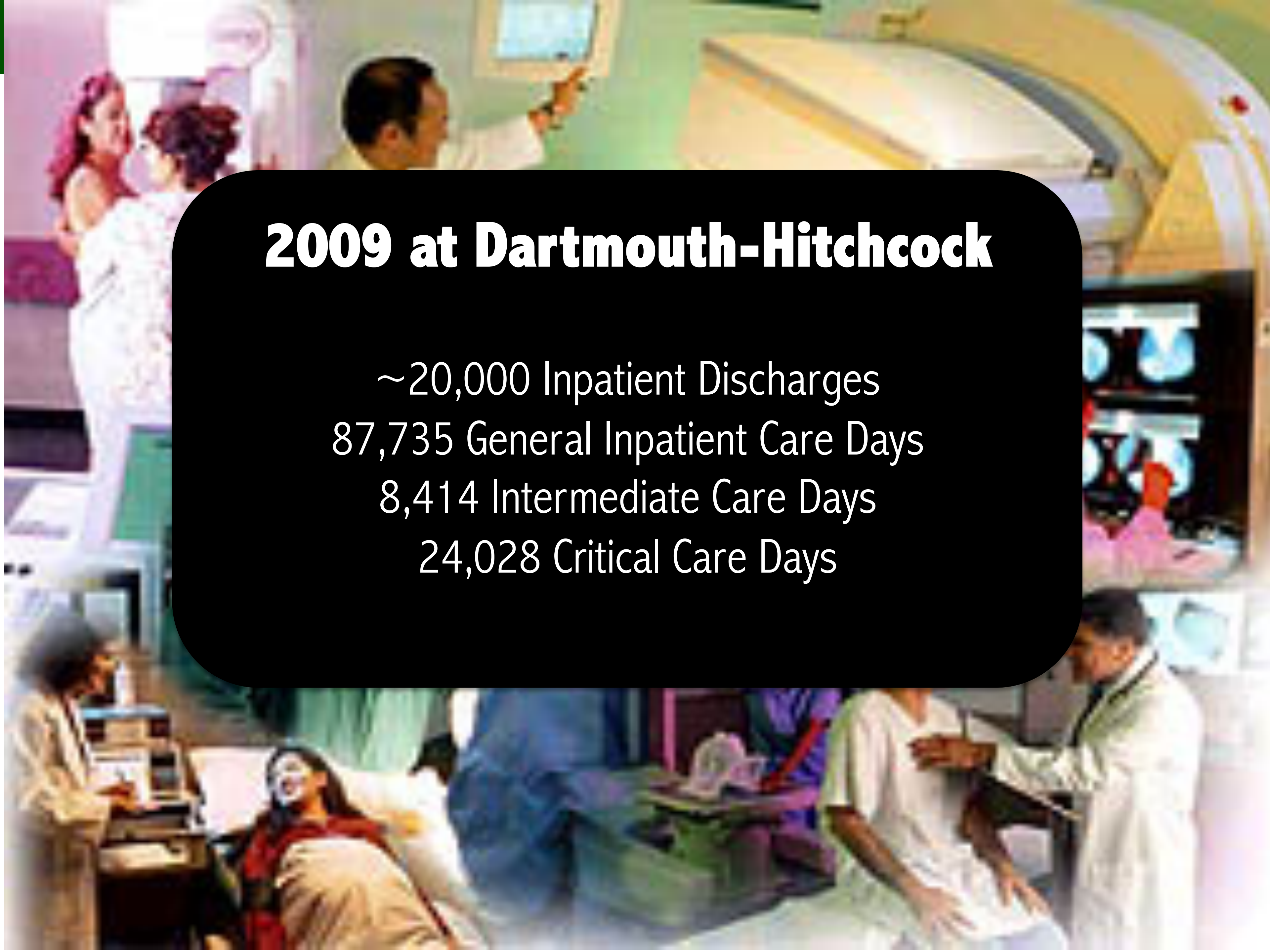
Transit and Treatment Center

- Physiological tracking and monitoring in transit
- ED display of patient data while en route

es

Command and Control

- Situational awareness
- Data filtering
- Event alerts



2009 at Dartmouth-Hitchcock

~20,000 Inpatient Discharges
87,735 General Inpatient Care Days
8,414 Intermediate Care Days
24,028 Critical Care Days

Continuum of Inpatient Care

General Care

- Nursing 1:5

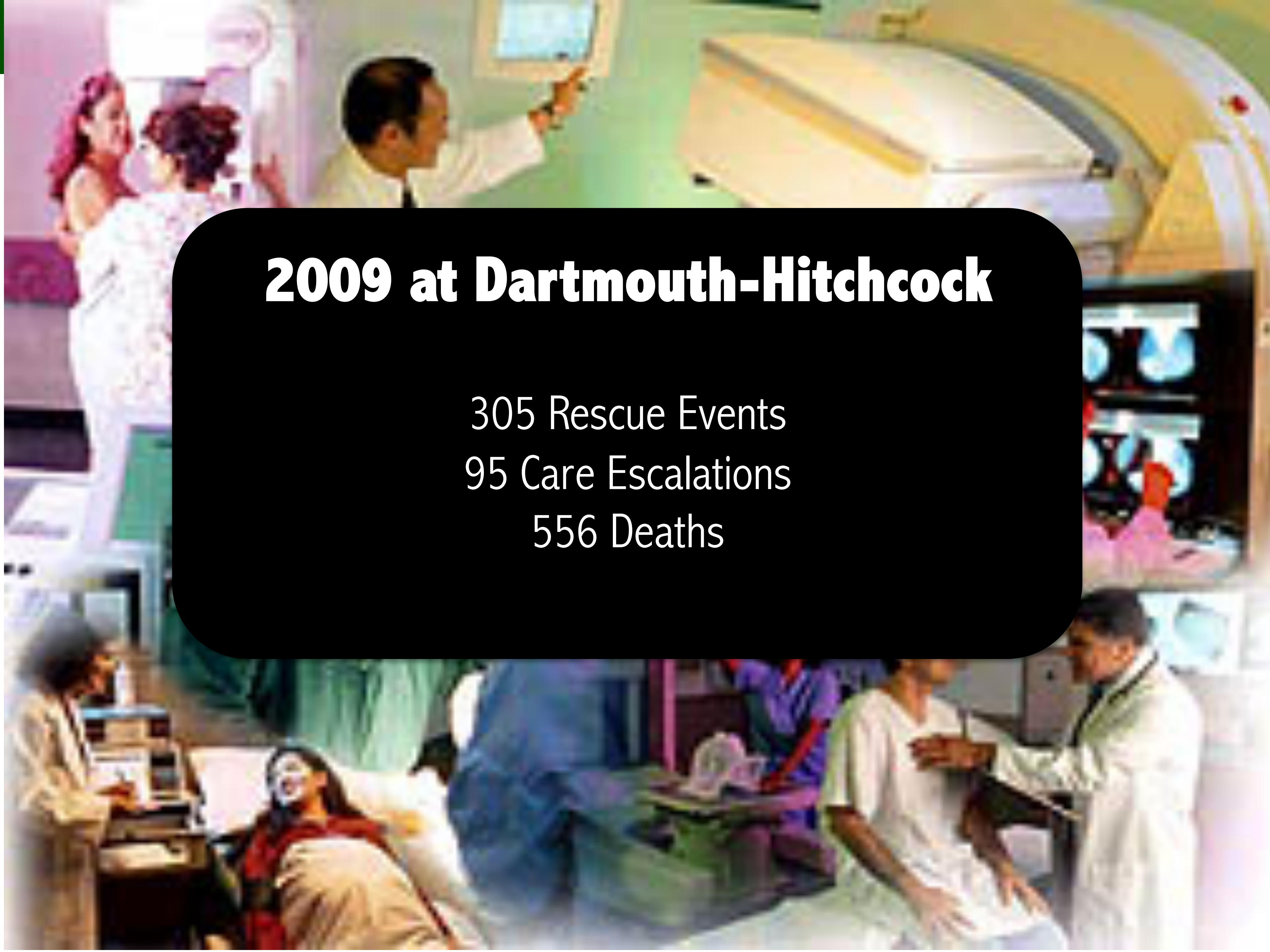
Intermediate Care

- Nursing 1:2

Critical Care/ (OR, ED, IPs)

- Nursing 1:1 and 1:2

Chang in Patient Status Triggers a Move



2009 at Dartmouth-Hitchcock

305 Rescue Events
95 Care Escalations
556 Deaths

Rapid Response Teams

- **Rapid response systems: A systematic review**

  Winters, BD, Pham JC, Hunt EA, Guallar E, Berenholtz S, Pronovost P.
  Critical Care Medicine 2007; 35: 1238-43

- **A prospective study of factors influencing the outcome of patients after a Medical Emergency Team review**

  Calzavacca P, Licari E, Tee A, Egi M, Haase M, Haase-Fielitz A, Bellomo R.
  Intensive Care Medicine 2008; 34: 2112-6

  - *"Delayed Medical Emergency Team activation and NRF orders are the strongest independent predictors of mortality in patients receiving Medical Emergency Team review. Avoidance of delayed Medical Emergency Team activation should be a priority for hospitals operating rapid response systems."*

PERIOPERATIVE MEDICINE

Anesthesiology 2010; 112:284 – 9

Impact of Pulse Oximetry Surveillance on Rescue Events and Intensive Care Unit Transfers

A Before-and-After Concurrence Study

Andreas H. Taenzer, M.D., F.A.A.P.,* Joshua B. Pyke, B.E.,† Susan P. McGrath, Ph.D.,‡
George T. Blike, M.D.§

ABSTRACT

Background: Some preventable deaths in hospitalized patients are due to unrecognized deterioration. There are no publications of studies that have instituted routine patient monitoring postoperatively and analyzed impact on patient outcomes.

Methods: The authors implemented a patient surveillance system based on pulse oximetry with nursing notification of violation of alarm limits via wireless pager. Data were collected for 11 months before and 10 months after implementation of the system. Concurrently, matching outcome data were collected on two other postoperative units. The primary outcomes were rescue events and transfers to the intensive care unit compared before and after monitoring change.

What We Already Know about This Topic

- Early recognition of deterioration is essential for early intervention to prevent cardiac or respiratory arrest
- Universal surveillance for such early recognition has not been applied to postoperative patients

What This Article Tells Us That Is New

- Implementation of universal surveillance with pulse oximetry was associated with a reduced need for patient rescue and intensive care unit transfers

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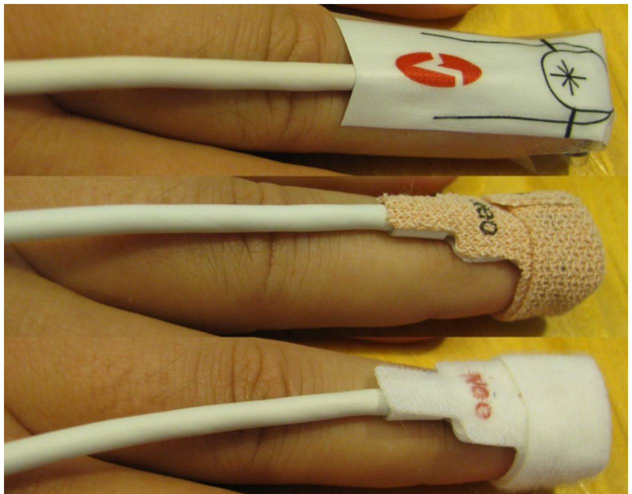
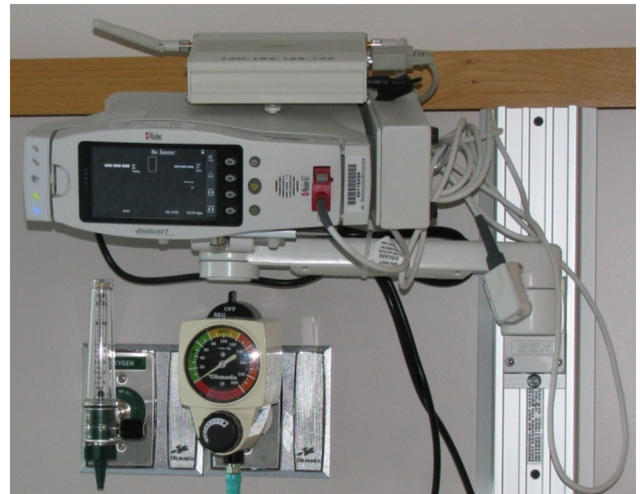
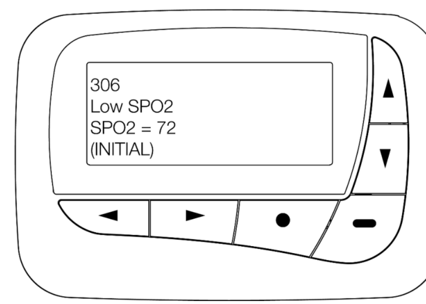
Masimo SET
Patient SafetyNet

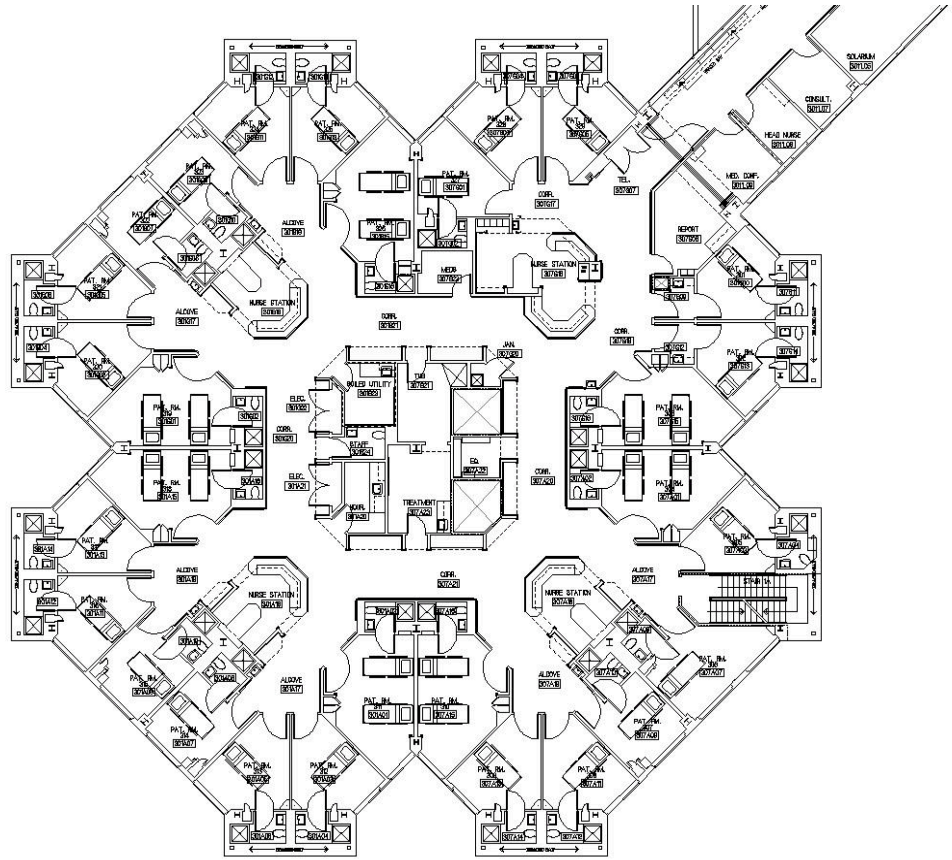






Test Unit

- 36 beds in a pod layout
- 2 nurses, 10 beds per pod (1:5)
- Primarily orthopedics, also plastics and trauma (elderly)
- Selective cardio-telemetry



Data Analysis

- Test unit before/after
- Comparator units before/after
- Rescue events per 1,000 discharges
- ICU transfers per 1,000 patient days
- Data analyzed with t-tests (Stata 10)

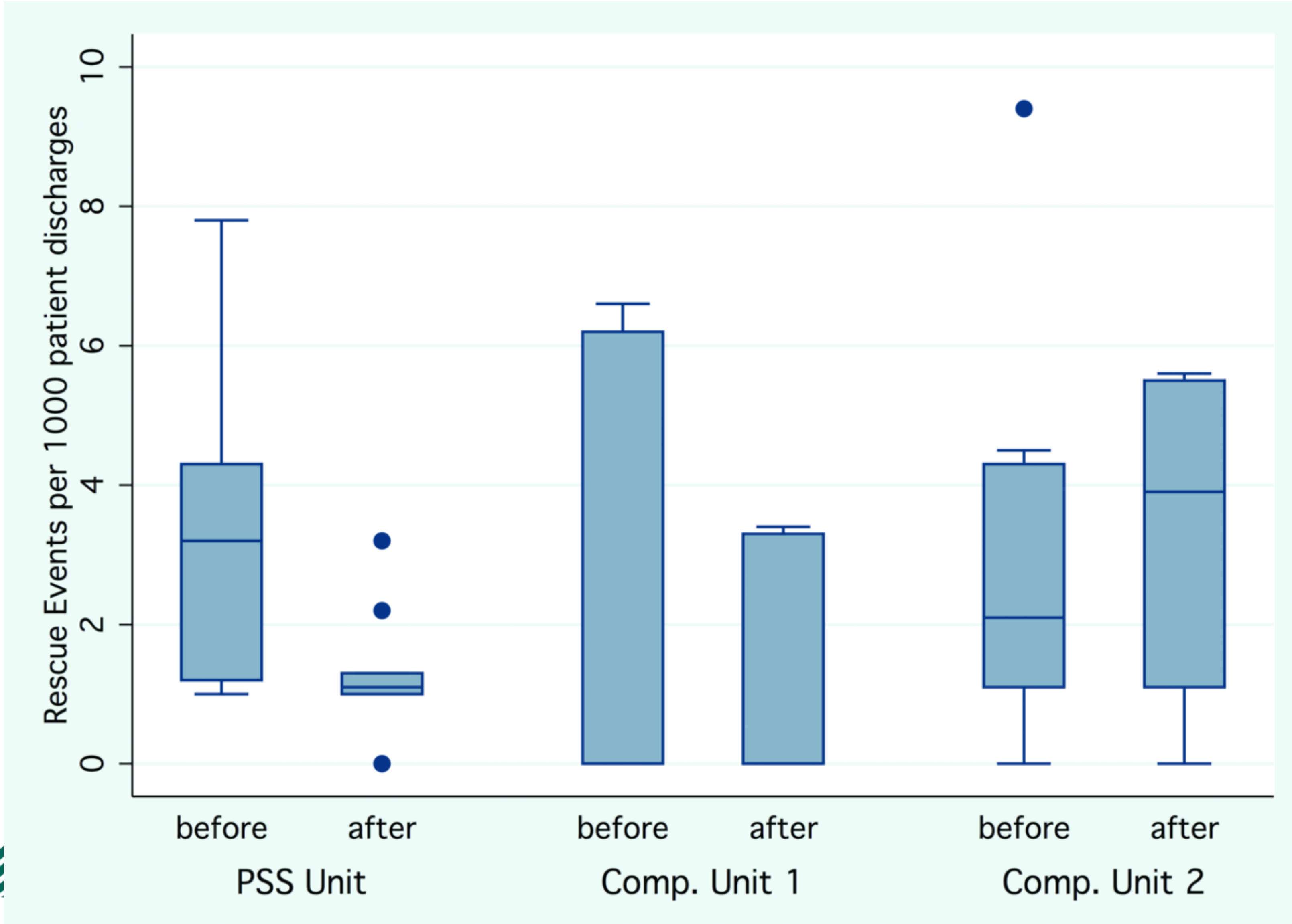
Results: *Rescue Events*

Unit	Rescues Before	Rescues After	p-values
PSS Unit	3.4 ± 2.2, [1.89 – 4.85]	1.2 ± 0.94, [0.53 – 1.88]	0.01
Comparison Unit 1	2.0 ± 0.88, [0.05 – 4.0]	1.3 ± 1.68, [0.1 – 2.50]	0.5
Comparison Unit 2	2.7 ± 0.82, [0.87 – 4.51]	3.4 ± 0.67, [1.87 – 4.9]	0.53

Table 3: Rescue Events (mean ± SD, CI) per 1000 patient discharges before and after

SD: Standard Deviation
CI: 95% Confidence Interval

Results: *Rescue Events*

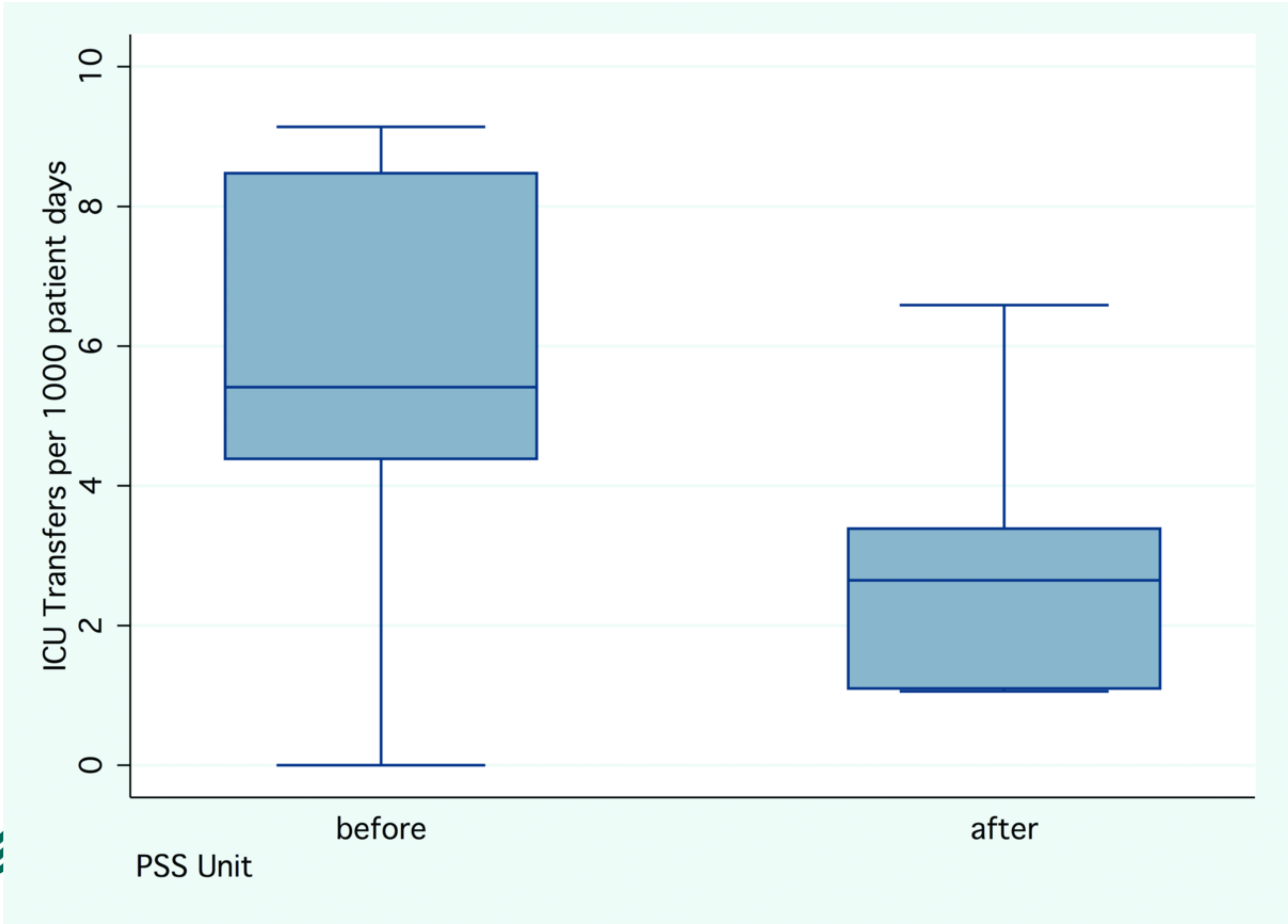


Results: *ICU Transfers*

Unit	ICU Transfers Before	ICU Transfers After	p-values
PSS Unit	5.6 ± 2.8, [3.7 – 7.4]	2.9 ± 2.0, [1.4 – 4.3]	0.02
Comparison Unit 1	5.7 ± 1.6, [2.1 – 9.2]	5.2 ± 1.3, [2.2 – 8.2]	0.8
Comparison Unit 2	15.0 ± 5.7, [11.1 – 18.9]	12.7 ± 3.7, [10.0 –15.3]	0.3

Table 4: Transfers to the ICU (mean ± SD, CI) per 1000 patient days before and after PSS implementation

Results: *ICU Transfer*

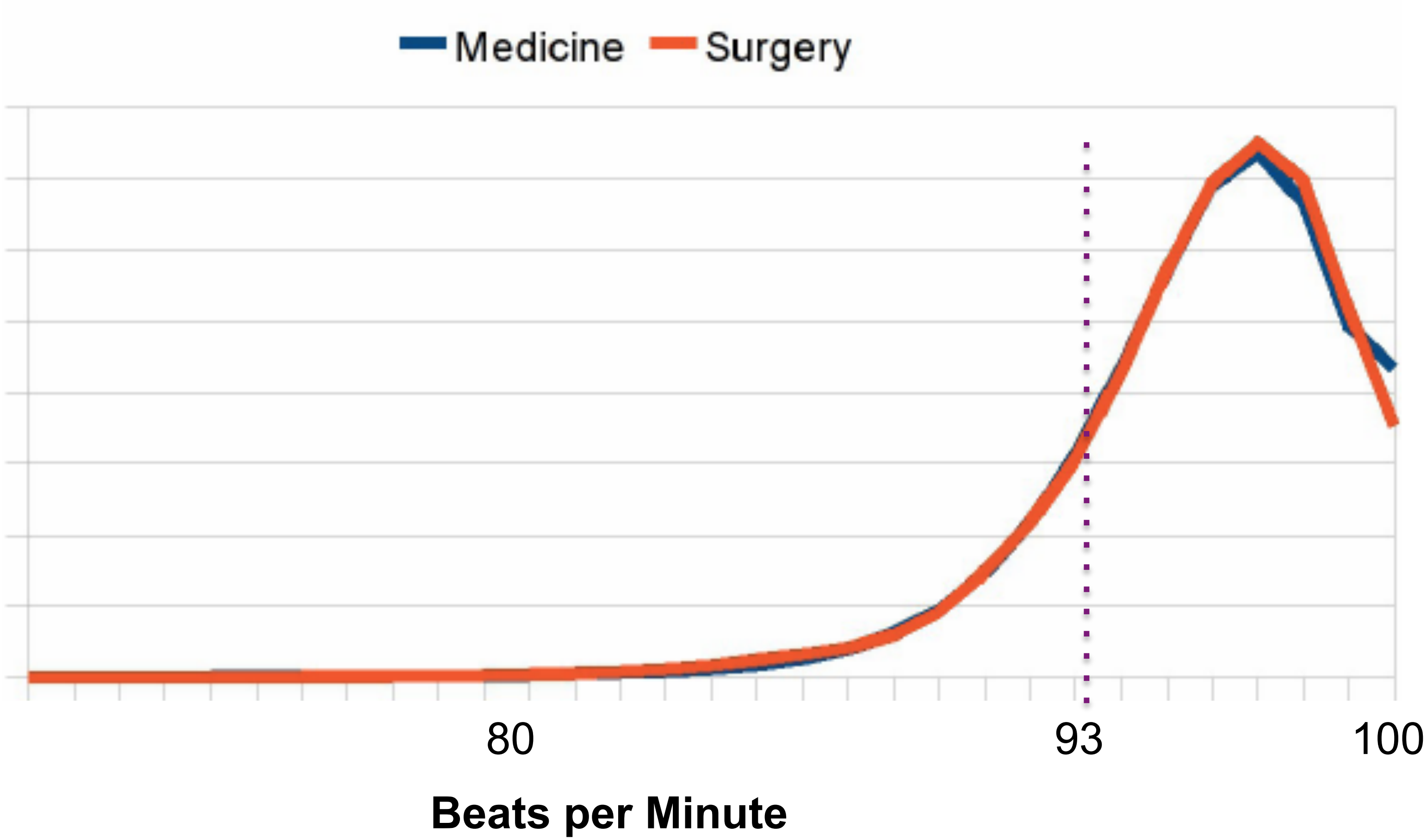


Conclusions

- Increasingly we work in teams managing populations of patients
- Data and information needs to be provided to clinicians performing supervisory control tasks to redirect attention
- Performance metrics need to be optimized at the sensor end of the system AND effectiveness metrics optimized on the outcome side

Dartmouth Hitchcock
Recipient of ECRI Institute
4th Annual Health Devices Achievement Award
September 2009

SpO2 Distribution



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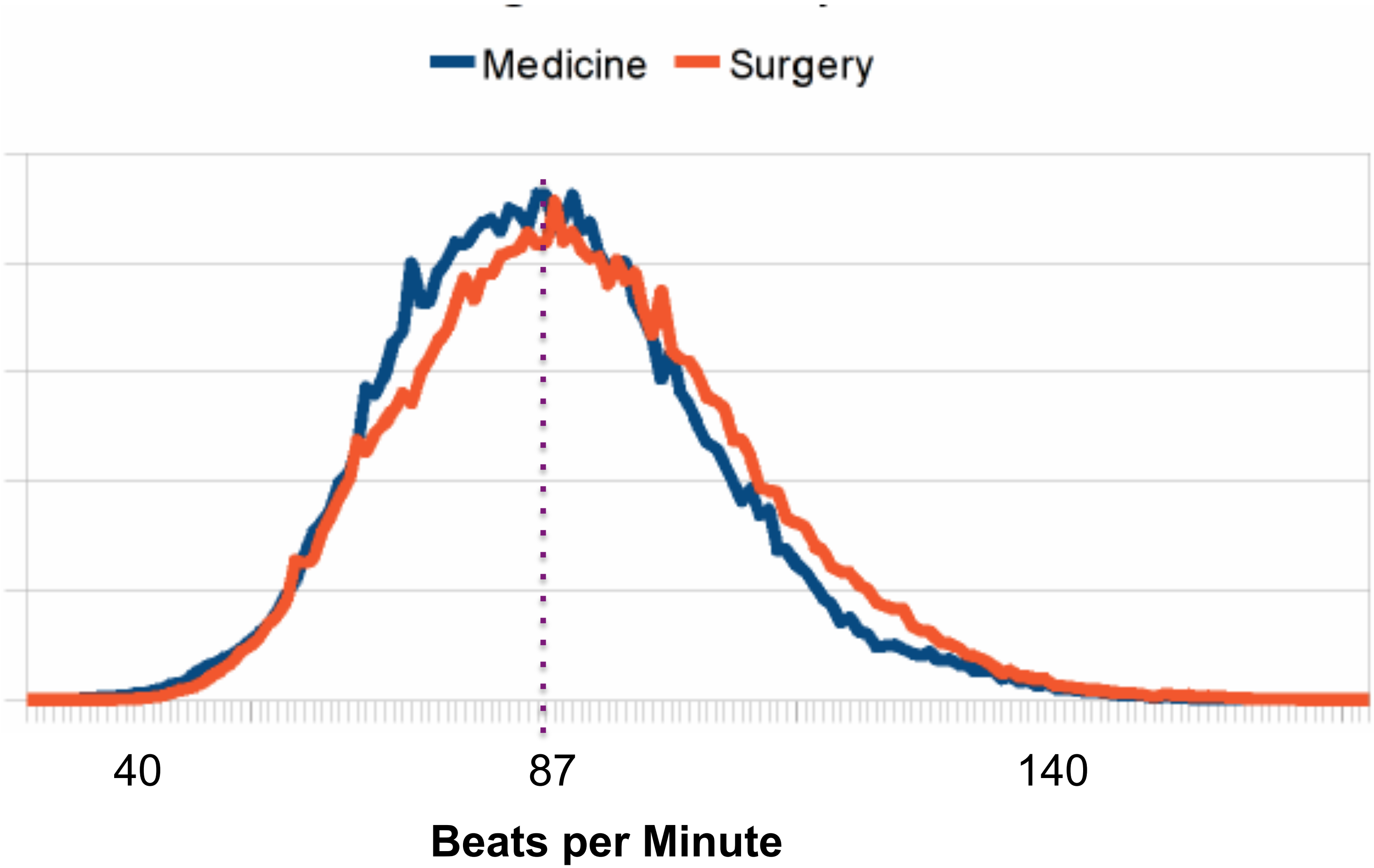
HR Distribution



Anesthesia Patient Safety Foundation recommendations in the setting of PCA use:

- Individualize the dose and infusion rate of opioid while considering the unique aspects of each patient's history and physical status.
- Make continuous monitoring of oxygenation (pulse oximetry) the routine rather than the expectation.
- Assess the need for supplemental oxygen, especially if pulse oximetry or intermittent nurse assessment are the only methods of identifying progressive hypoventilation.
- Consider monitoring ventilation (even if intermittent) with technology capable of detecting progressive hypoventilation.

Summary

- Patient Safety Net deployment was associated with decreased rescue events and the need to escalate care (ICU transfers)

- In a bed constrained environment, this opens up ICU space for other patients and resulted in a favorable impact on cost