32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

in Response to the COVID-19 Pandemic

Rapid Application of Systems Engineering: Quantifying Airborne Dispersion & Solutions

Nathan Edwards, Richard Potember
nedwards@mitre.org rpotember@mitre.org

www.incose.org/symp2022

Concerns for COVID-19 Airborne Transmission

Transportation and facilities are essential for U.S. economy, national security, and the next generation.

Shared air spaces

The concerns are broad reaching

Common research approaches have many assumptions

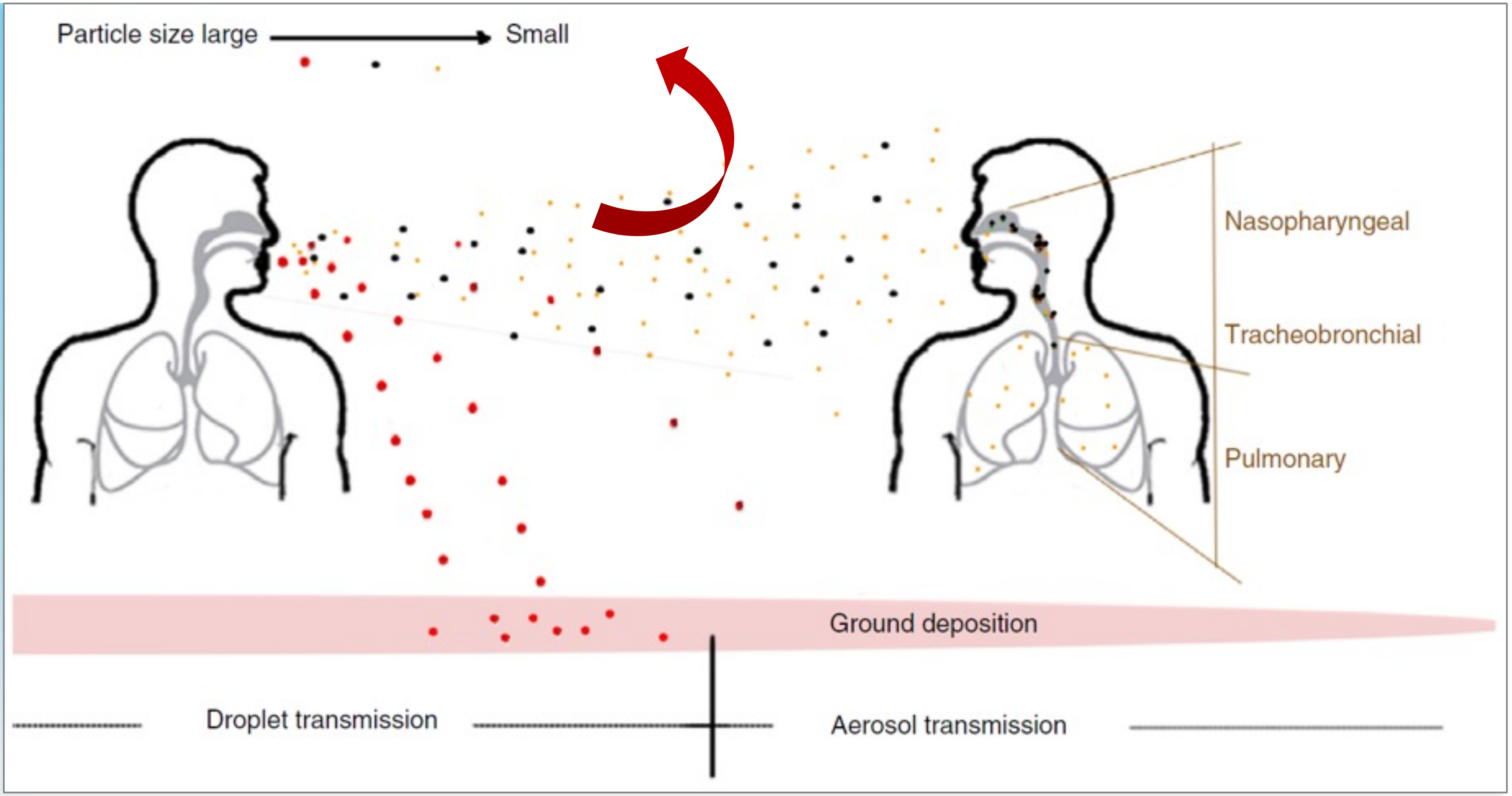
MITRE

Framing the Problem: Airborne Transmission & Misnomers

Social Distancing only **applies to droplets**

Debate on **aerosol transmission**

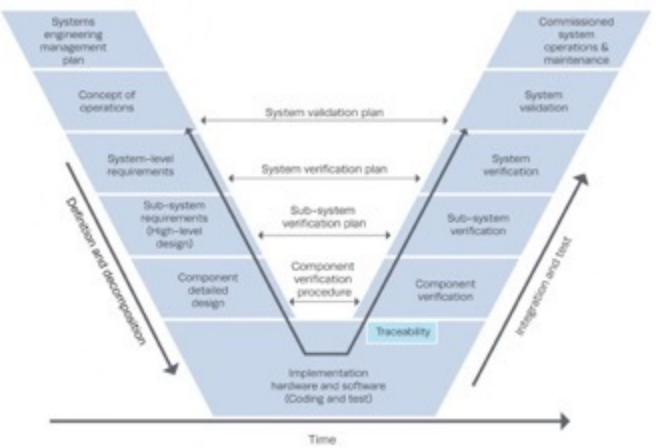
How do we disrupt the **chain of transmission?**

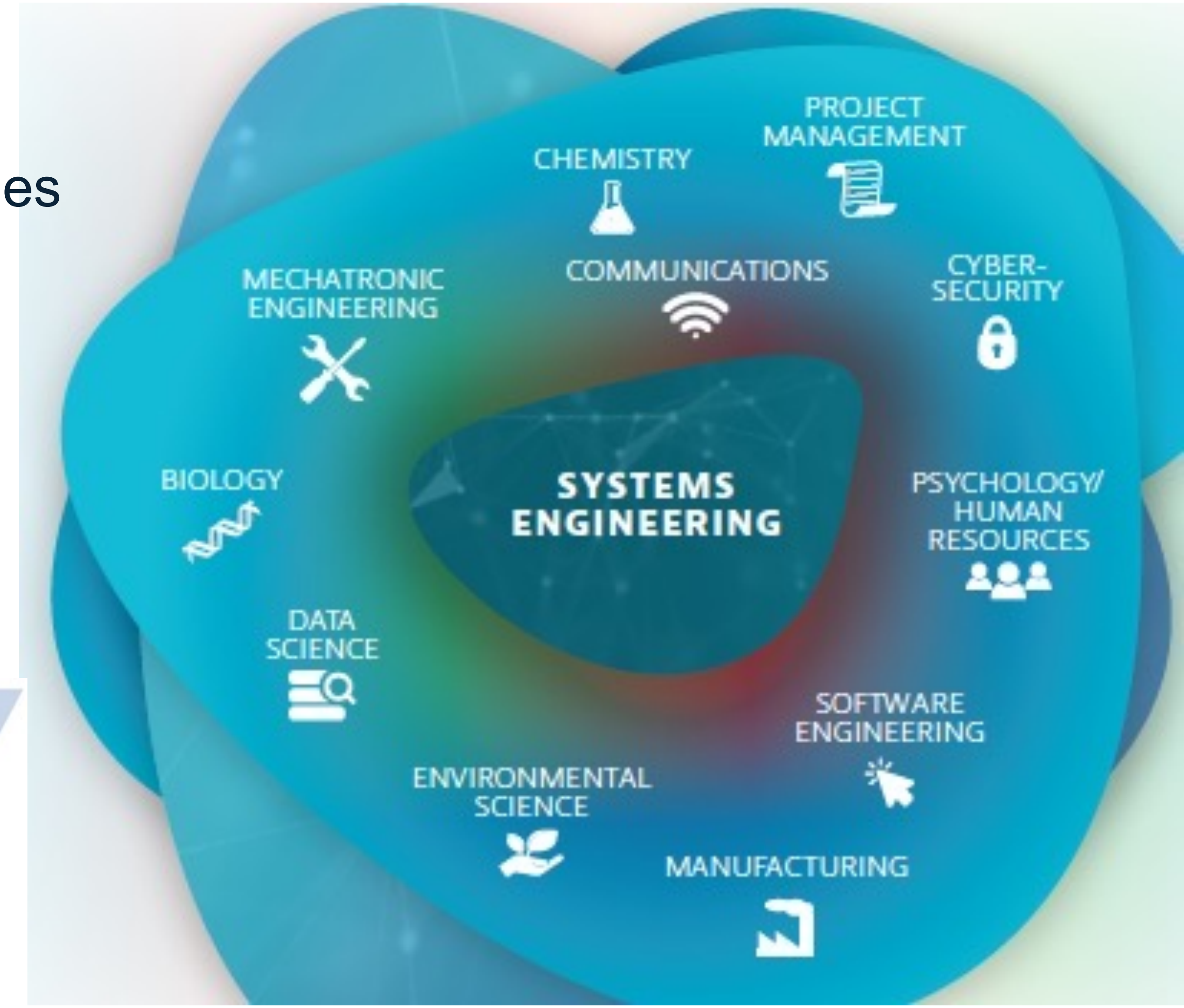


Pan M, Lednicky JA, Wu C-Y. Collection, particle sizing and detection of airborne viruses. Journal of Applied Microbiology. 2019;127:1596–611.

Systems Engineering

- How do you manage all these disciplines on a rapid timeline?
- Interactions between each domain?
- Precision vs Sufficiency?
- Product vs Knowledge Discovery?
- What SE approach to use?
  - Loss-driven
  - Feature-driven
  - Usage-driven
  - ISO 15288





https://www.incose.org/about-systems-engineering/se-vision-2035

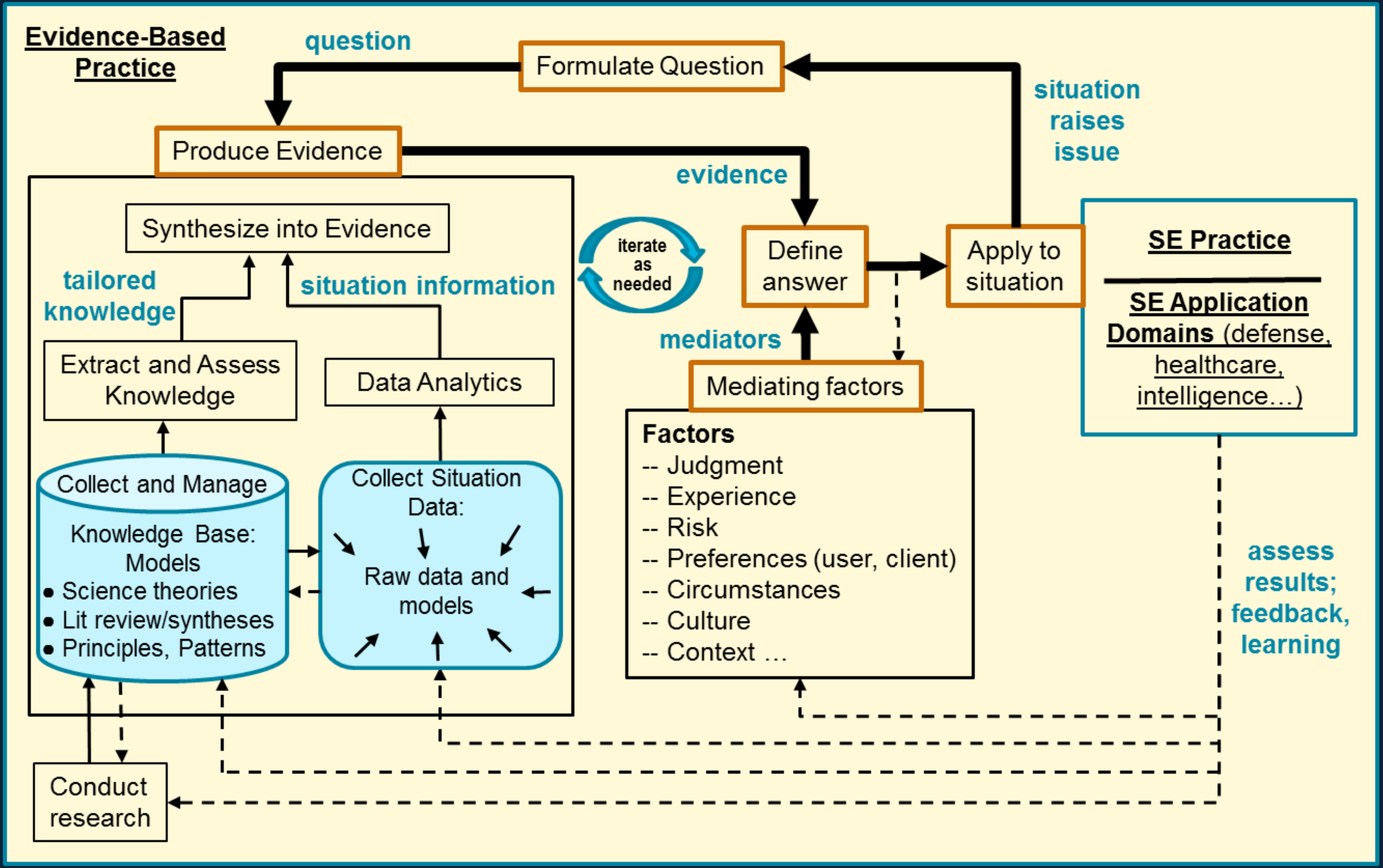
Theoretical Foundations (INCOSE Vision 2035)

- Observable Phenomena as the Basis for Theoretical Foundations:
  - Provide principles and derived theories that capture the interactions between components (state-impacting exchange of energy, force, material, etc.)
  - The foundations and their supporting mathematical-based descriptive models provide the basis for virtual explorations of the system design-interaction space

With many scientific unknowns, how do we rapidly get to an ideal SE state during a pandemic?

Evidence-Based Systems Engineering

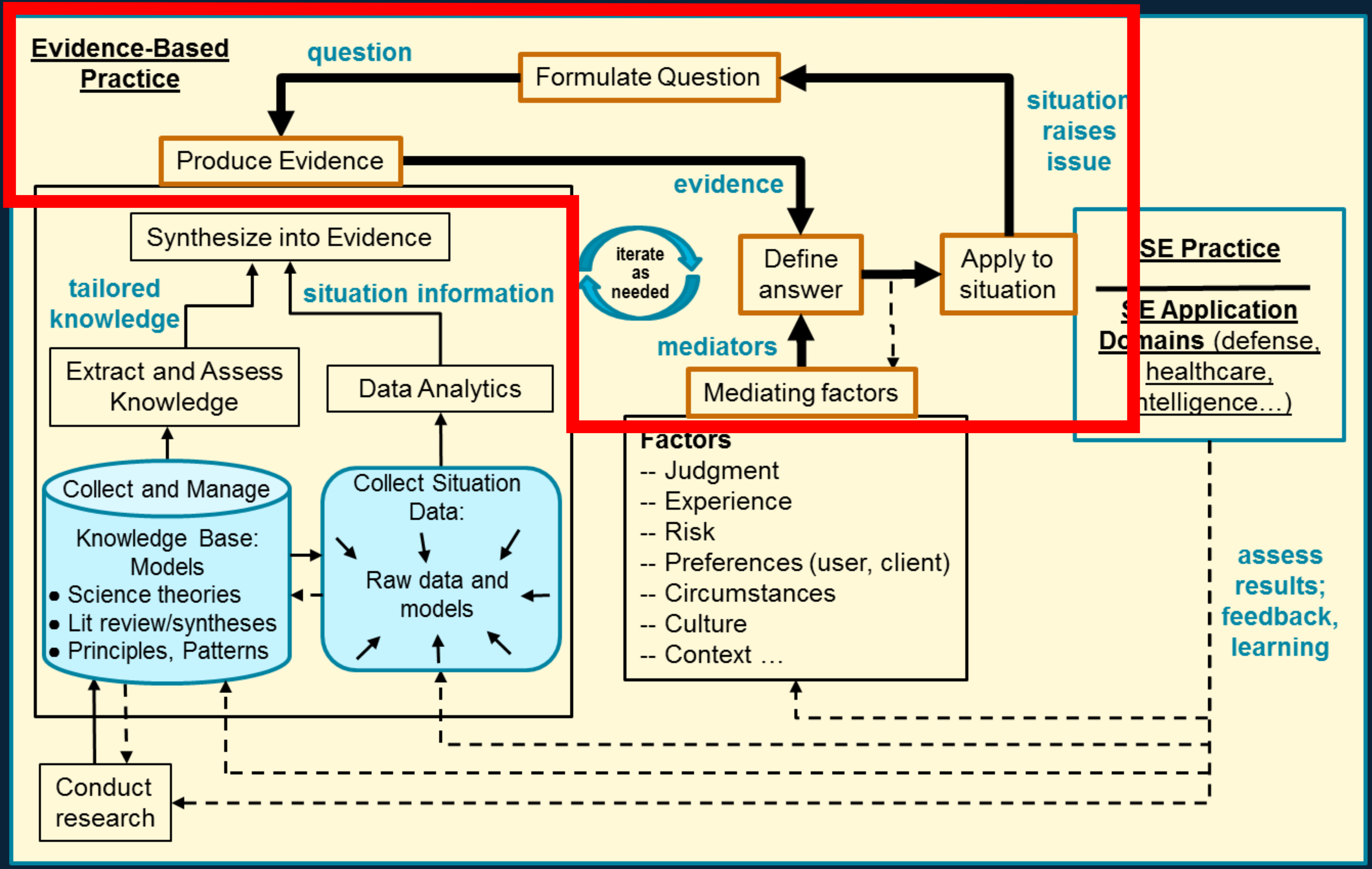
1. Formulate question
2. Produce evidence
3. Mediating factors
4. Define answer
5. Apply & iterate



Hybertson D, Hailegiorghis M, Griesi K, Soeder B, Rouse W. Evidence-based systems engineering. *Systems Engineering*. 2018;21(3):243-258. doi:10.1002/sys.21427

Evidence-Based Systems Engineering

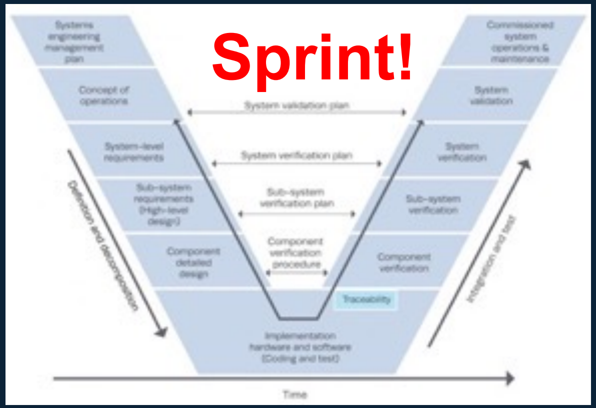
1. Formulate question
2. Produce evidence
3. Mediating factors
4. Define answer
5. Apply & iterate



Hybertson D, Hailegiorghis M, Griesi K, Soeder B, Rouse W. Evidence-based systems engineering. *Systems Engineering*. 2018;21(3):243-258. doi:10.1002/sys.21427

Rapid SE & The Search for Knowledge

Unknown



Knowledge, but …

- More unknowns
- Constraints
- Implications

Decision / Application

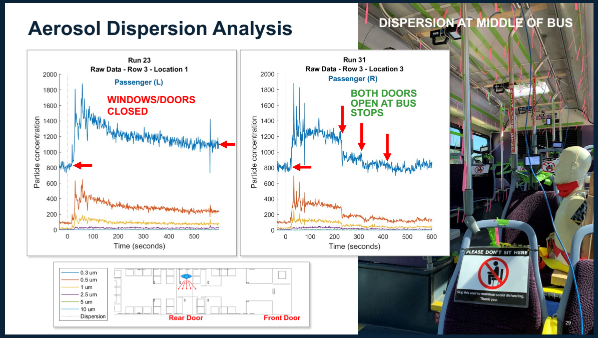
Goals of rapid effort

MITRE

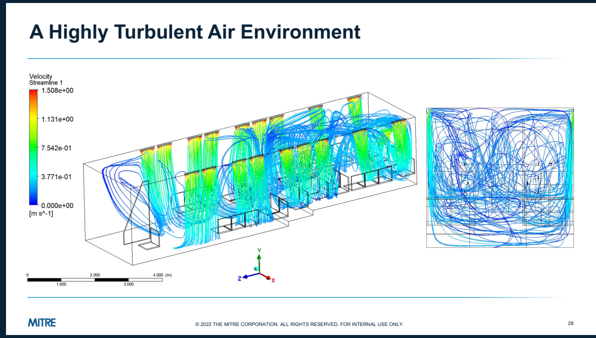
Problem Statements to Reusable Models at 90mph

- Observable Phenomena as the Basis

The Infectious Aerosol Problem



Rapid Experiments & Knowledge Discovery



Simulations of the “known,” identify “unknowns”

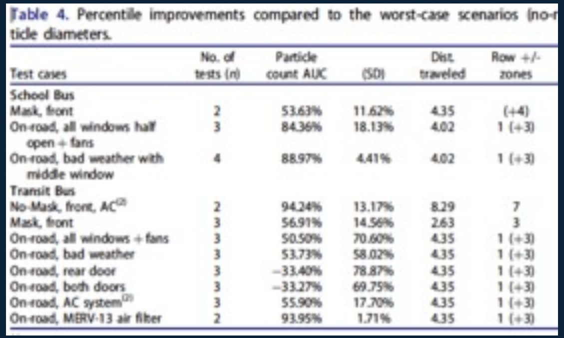
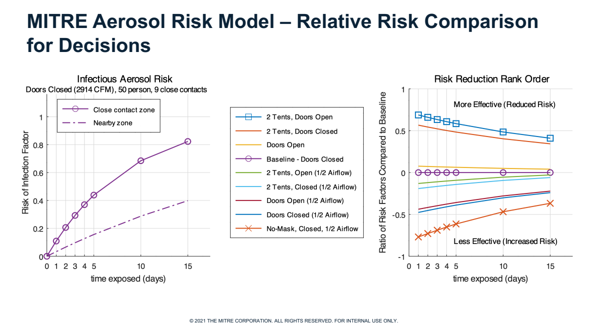


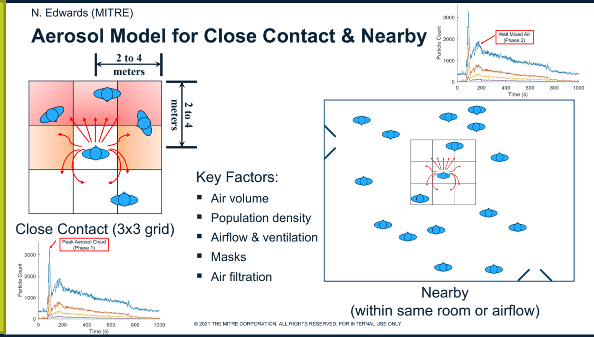
Table 4. Percentile improvements compared to the worst-case scenarios (no-r… ticle diameters.

Test cases	No. of tests (n)	Particle count AUC	(SD)	Dist. traveled	Row +/- zones
School Bus					
Mask, front	2	53.63%	11.62%	4.35	(+4)
On-road, all windows half open + fans	3	84.36%	18.13%	4.02	1 (+3)
On-road, bad weather with middle window	4	88.97%	4.41%	4.02	1 (+3)
Transit Bus					
No-Mask, front, AC[2]	2	94.24%	13.17%	8.29	7
Mask, front	3	56.91%	14.56%	2.63	3
On-road, all windows + fans	3	50.50%	70.60%	4.35	1 (+3)
On-road, bad weather	3	53.73%	58.02%	4.35	1 (+3)
On-road, rear door	3	−33.40%	78.87%	4.35	1 (+3)
On-road, both doors	3	−33.27%	69.75%	4.35	1 (+3)
On-road, AC system[2]	3	55.90%	17.70%	4.35	1 (+3)
On-road, MERV-13 air filter	2	93.95%	1.71%	4.35	1 (+3)

Data Analysis, Develop Necessary Metrics (& Theory)



Share Observations, Decision Support



Develop the Model based on Phenomena

Theoretical Foundations

Digital Engineering

MBSE-SMS

Quantifying Airborne Dispersion Through Improvised Washable Masks

April 2020 to June 2020

MITRE | SOLVING PROBLEMS FOR A SAFER WORLD

Two Uses for Masks (Medical or Improvised)

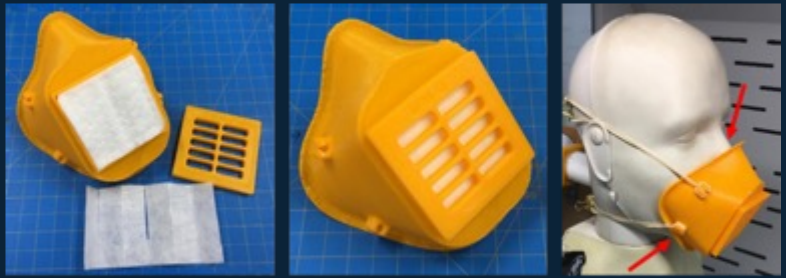
Personal Protective Equipment (PPE): Inhalation filtration

Community Transmission Reduction: Dispersion control

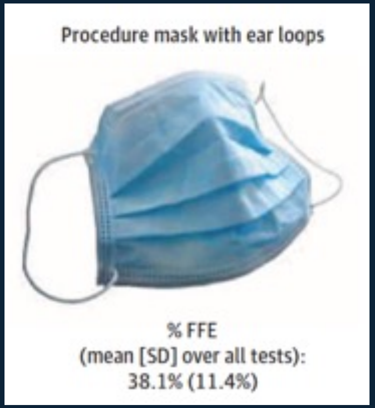
Image adopted from: https://www.osha.gov/Publications/OSHA3767.pdf

A Large Variety of Masks
(Source Control, Filtration, Fit)

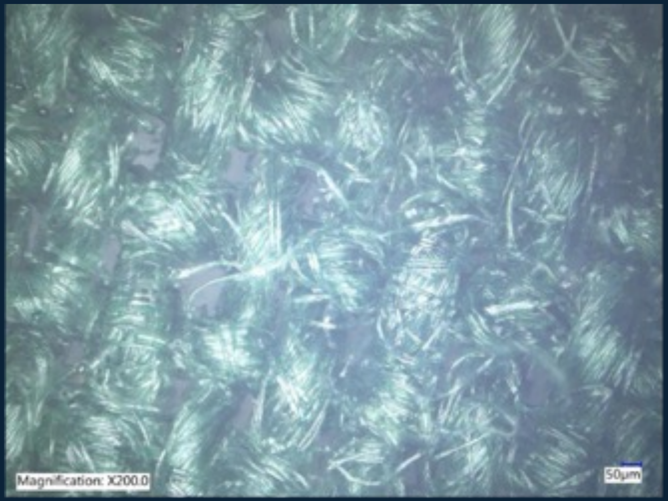
Edwards et al. 2020 (MITRE) "**Quantifying Respiratory Airborne Particle Dispersion Control Through Improvised Reusable Masks: The Physics of Non-Pharmaceutical Interventions for Reducing SARS-COV-2 (COVID-19) Airborne Transmission**", *Journal of Nanotechnology and Nanomaterials.* https://doi.org/10.33696/Nanotechnol.1.015

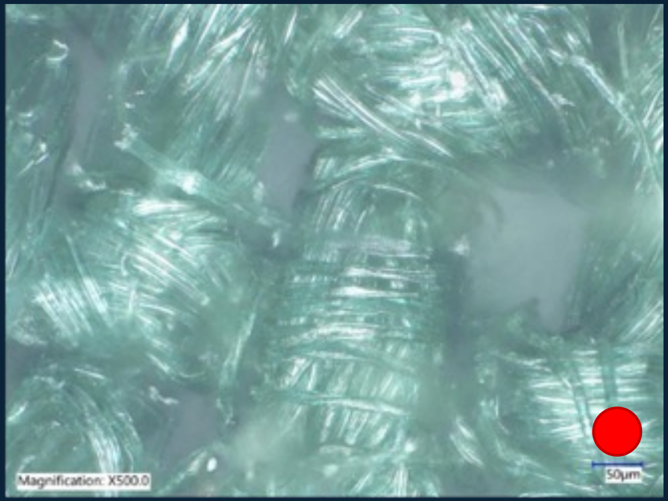


Sickbert-Bennett EE, Samet JM, Clapp PW, et al. Filtration Efficiency of Hospital Face Mask Alternatives Available for Use During the COVID-19 Pandemic. *JAMA Intern Med*. 2020;180(12):1607. doi:10.1001/jamainternmed.2020.4221



Filtration Mechanisms – How Masks Work

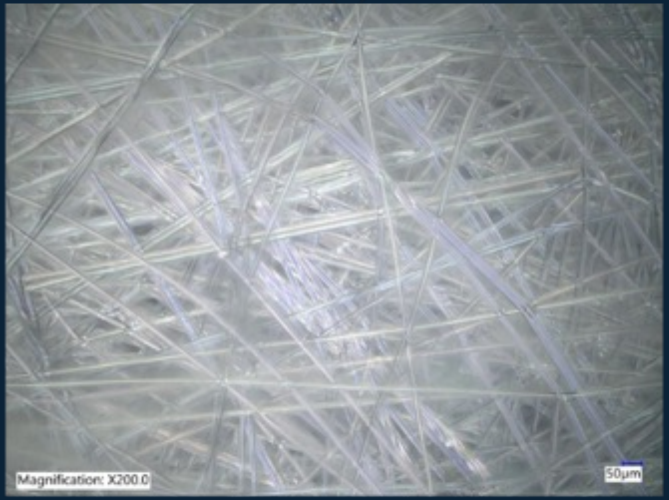


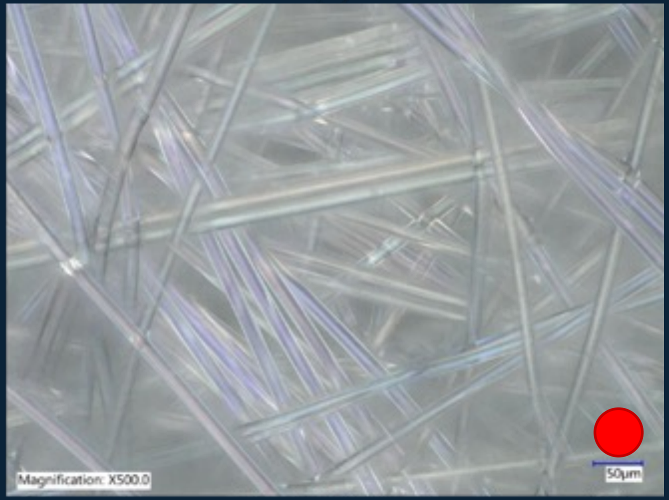


Cloth Mask
60% cotton,
40% polyester

(Inertial Impaction & Brownian diffusion)

Soil levels,
Decontamination,
Effective use period

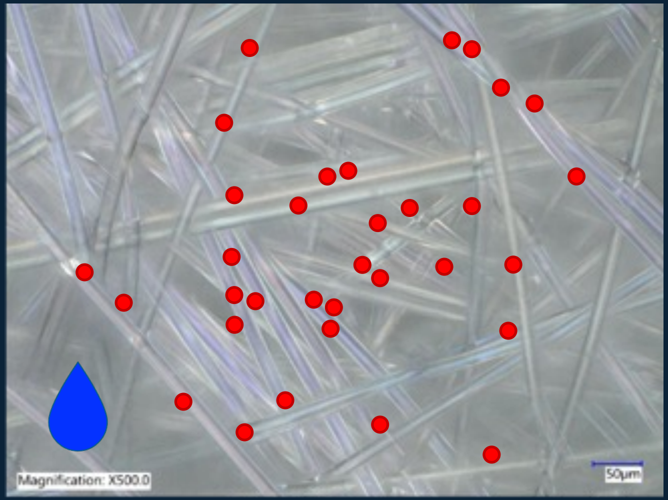




Longer Use

N95, KN95, FFP2
Melt-blown
polypropylene

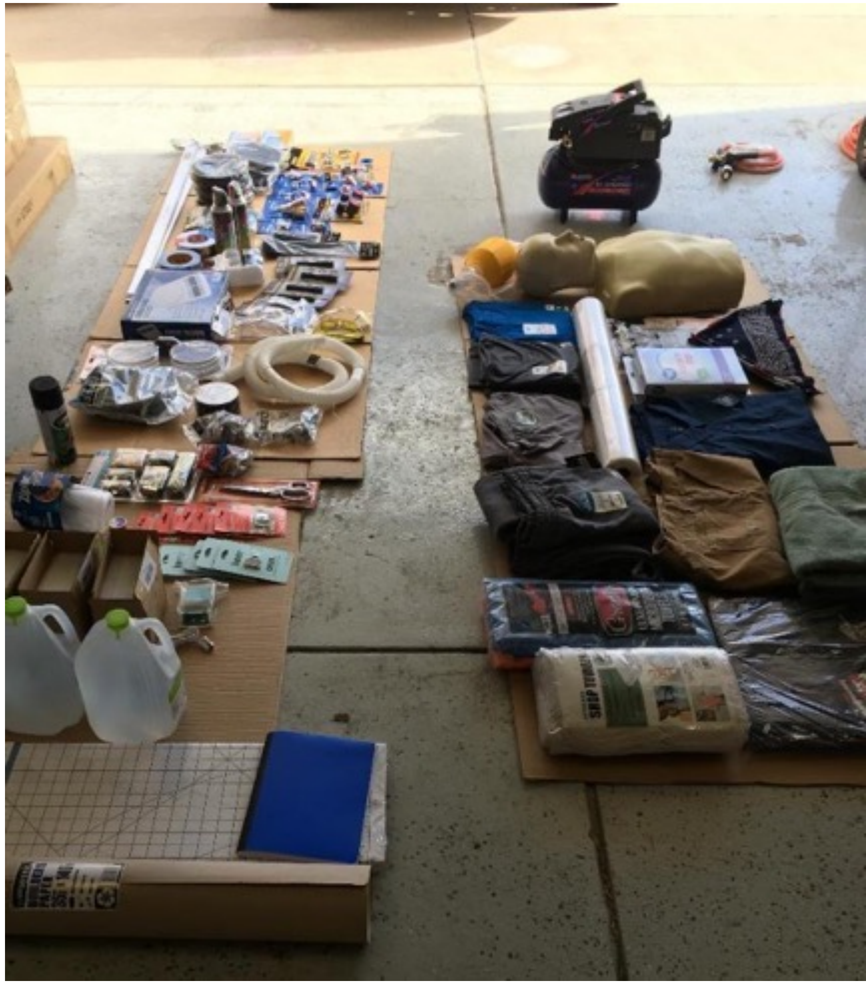
(Electrostatic)



Edwards et al. 2020 (MITRE) "Quantifying Respiratory Airborne Particle Dispersion Control Through Improvised Reusable Masks: The Physics of Non-Pharmaceutical Interventions for Reducing SARS-COV-2 (COVID-19) Airborne Transmission"

Rapid Project Timeline – Run Fast!

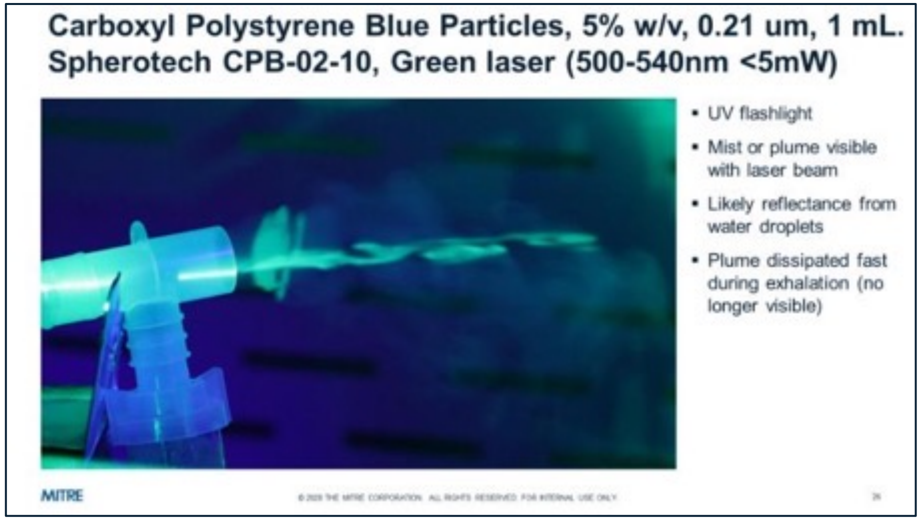
- **Day 1** (April 3): Team meeting to kick off effort, create shopping list, contact local health organizations to borrow CPR training equipment for test
- **Day 2** (April 4 Sat): Acquired essential items, fabrics, etc. from local sources + online
- **Day 3:** Construct manikin basic test apparatus, fabric coupons

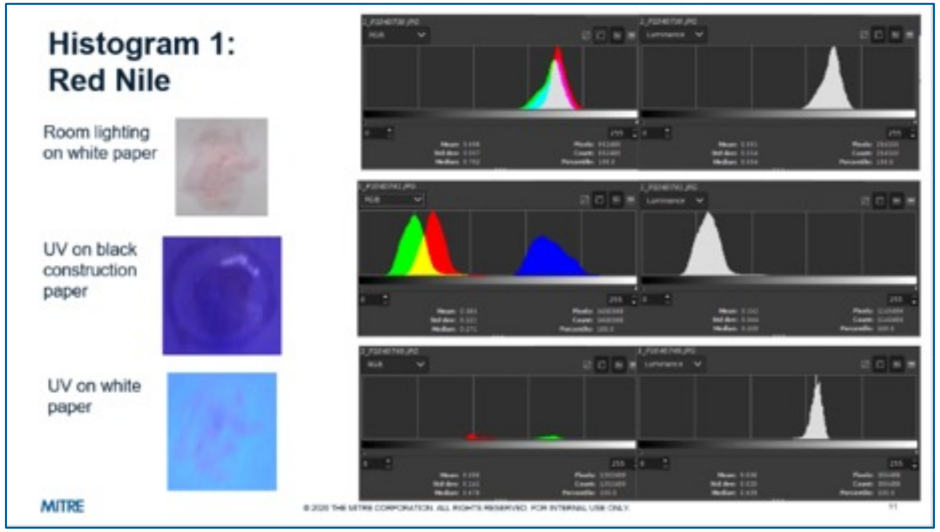


Not All Concepts are Successful – Week 2

- Investigate feasibility of using fluorescing monodisperse particles, NDAs, optical testing (UVA, red laser, green laser)

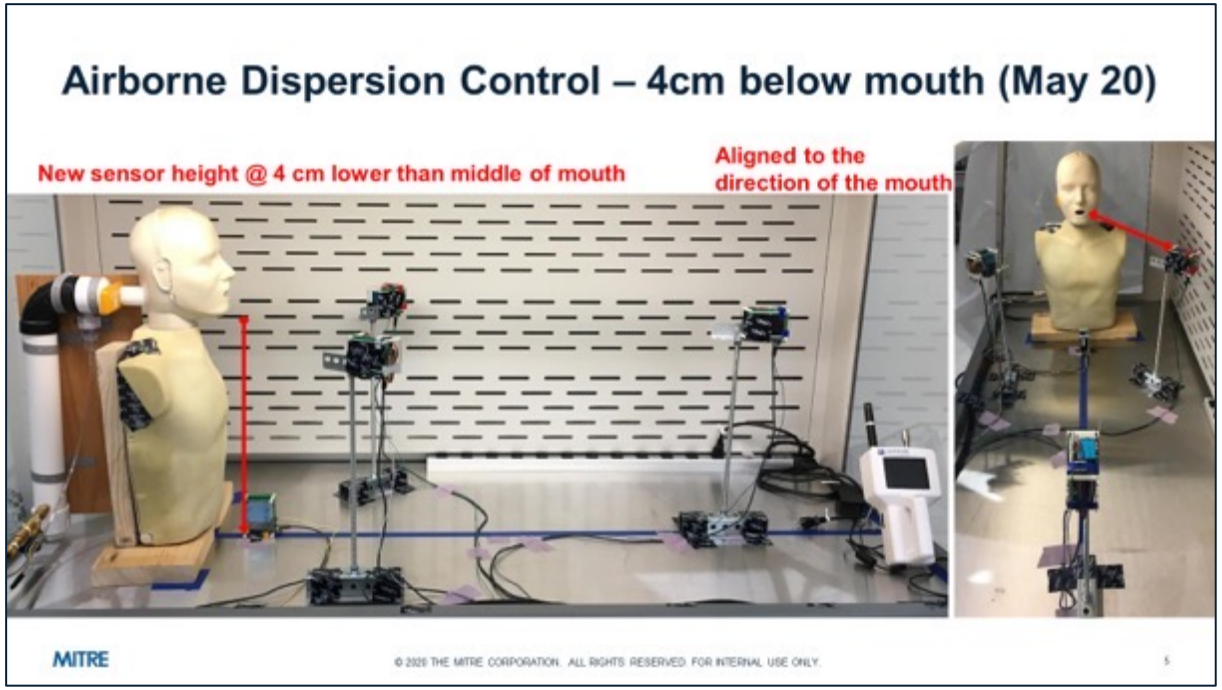
Fluorescent Particles, Nile Red, 1% w/v, 0.25 um, 0.5 mL.
Spherotech FP-0256-2

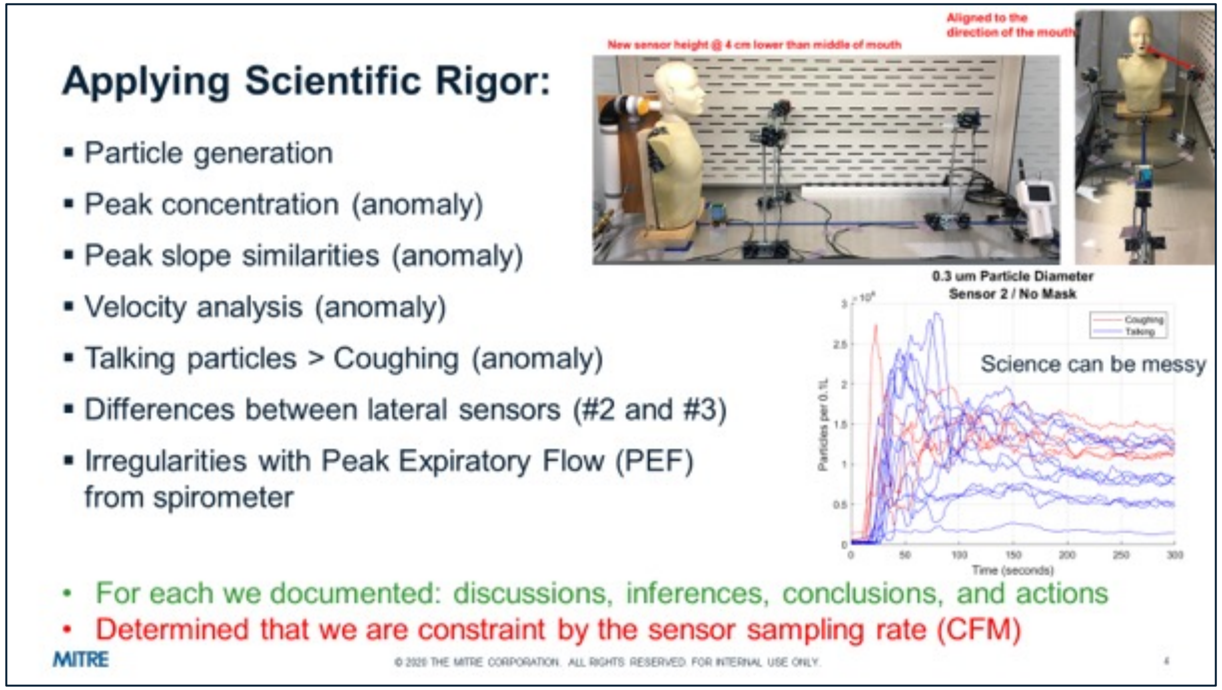




Scientific Rigor was Critical

- Going in position for the study: decision processes involving human lives depended on our results
- Validate, verify, and debate the results - 108 experimental runs completed





Edwards et al. 2020 (MITRE) **"Quantifying Respiratory Airborne Particle Dispersion Control Through Improvised Reusable Masks: The Physics of Non-Pharmaceutical Interventions for Reducing SARS-COV-2 (COVID-19) Airborne Transmission",** *Journal of Nanotechnology and Nanomaterials.* https://doi.org/10.33696/Nanotechnol.1.015

Quantifying Airborne Dispersion & Solutions in Public Transportation

July 2020 to Sept 2020

MITRE | SOLVING PROBLEMS FOR A SAFER WORLD

66-Seat School Bus and 35-Foot Low-floor Transit Bus

84 test runs
over 2 weeks

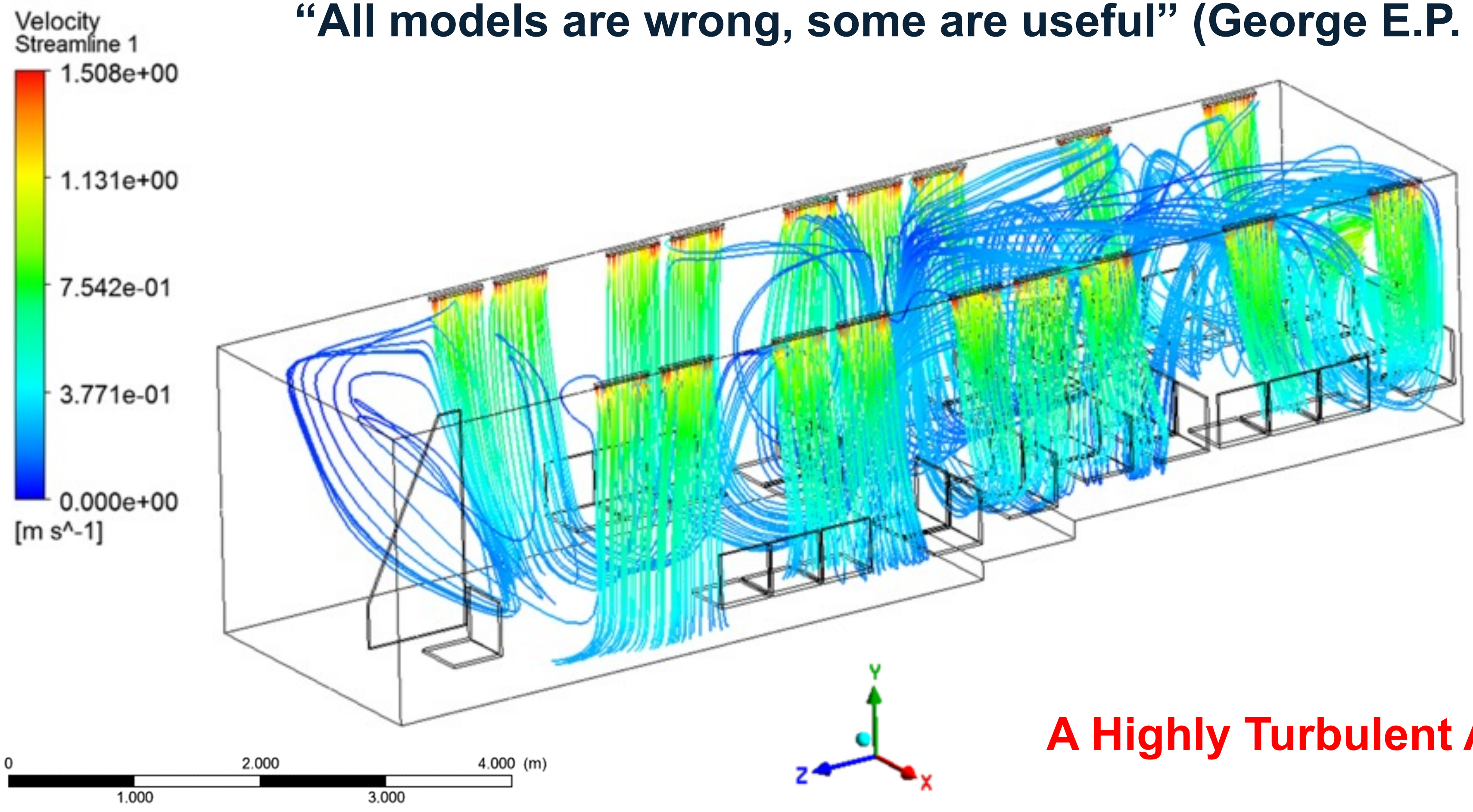
78.3 million points
of real-time data collected

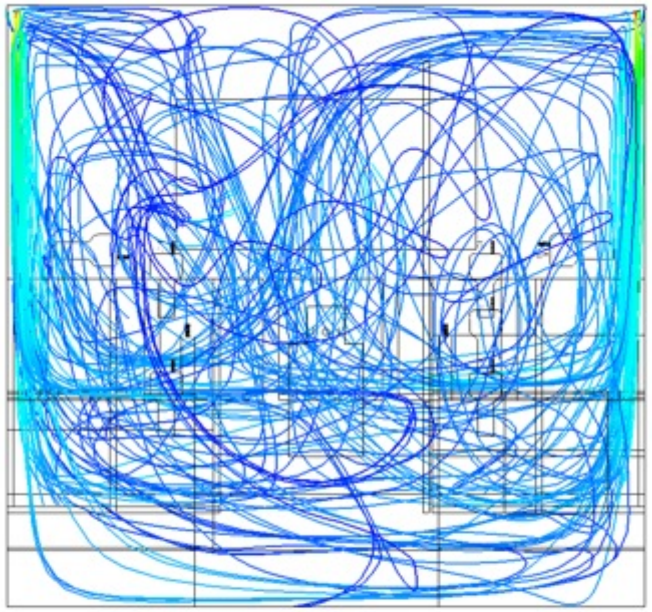
124.73 miles
of “bus-in-motion” testing

Focus
on risk-based decisions

CFD Modeling used to Inform Sensor Positions

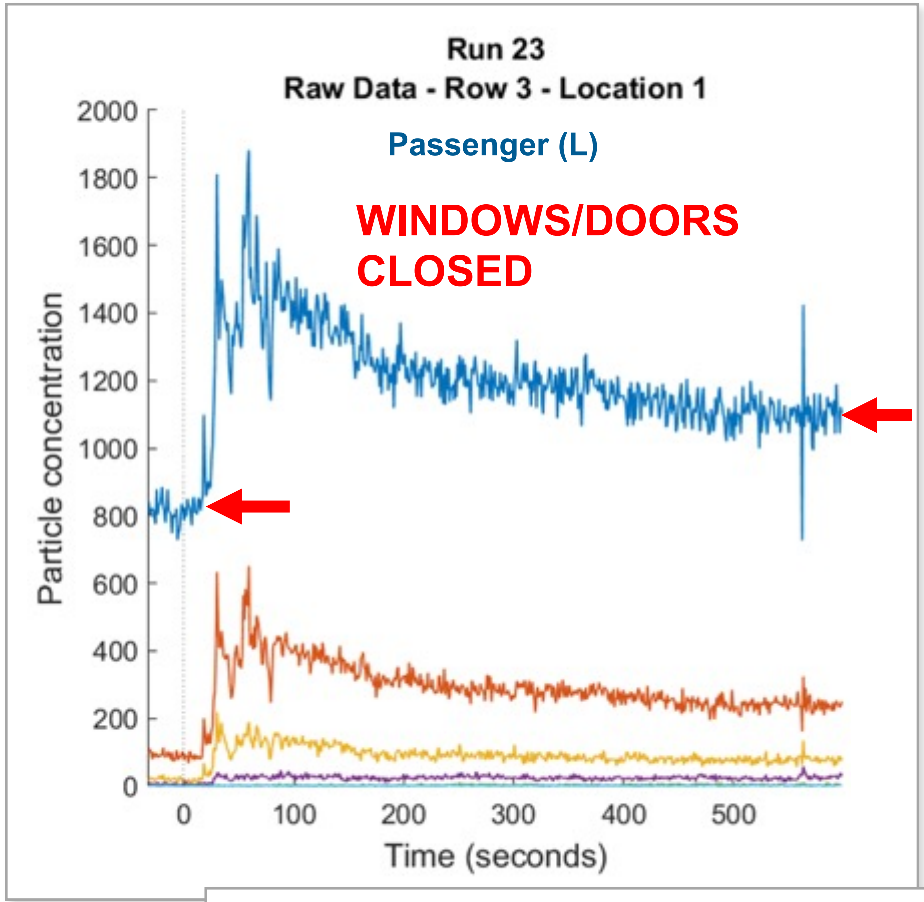
“All models are wrong, some are useful” (George E.P. Box 1978)

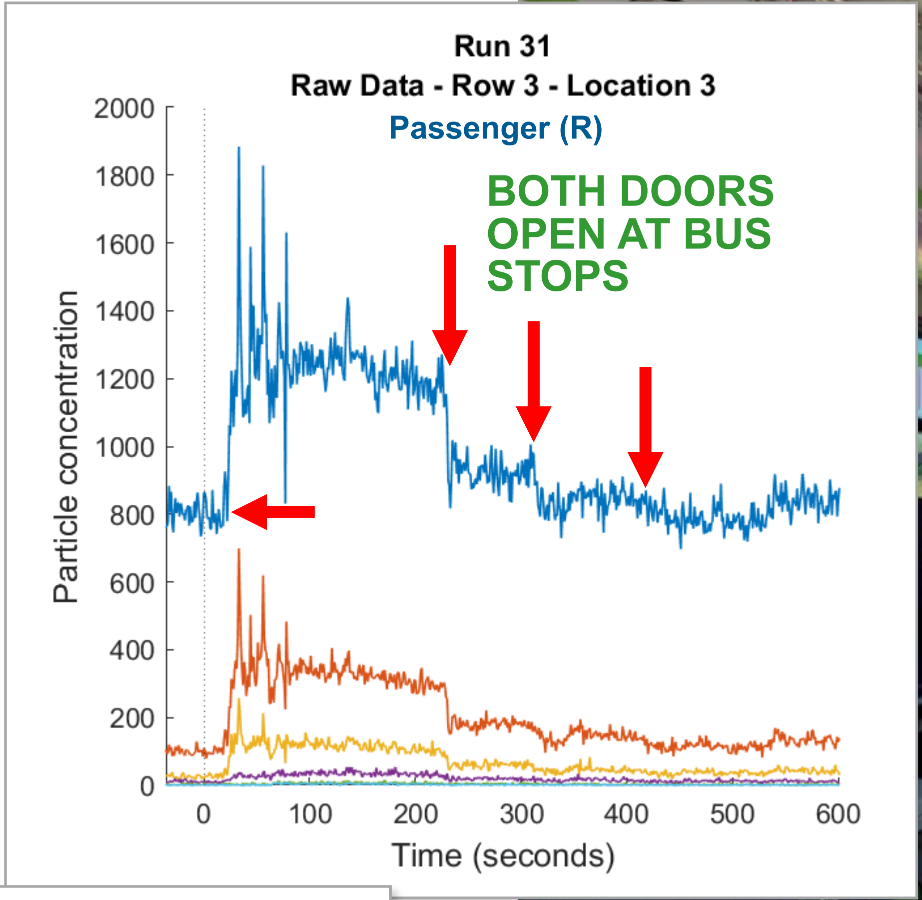




A Highly Turbulent Air Environment

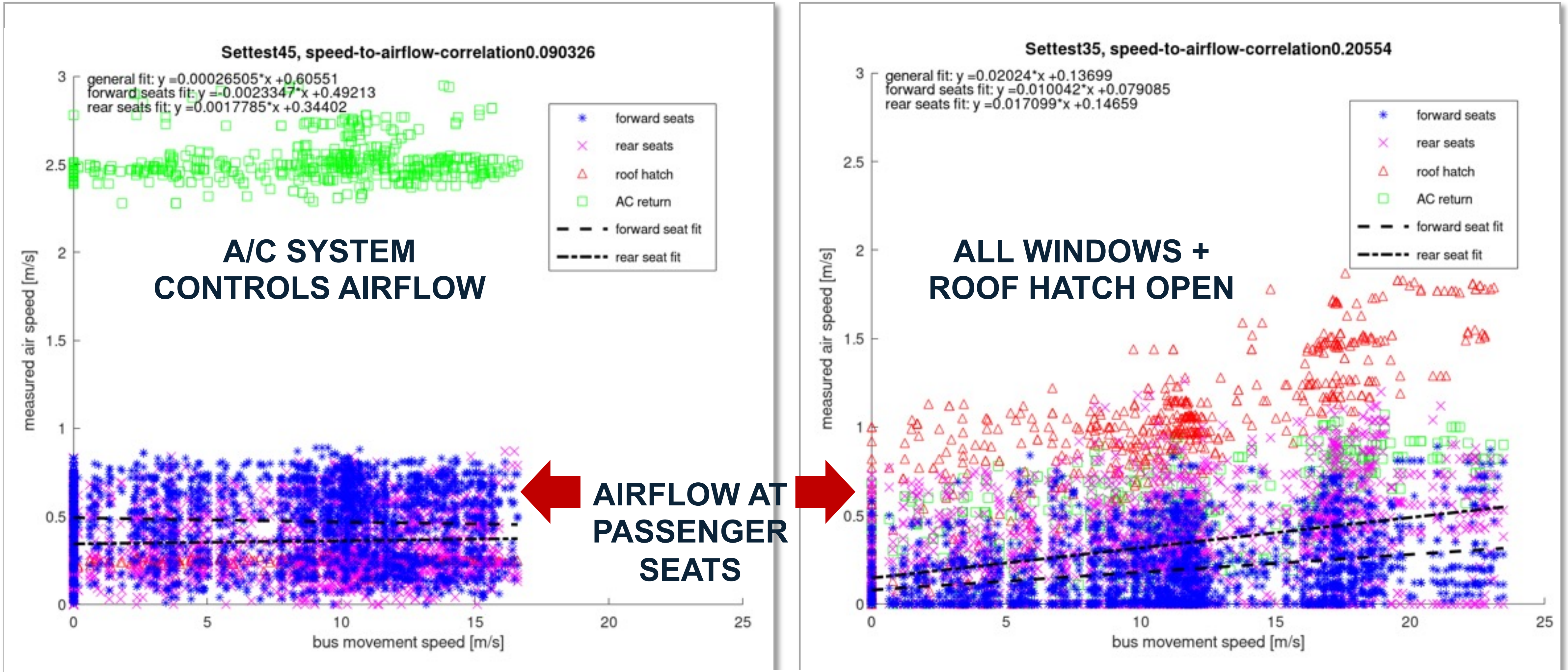
Aerosol Dispersion Analysis





Airflow to Bus Speed Correlation

https://www.mitre.org/news/press-releases/face-masks-open-windows-on-buses-reduce-potentially-infectious-particles



Edwards NJ, Widrick R, Wilmes J, et al. **Reducing COVID-19 Airborne Transmission Risks on Public Transportation Buses: An Empirical Study on Aerosol Dispersion and Control**. *Aerosol Science and Technology*. 2021;55(12):1378-1397. doi:10.1080/02786826.2021.1966376

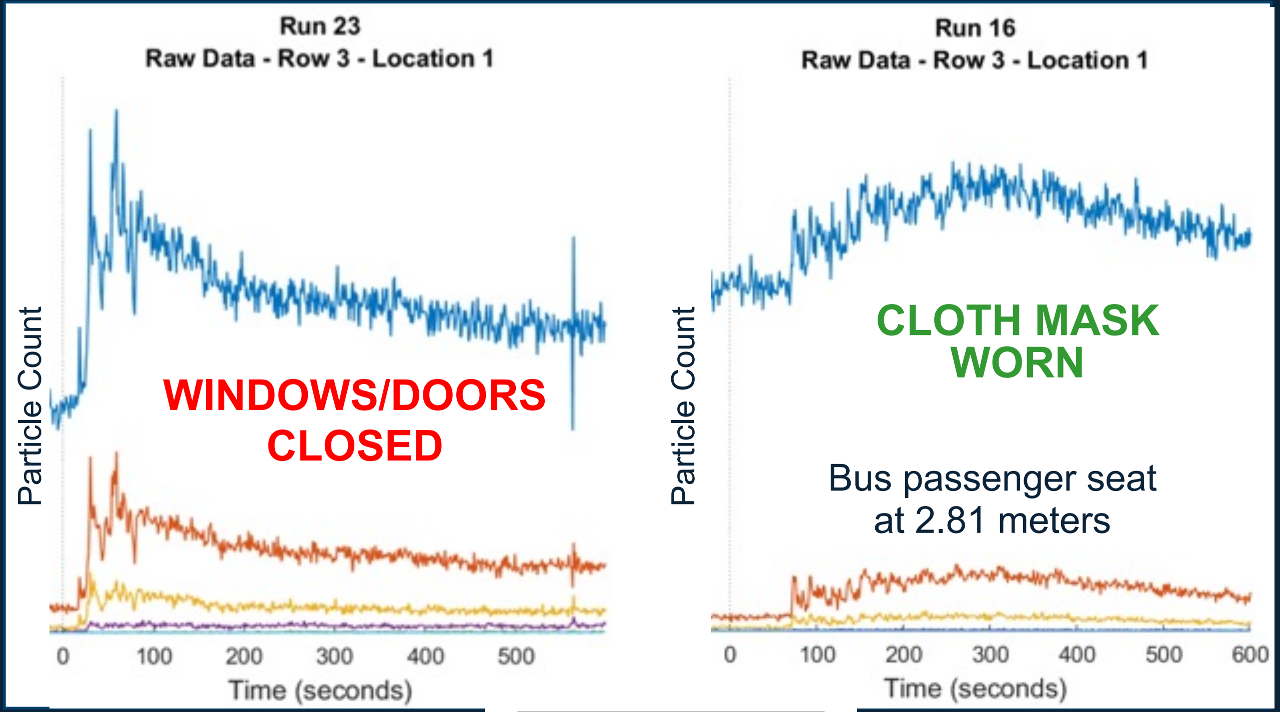
Towards MBSE Reusable Artifacts

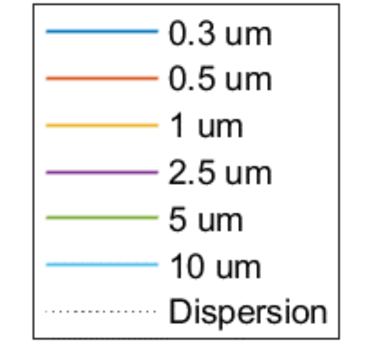
Jan 2021

MITRE | SOLVING PROBLEMS FOR A SAFER WORLD

Quality of Masks, Time and Virion Transmission

(~Infection Probability Risk based on Exposure)





Masks decrease emissions, distance and exposure

Est. VIRION COUNT

Mask for Exhalation Control \ Mask for Protection	None	Procedure Mask	Cloth (mixed)	Surgical (medical)	Cloth + Procedure	N95
None	22500	13928	13707	6413	5135	338
Procedure Mask	13928	8621	8485	3969	3178	209
Cloth (mixed)	13707	8485	8350	3906	3128	206
Surgical (med)	6413	3969	3906	1828	1463	96
Cloth + Procedure	5135	3178	3128	1463	1172	77
N95	338	209	206	96	77	5

15 Minutes at 6 ft , 50% air exchange

- Think like an aerosol ➞ ventilate
- Use time, distance, shielding
- Don’t let your guard down

MITRE

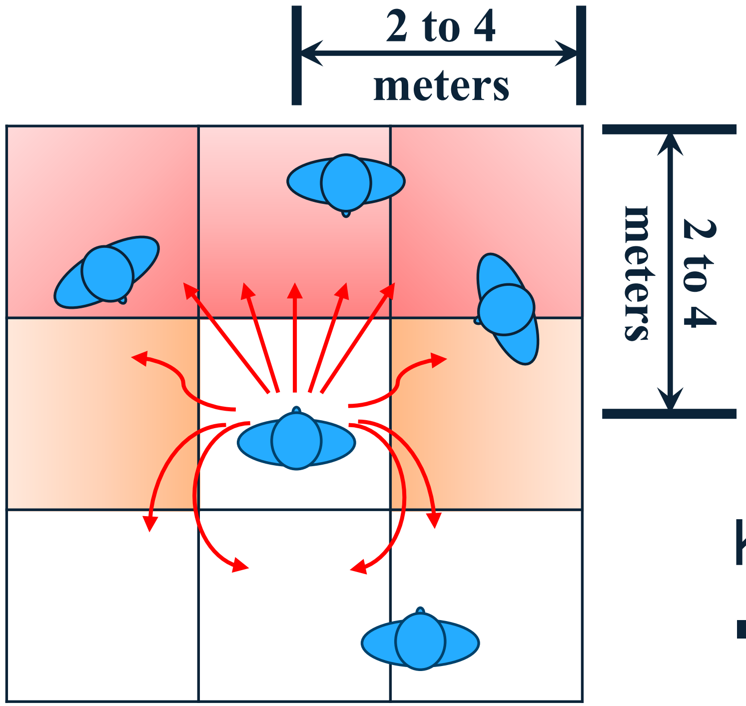
Transitioning Science to Practice: Strategies for Indoors

Strategy	Indoor Air Quality Control
Remove	Improve HVAC filtration using MERV-13 / HEPA air filters; general facility hygiene.
Avoid	Stay out of a room; Maintain greater social distancing with indoor air environments.
Prevent	Wearing of face masks for source control.
Protect	Wearing of face masks to protect from inhalation.

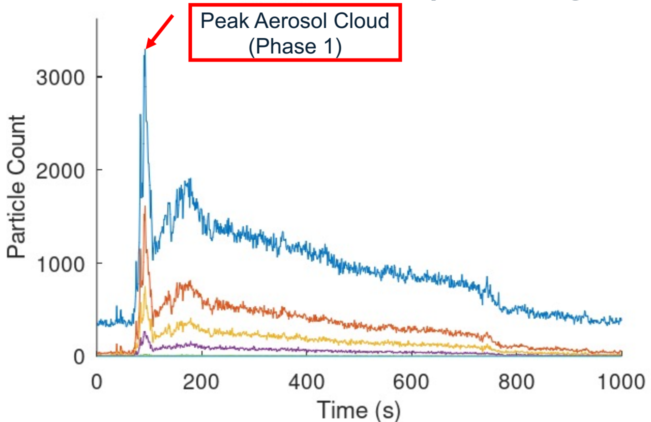
Edwards NJ, Colder B, Sullivan J, Naramore L. **A Practical Approach to Indoor Air Quality for Municipal Public Health and Safety**. *Open Journal of Political Science (OJPS)*. 2021;11(1):176-191. doi:10.4236/ojps.2021.111012

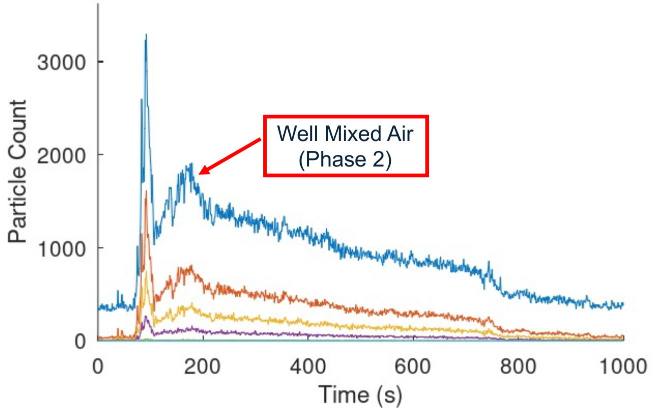
N. Edwards (MITRE)

Aerosol Model for Close Contact & Nearby



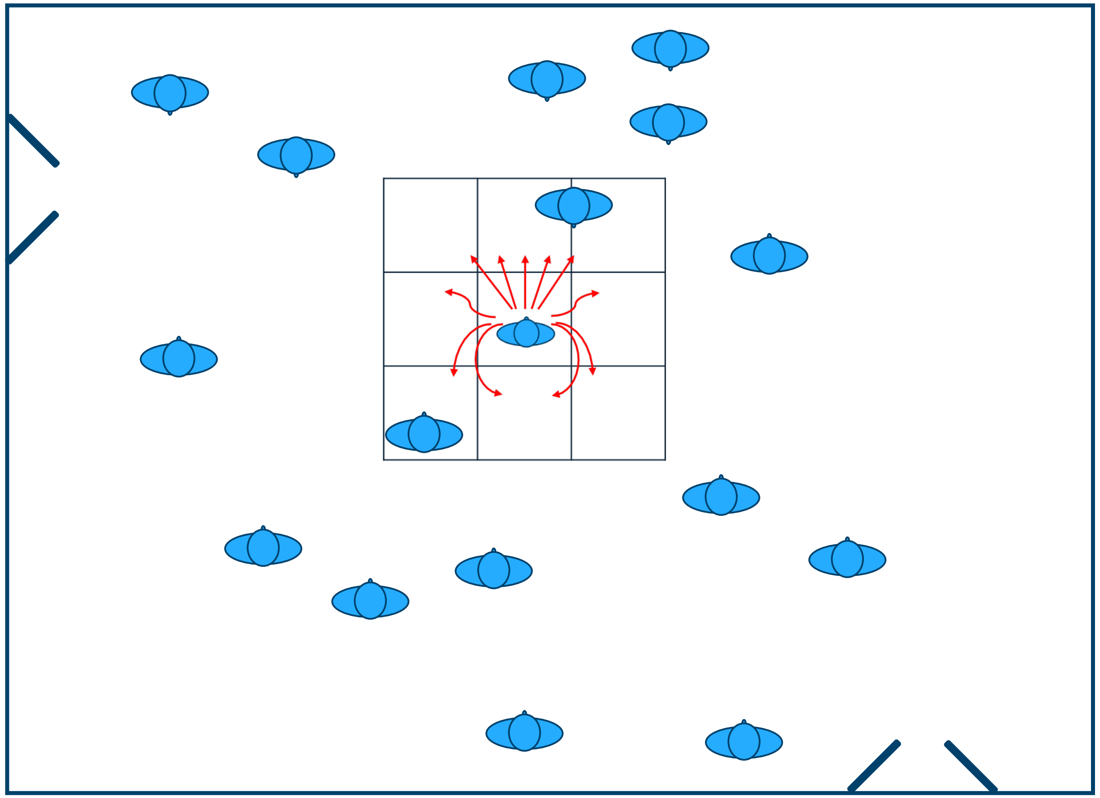
Close Contact (3x3 grid)





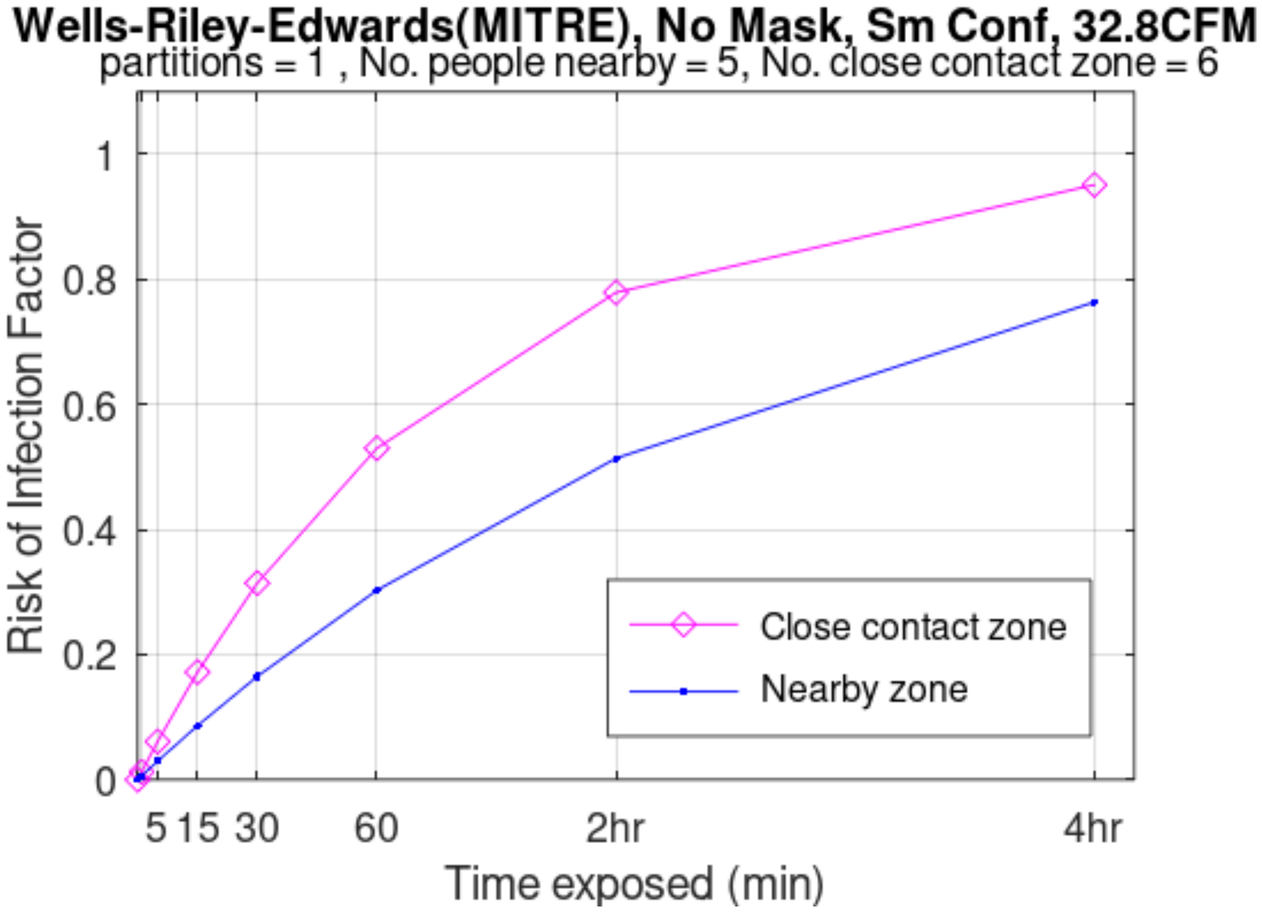
Key Factors:

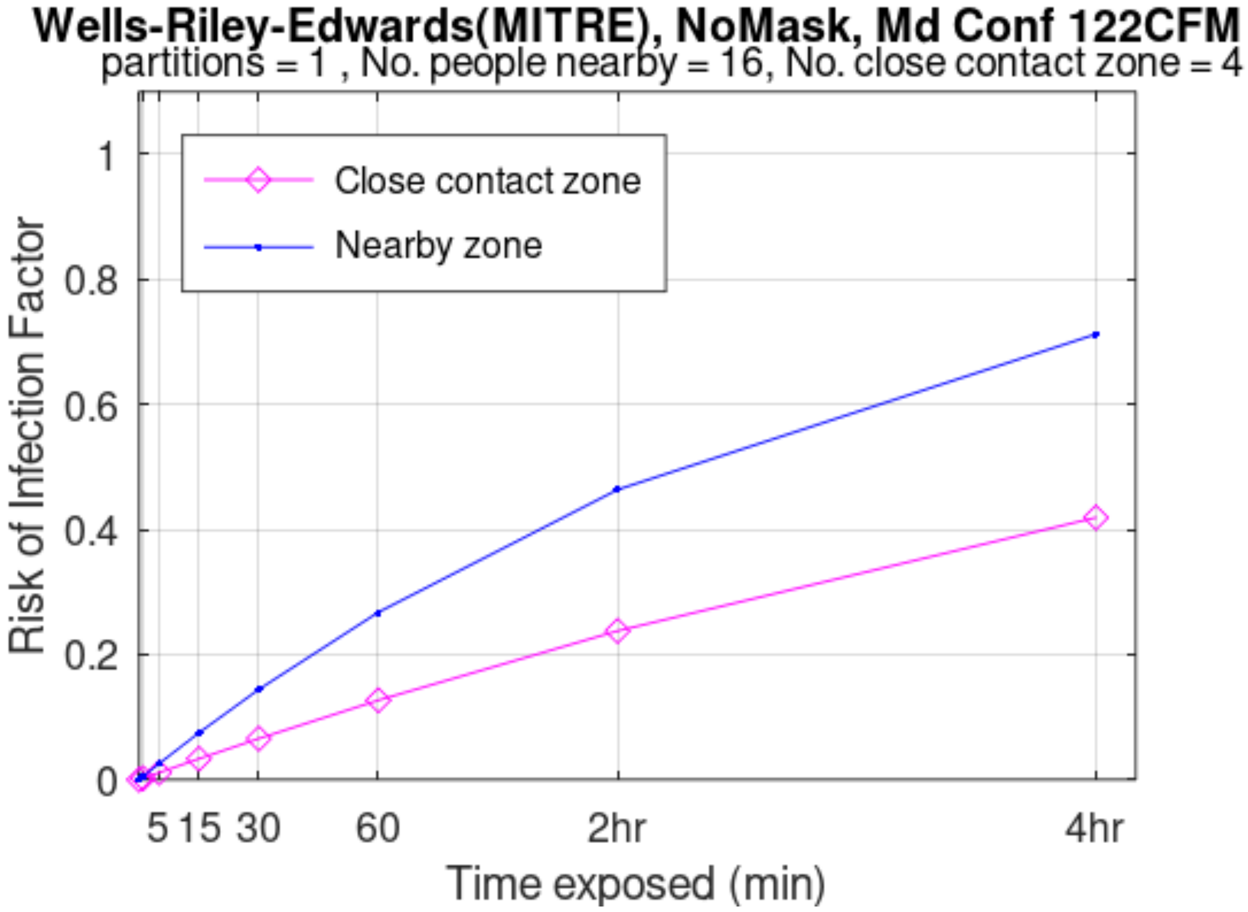
- Air volume
- Population density
- Airflow & ventilation
- Masks
- Air filtration



Nearby
(within same room or airflow)

10 Office Building Scenarios





Large room, higher airflow ➞ buildup of infectious particles becomes the overall risk driver. Don't forget the immediate risk close to infected person (4 people).

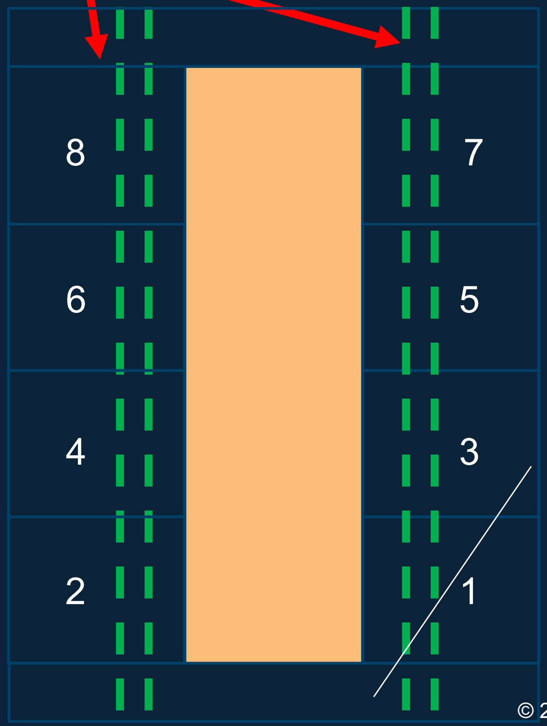
Analysis for Improving Covid Resiliency of USBP Facilities

March 2021

MITRE | SOLVING PROBLEMS FOR A SAFER WORLD

Temporary Holding Facility - Assumptions

- Immigrants roam free inside, but generally stay within partition area
- 2 HVAC units per partition (27,000 CFM total)
- Overhead fabric duct for cooling, 4 ducts per tent partition

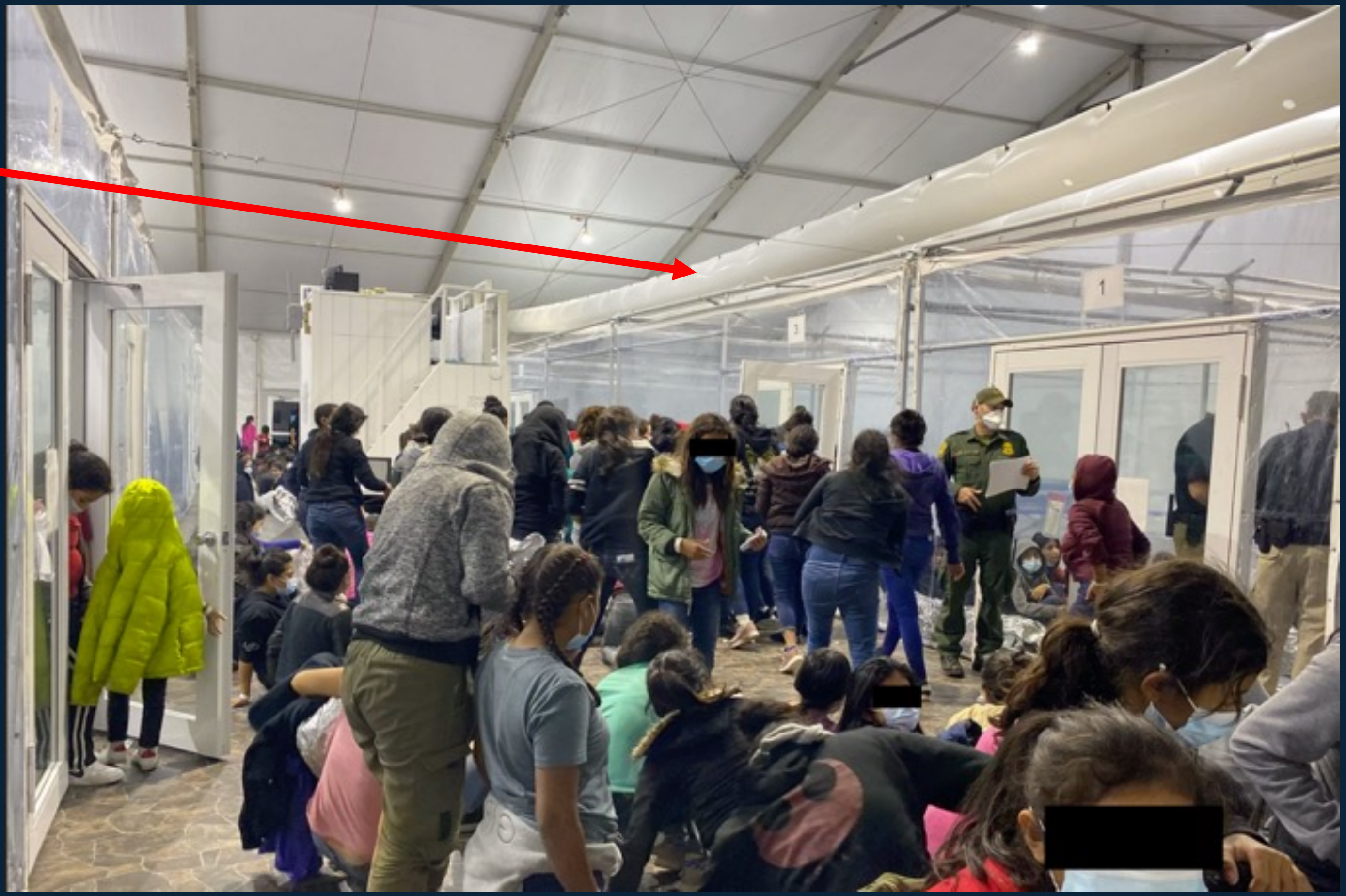


$$6.07\ min = \frac{164000\ cuft}{27000\ CFM}$$

$$\textit{Ideal}\ 9.88\ ACH = \frac{60\ min}{6.074\ min}$$

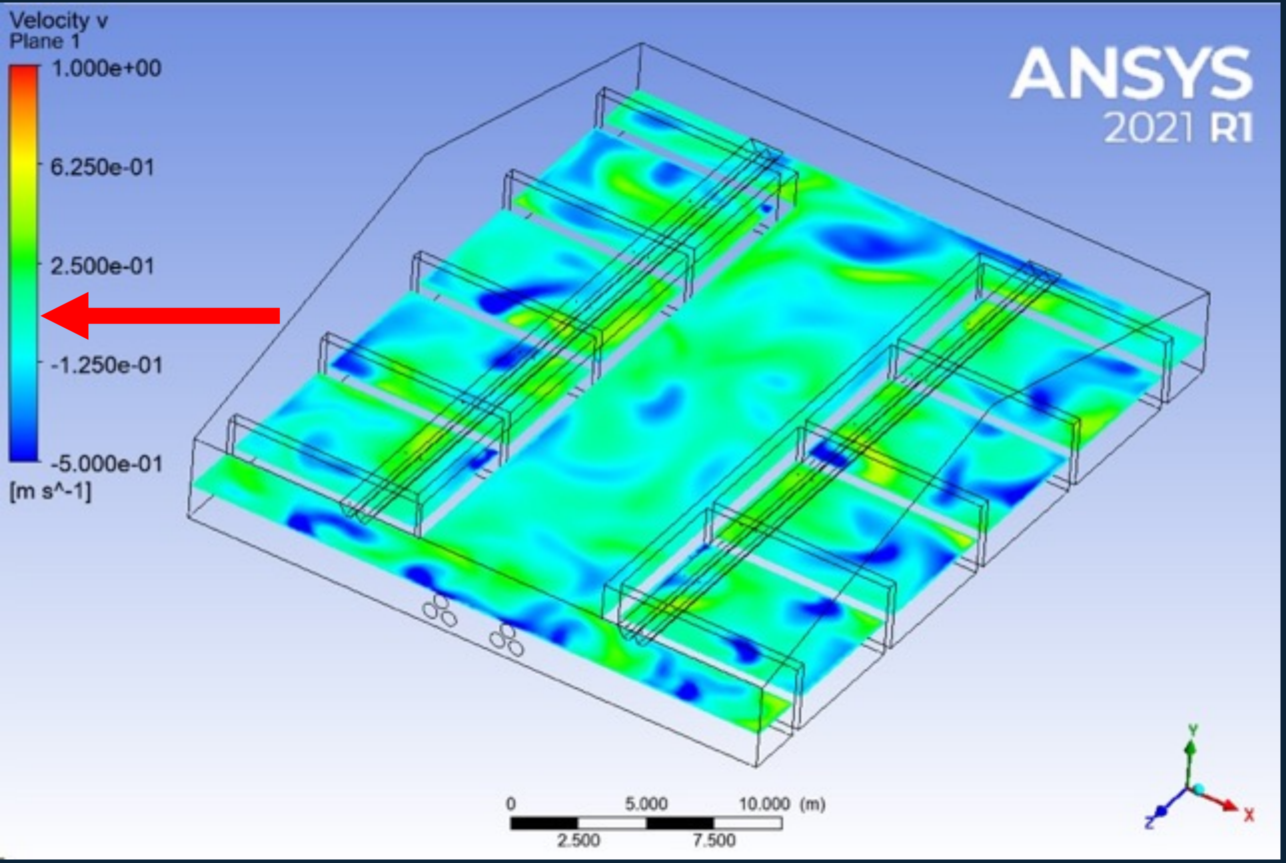
Return Air duct is at end, ~5 feet above ground

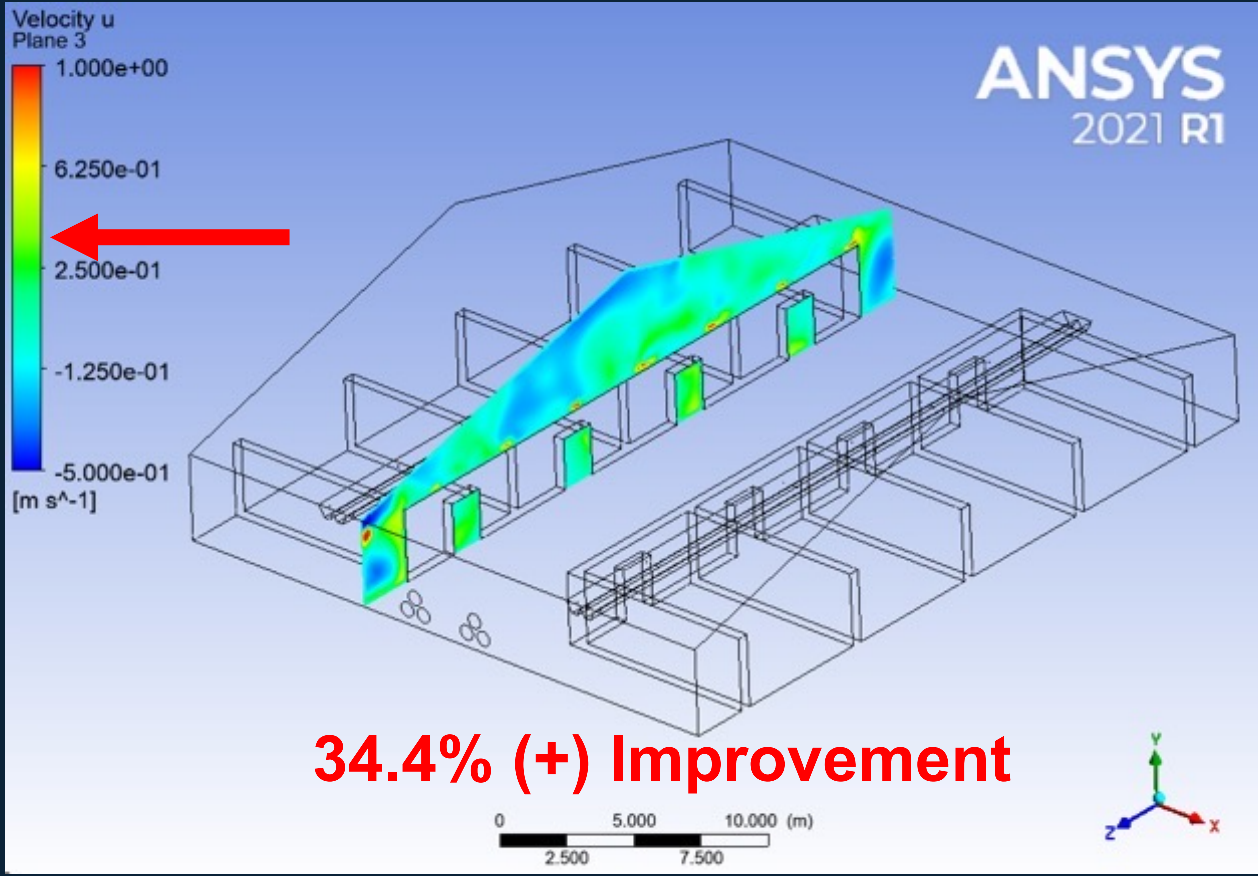
https://www.axios.com/photos-overcrowded-border-patrol-migrant-tents-0525a96b-0dc8-473f-b59c-38b0b3e52760.html



Example of Air Flow Analysis

CFM = cross section area sq ft x Velocity
CFM is proportional to Velocity





Existing Configuration – Inner Doors Closed
~16.4 ft/min (0.08 m/s) flow, (21 x 25)*1/3 upward area
~2870 CFM ave upward, mixing but poor exhaust

Inner Doors Open or Removed
~78.74 ft/min (0.4 m/s) flow, 7x7 door
~3858 CFM ave in doorways (near people)

Social System Challenges to Science & Engineering

The Schools are Open!

Sept 2021

MITRE | SOLVING PROBLEMS FOR A SAFER WORLD

Social System Challenges

- Public trust had been destroyed
- Masks were made political
- Strong debates on "singular" aerosol mitigations
- Observable phenomena not well understood
- Pandemic fatigue

Russell S, Edwards NJ. ***Evidence-Based Strategies to Reduce Airborne Risks of COVID-19 in School Settings***. The MITRE Corporation; Sept 5, 2021. https://www.linkedin.com/posts/nathanjedwards_evidence-based-strategies-to-reduce-covid19-activity-6879209750303703040--Ijj/

SOLVING PROBLEMS FOR A SAFER WORLD™

Evidence-Based Strategies to Reduce Airborne Risks of COVID-19 in School Settings

Sybil Russell, MD, MPH
Nathan J. Edwards, MS

Summary

At the beginning of last school year in 2020, many schools struggled to develop pandemic risk plans for reopening of schools without having data to base their decisions upon. One year later, we now have the results of several peer-reviewed scientific studies in U.S. school settings of more than a million students and staff which show wearing face masks and opening windows have significantly reduced in-school transmission of COVID-19. This brief letter provides a summary of the evidence on strategies to protect students and teachers from COVID-19 transmission on school buses and in classrooms.

Dr. Sybil Russell leads the health research portfolio at MITRE and is a practicing pediatrician at Johns Hopkins University and Kennedy Krieger Institute in Baltimore, Maryland.

Nathan Edwards leads the aerosol dispersion research at MITRE; he is a former occupational health & safety professional and mobile intensive care paramedic.

September 5, 2021 1

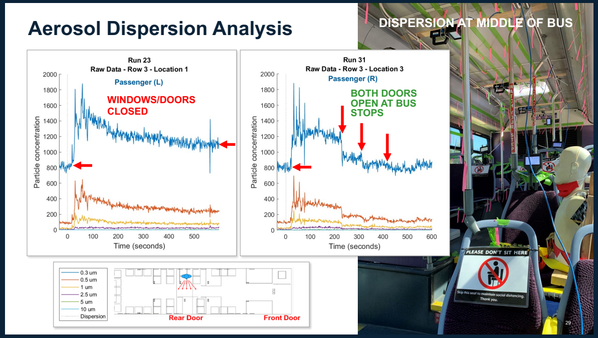
Concluding Remarks

Problem Statements to Reusable Models at 90mph

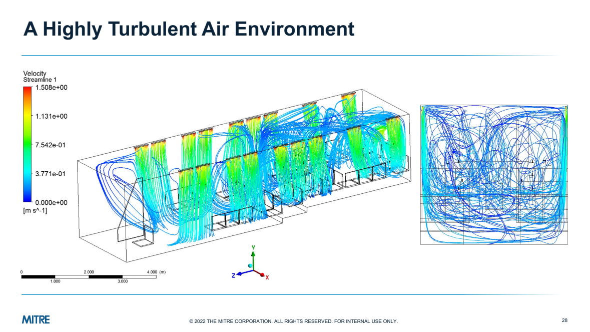
Observable Phenomena:

- Masks
- Buses
- Reusable models
- Indoor office environment
- Societal challenges

The Infectious Aerosol Problem



Rapid Experiments & Knowledge Discovery

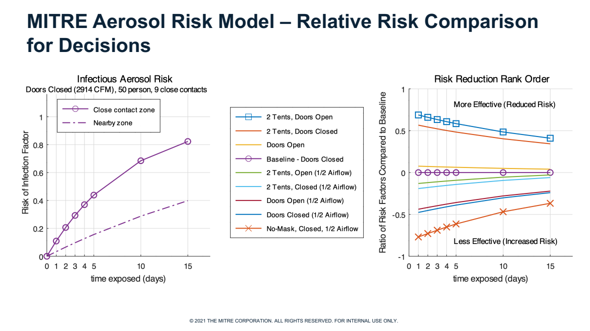


Simulations of the “known,” identify “unknowns”

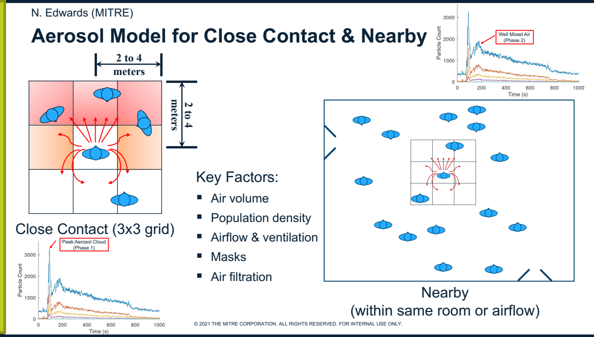
Table 4. Percentile improvements compared to the worst-case scenarios (no-r… ticle diameters.

Test cases	No. of tests (n)	Particle count AUC	(SD)	Dist. traveled	Row +/- zones
School Bus					
Mask, front	2	53.63%	11.62%	4.35	(+4)
On-road, all windows half open + fans	3	84.36%	18.13%	4.02	1 (+3)
On-road, bad weather with middle window	4	88.97%	4.41%	4.02	1 (+3)
Transit Bus					
No-Mask, front, AC[2]	2	94.24%	13.17%	8.29	7
Mask, front	3	56.91%	14.56%	2.63	3
On-road, all windows + fans	3	50.50%	70.60%	4.35	1 (+3)
On-road, bad weather	3	53.73%	58.02%	4.35	1 (+3)
On-road, rear door	3	−33.40%	78.87%	4.35	1 (+3)
On-road, both doors	3	−33.27%	69.75%	4.35	1 (+3)
On-road, AC system[2]	3	55.90%	17.70%	4.35	1 (+3)
On-road, MERV-13 air filter	2	93.95%	1.71%	4.35	1 (+3)

Data Analysis, Develop Necessary Metrics (& Theory)



Share Observations, Decision Support



Develop the Model based on Phenomena

Theoretical Foundations

Digital Engineering

MBSE-SMS

Take Aways from our Lessons Learned

- Keep your eyes on the goal
- Always plan for contingencies
- Observable phenomena as the basis for theoretical foundations
- Evidence-based systems engineering
- Think reusable artifacts and transition to practice

32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

in Response to the COVID-19 Pandemic

Rapid Application of Systems Engineering: Quantifying Airborne Dispersion & Solutions

Nathan Edwards, Richard Potember
nedwards@mitre.org rpotember@mitre.org

www.incose.org/symp2022

32nd Annual **INCOSE**
international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

www.incose.org/symp2022