
Workflow design and errors. An anesthesiologist's perspective.

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Objectives

- Understand anesthesiology and see the parallels to radiation oncology and radiology
- See examples of system modeling methodologies
- Learn basic human factors concepts
- Understand that context matters.
 - How we use our equipment impacts safety



Anesthesia for the Non-Anesthesiologist





Anesthesia Related Mortality

In 1954, 1 in 1560 anesthetics led to patient deaths¹

In 2006, ~0.7 in 100,000 anesthetics resulted in patient deaths²



Patient Safety in Anesthesia

AKA “How did we make anesthesia ~100 times safer in 50 years?”

- New medications with larger therapeutic indexes and more favorable side effect profiles
- Improvements in technology for sensors and drug delivery
- **Thoughtful integration of new technology into anesthetic delivery workflows**

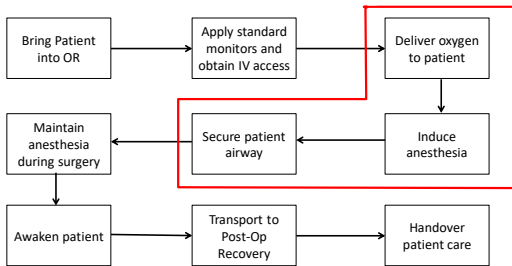


What is Safety?

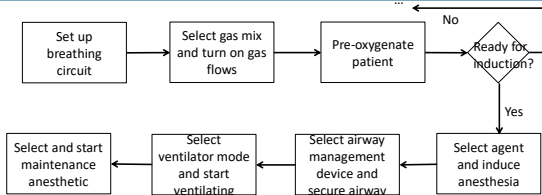
- Safety – state of being free from harm³
- Emergent system property⁴
 - Safety is not inherent solely to any device or person
 - Arises from the interactions of the components in your system



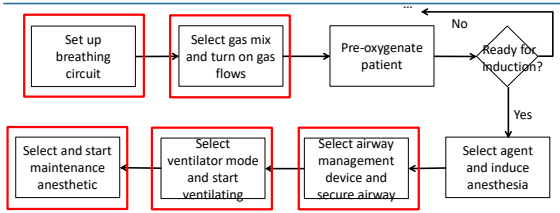
Workflow For Delivering Anesthesia



More Detailed Process Map



More Detailed Process Map





Failure Modes Effects Analysis

Process Step	Failure Mode	Severity
Set up breathing circuit	System leak	Low
	System disconnect	High
Select gas mix and turn on gas flows	Hypoxic gas mixture	High
Select airway management device and secure airway	Unidentified esophageal intubation	High
Select ventilator mode and start ventilating	Failure to start the ventilator	High
	Incorrect ventilator settings	Medium
Select and start maintenance anesthetic	Failure to start a maintenance anesthetic	Medium



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Hypoxic Gas Mixtures

- Refers to any gas mixture that is less than 21% oxygen (25% in some machines)⁵
- Two major ways that this can occur:
 1. The anesthesiologist accidentally sets the machine to deliver a hypoxic gas mixture
 - i.e. turning on the nitrous oxide instead of the oxygen
 2. The machine is set properly but is not delivering what was set



Gas Flow in Anesthesia Machine

Medical gases (i.e. oxygen, nitrous oxide, air) are piped into the operating room or held in tanks in the operating room

Pipelines and/or tanks are connected to the anesthesia machine

Valve decreases the gas pressures as they go from the high pressure to the low pressure circuit

Gases pass through a flow meter to the patient circuit in the settings established by the anesthesiologist



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Gas Input Safety Mechanisms

- Pipeline gases use a **diameter-indexed safety system**
- Gas tanks use a **pin-indexed safety system**
- These measures ensure that the gas going into the flow meters is what the machine and the anesthesiologist expect



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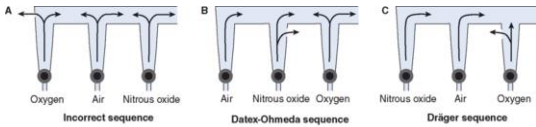
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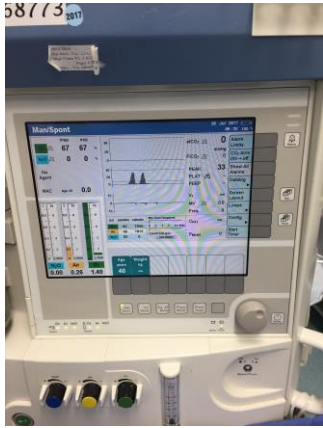
Flow Meter Leak Fail-safe Design

The order of the gases entering the circuit is designed to prevent hypoxia in the event of a leak between flow meters



Source: Butterworth JF, Mackay DC, Wannick JD, Morgan B. *MAHA's Clinical Anesthesiology*. 9th Edition. www.accessmedicine.com
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How do we now prevent anesthesiologists from turning the wrong knob and giving the wrong gas mixtures?

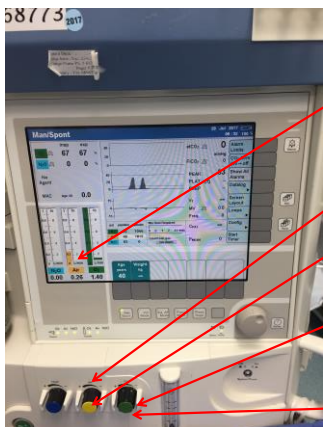
Human Factors Safety Measures

Dual encoding: using two or more methods to communicate information



MASSACHUSETTS
GENERAL HOSPITAL
ANESTHESIA, CRITICAL CARE
AND PAIN MEDICINE

HARVARD
MEDICAL SCHOOL



Geographic Mapping to Display

Text Labels

Standardized Color Coding

Tactile Differences

Standardized Oxygen Placement



Credit to The Far Side and Gary Larson

Interlock – Safety Measure

Oxygen/Nitrous Oxide Ratio Controller

- Physical or pneumatic interlock between the nitrous oxide and the oxygen flow meters
- Limits the ratio of the two to 25%

This safety feature came from an understanding of the device's use in real-life workflows and environments

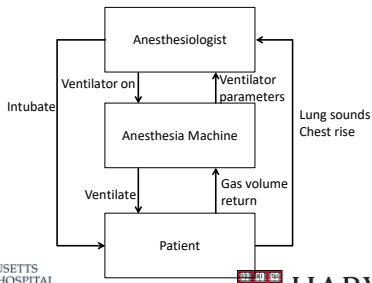


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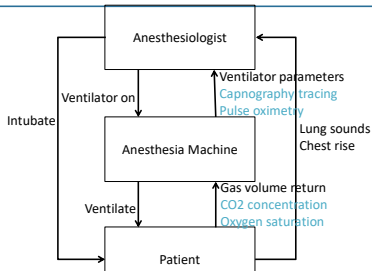
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Systems Theoretic Process Analysis



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Alarm Fatigue

Too many alarms lead to people ignoring alarms and potentially dangerous situations





Graded Alarms

- Alarm information is coded in multiple ways:
 - Alphanumeric data
 - Color coding
 - Differential auditory alarms
- Machines **grade** alarms by the severity of the problem
 - Circuit Leak: low severity
 - Low Minute Ventilation: medium severity
 - Apnea: high severity



Adjustable Alarms

- Not all patients have the same physiology
 - Pediatrics vs young healthy adults vs chronically ill geriatric patients
- Therefore, alarm limits are adjustable, so you only see alarms that are pertinent to your patient



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Take Home Points

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References

¹Beecher, H.K., & Todd, D.P. (1954). A Study of the Deaths Associated with Anesthesia and Surgery: Based on a Study of 599,548 Anesthesias in Ten Institutions 1948-1952, Inclusive. *Annals of Surgery*, 140(1), 2-34.

²Lienhart, A., Auroy, Y., Pequignot, F., Behnhamou, D., Warszawski, J., Bovet, M., & Jouglu, E. (2006). Survey of Anesthesia-related Mortality in France. *Anesthesiology*, 105, 1087-1097.

³Merriam-Webster Dictionary. (2017). Accessed July 27, 2017 from <https://www.merriam-webster.com/dictionary/safety>.

⁴Leveson, NG. (2011). *Engineering a Safer World*. Cambridge, MA: MIT Press.

⁵Chapter 4: The Anesthesia Machine. (2013). In Butterworth, J.F., IV, Mackey, D.C., & Wasnick, J.D. *Morgan & Mikhail's Clinical Anesthesiology* (5th ed.). New York, NY: McGraw-Hill.