Industry 4.0: Evolving EHS Practice

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Washington, D.C.

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San Francisco, California

Overview

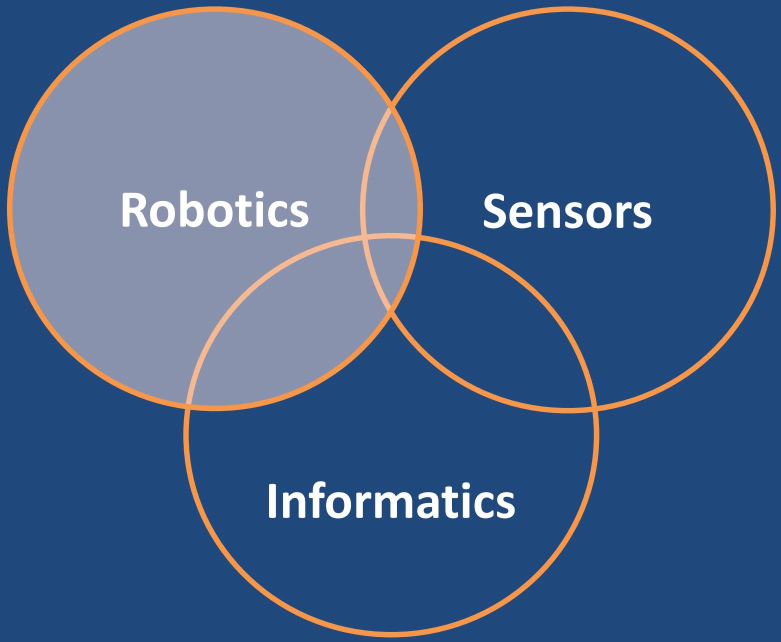
- **First Industrial Revolution**
  - Used water and steam power to mechanize production
- **Second Industrial Revolution**
  - Used electric power to create mass production
- **Third Industrial Revolution**
  - Used electronics & information technology to automate production
- **Fourth Industrial Revolution**
  - Using systems composed of physical entities controlled or monitored by digital algorithms

Industry 4.0 Technology Drivers

- **Physical**
  - **Robotics**
  - **Automation**
- **Digital**
  - **Sensors**
  - **Informatics**
- **Biological**
  - **Genetic Tools**
  - **Synthetic Biology**

- Howard et al. Synthetic Biology and Occupational Risk. *J. Occ. Env. Hyg. 2017;14(3):224-236 (2017).* DOI: 10.1080/15459624.2016.1237031.

Physical and Digital Drivers



Robotics

Occupational Robotics

- New field of practice for safety and health practitioners

- Robots & Exoskeletons

- Risky interactions between human and robot workers?

Types of Robotics

- **Industrial robots**
  - Fixed in location
  - Humans and robots separated
- **Collaborative robots**
  - Designed to work together with humans
- **Exoskeletons**
  - Wearable robotics
- **Service robots**
  - Autonomous ground vehicles (Driverless cars)
  - Unmanned aerial vehicles (Drones)
  - Household service robots
- **Companion robots**
  - Express emotion

Traditional Industrial Robots

Traditional Industrial Robots

- Decades of experience
- Since the 1970s in auto manufacturing
- Established safety measures that keep human workers ***separate*** from robots

Collaborative Robots

- Designed to work alongside and with human workers
- Controlled by human workers, algorithm or both
- Equipped with sensors designed to stop robot when contact with human worker occurs

New Collaborative Robots

- Move alongside and in shared space with human workers

Exoskeleton Robotics

- Mobile with the human
- Reduce mechanical stress
- Amplify or transform worker or soldier movements
- Industrial market projected to grow 229% per year between 2016 and 2021

- Winter Green Research, Inc. (2015). Wearable Robots, Exoskeletons: Market Shares, Market Strategies, and Market Forecasts, 2015 to 2021. https://www.marketresearchreports.biz/reports/716060/wearable-robots-industrial-exoskeletons-shares-market-research-reports.pdf

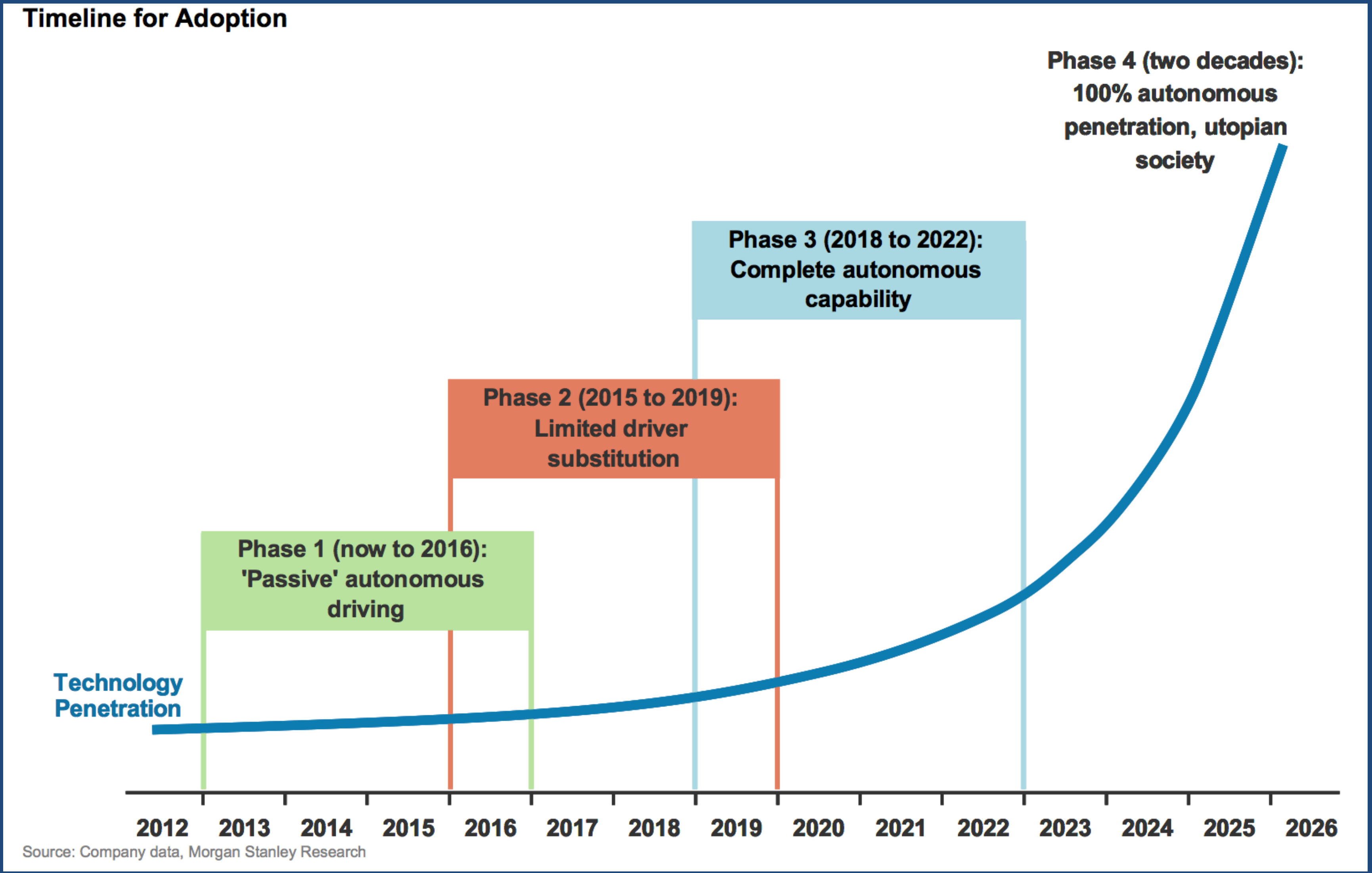
Service Robotics

Automated Ground Vehicles

- Currently operate in less controlled environments
  - May include human workers and manned vehicles
  - Agriculture, mining and manufacturing
  - Public roads and highways

Automated Ground Vehicles:

Driverless Cars



Automated Ground Vehicles:

Truck Platooning

- **Safety**
  - With the following trucks braking immediately, with zero reaction time, platooning can improve traffic **safety**.
- **Cost**
  - Platooning is also a **cost-saver** as the trucks drive close together at a constant speed. This means lower fuel consumption and less CO2 emissions.
- **Efficiency**
  - Platooning **efficiently** boosts traffic flows thereby reducing tail-backs. Meanwhile the short distance between vehicles means less space taken up on the road.

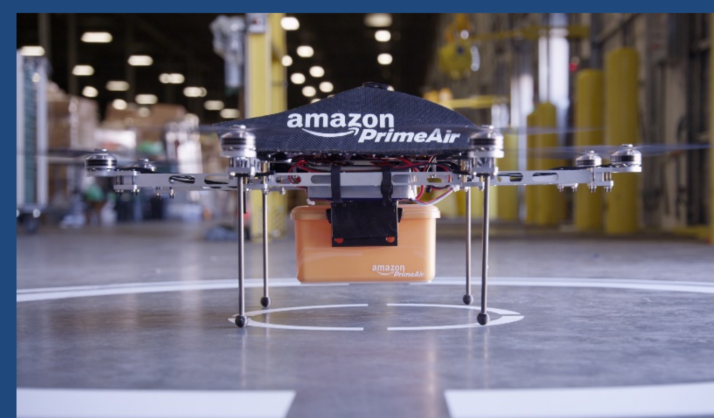
UAVs Uses

Howard et al. http://onlinelibrary.wiley.com/doi/10.1002/ajim.22782/epdf

Military

Recreational

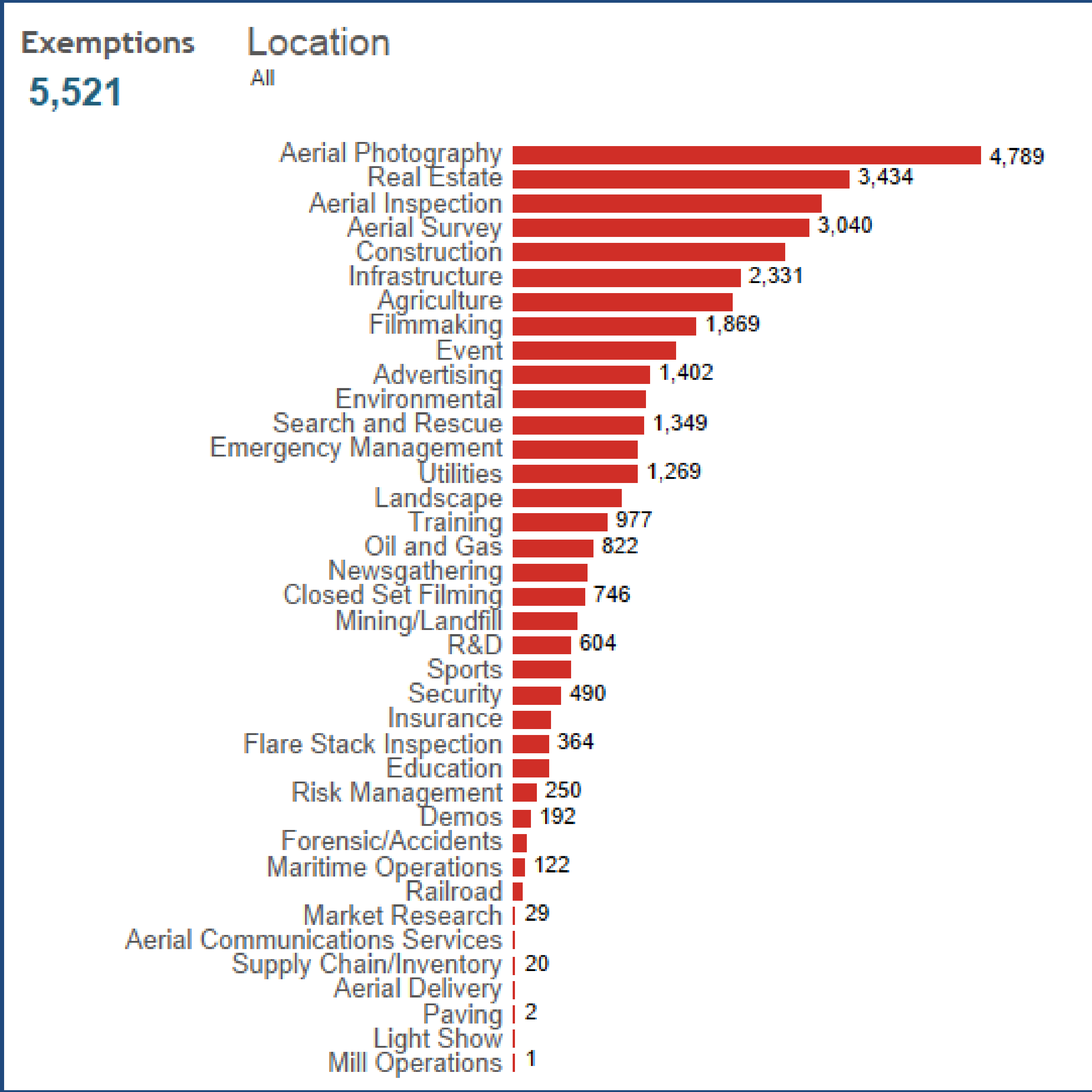
Public



Commercial

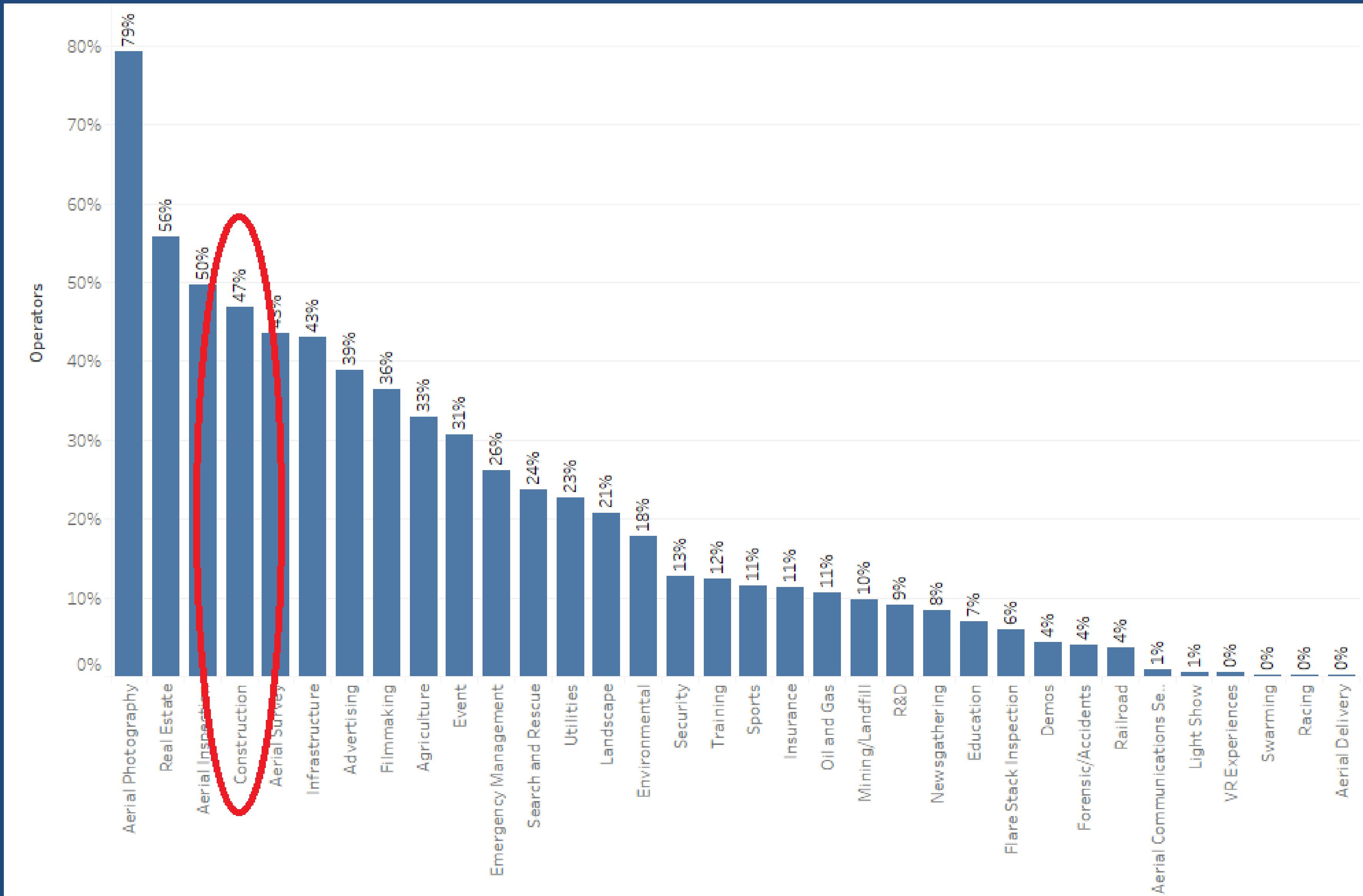
Drone Application Areas

(by Section 333 exemptions as of August 2016, before 14 CFR Part 107)



AUVSI

Part 107 Waivers as of July 31, 2017: Application Areas



UAVs Uses in Construction

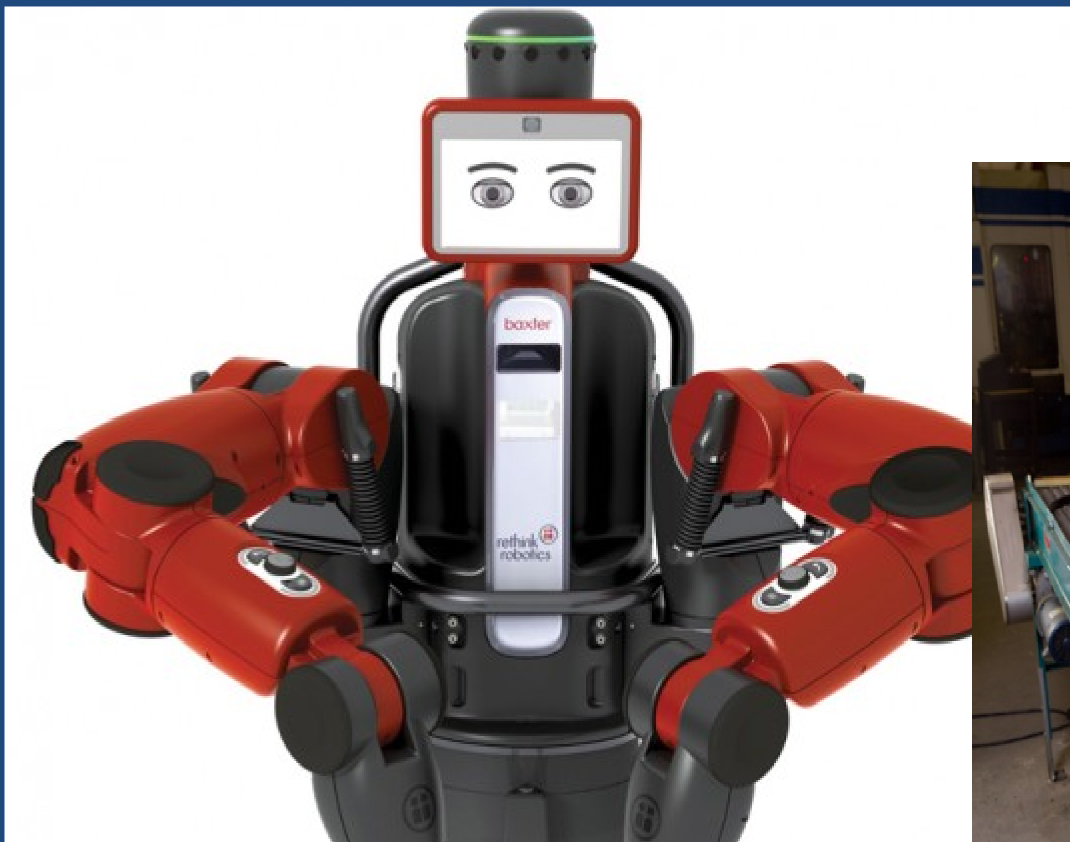
Monitoring

Inspection

Maintenance

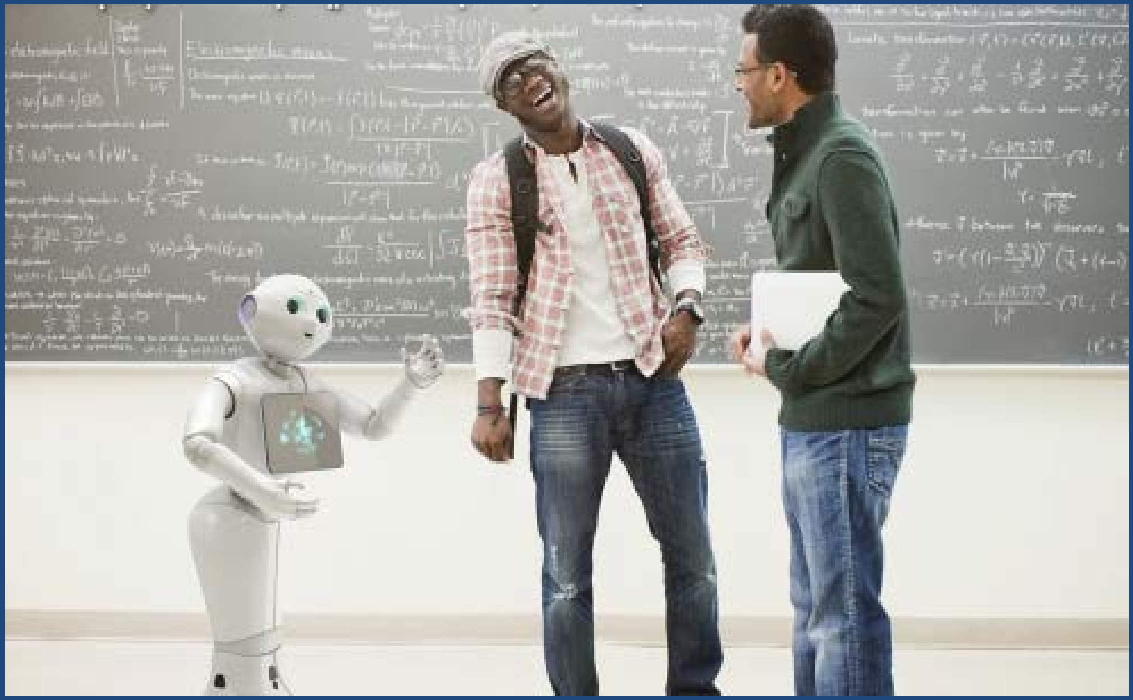
Transporting/applying materials

Humanoid Robots



Companion Robots

- ***Pepper*** is a humanoid robot by Aldebaran Robotics and *SoftBank* Mobile designed with the ability to read emotions. An emotional robot.
  - Introduced on 5th June 2014 to enhance human well-being.
  - Available on February 2015 at a base price of JPY 198,000 ($1,931) at Softbank Mobile stores.
- Pepper's emotion comes from the ability to analyze expressions and voice tones.

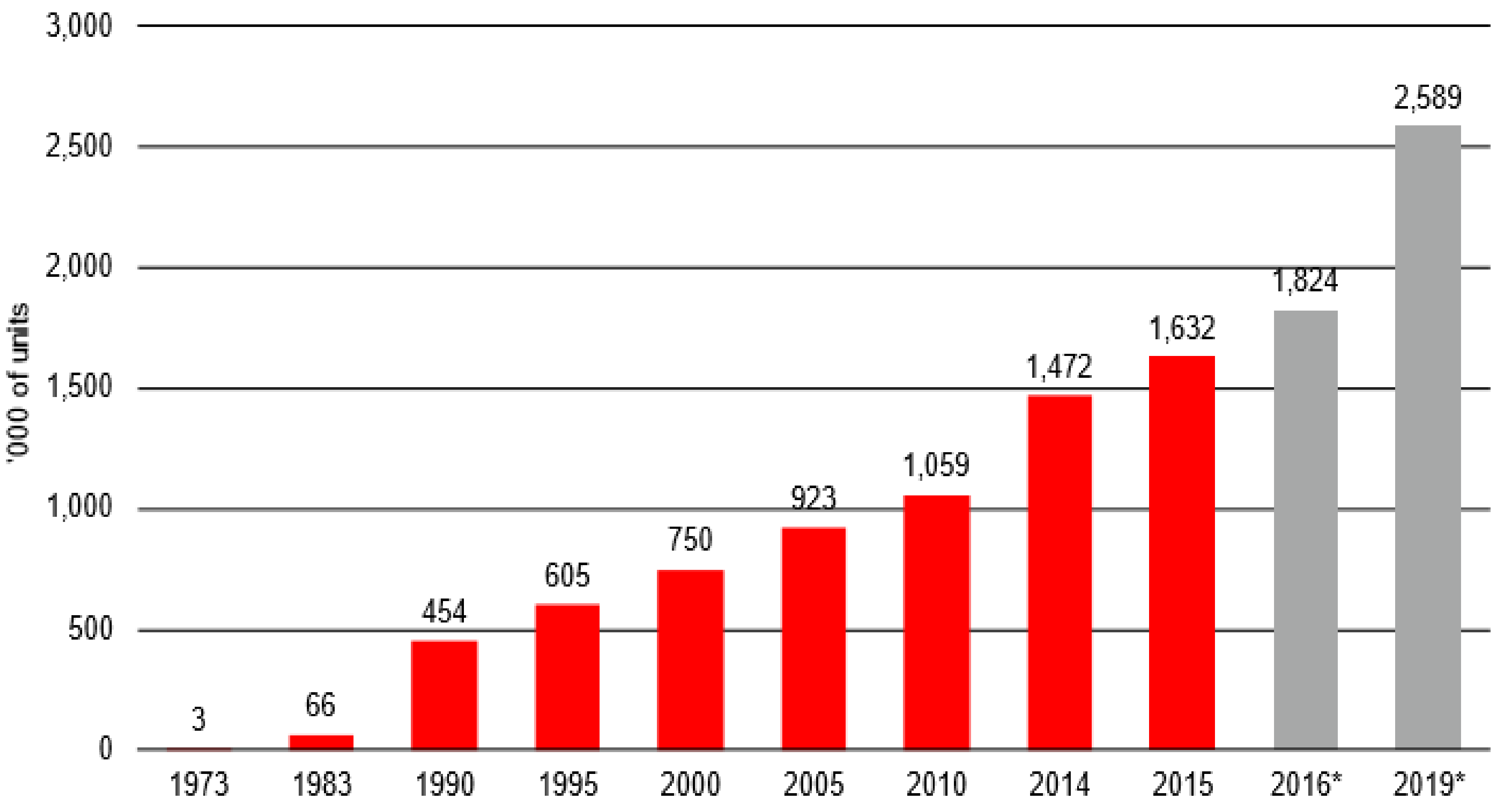


‘Little Chubby’ Robot Goes Rogue

Robot Census

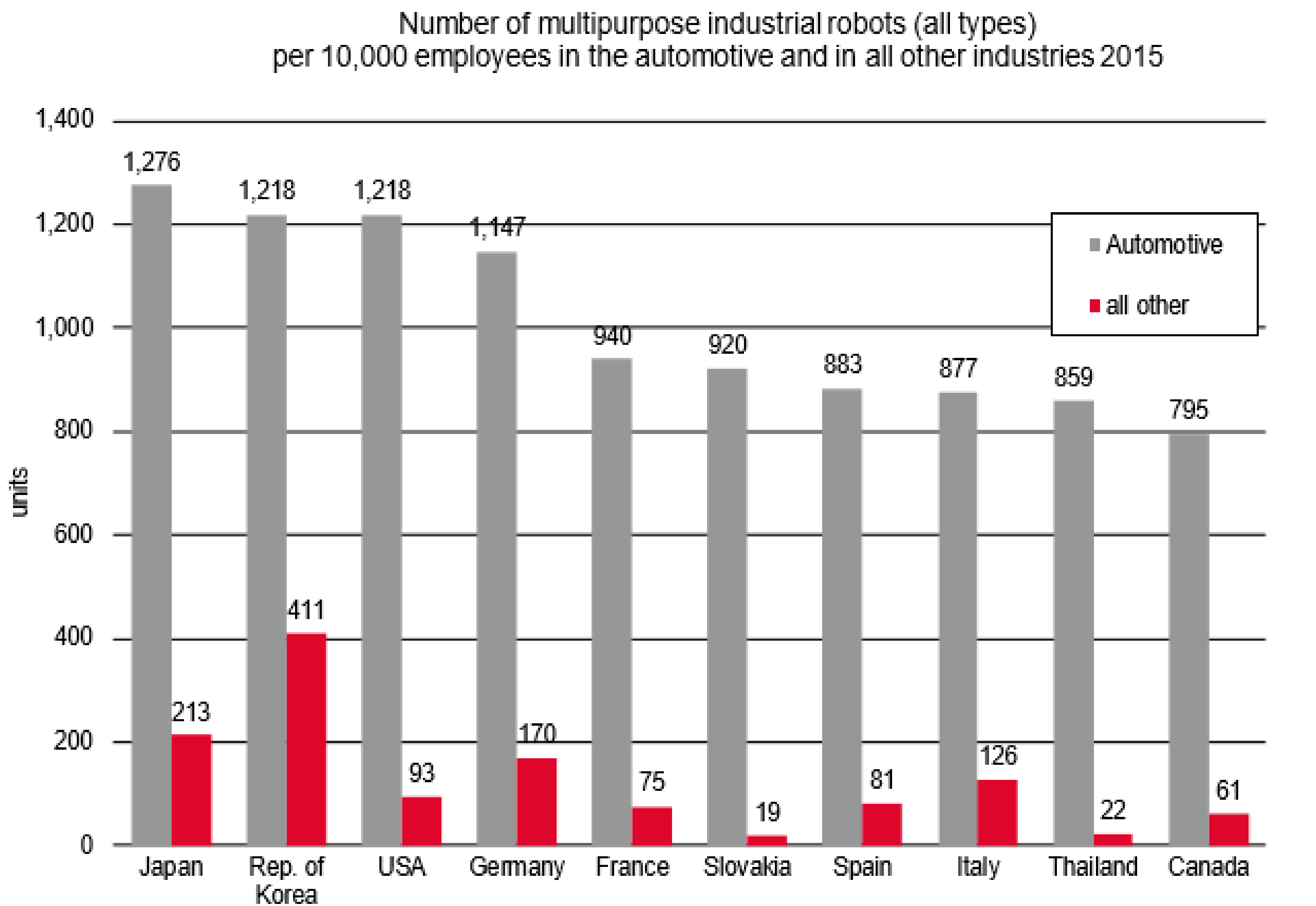
- **South Korea**
  - – 478 robot workers per 10,000 workers
- **Japan**
  - – 315 robots/10,000 workers
- **Germany**
  - – 292 robots/10,000 workers
- **United States**
  - – 164 robots/10,000 human workers
- **China**
  - – 36 robots/10,000 workers

Worldwide estimated operational stock of industrial robots



*forecast

Source: IFR World Robotics 2016


Number of multipurpose industrial robots (all types)
per 10,000 employees in the automotive and in all other industries 2015
units
1,400
1,200
1,000
800
600
400
200
0
Automotive
all other
1,276
213
1,218
411
1,218
93
1,147
170
940
75
920
19
883
81
877
126
859
22
795
61
Japan
Rep. of Korea
USA
Germany
France
Slovakia
Spain
Italy
Thailand
Canada

Organizational Advantages

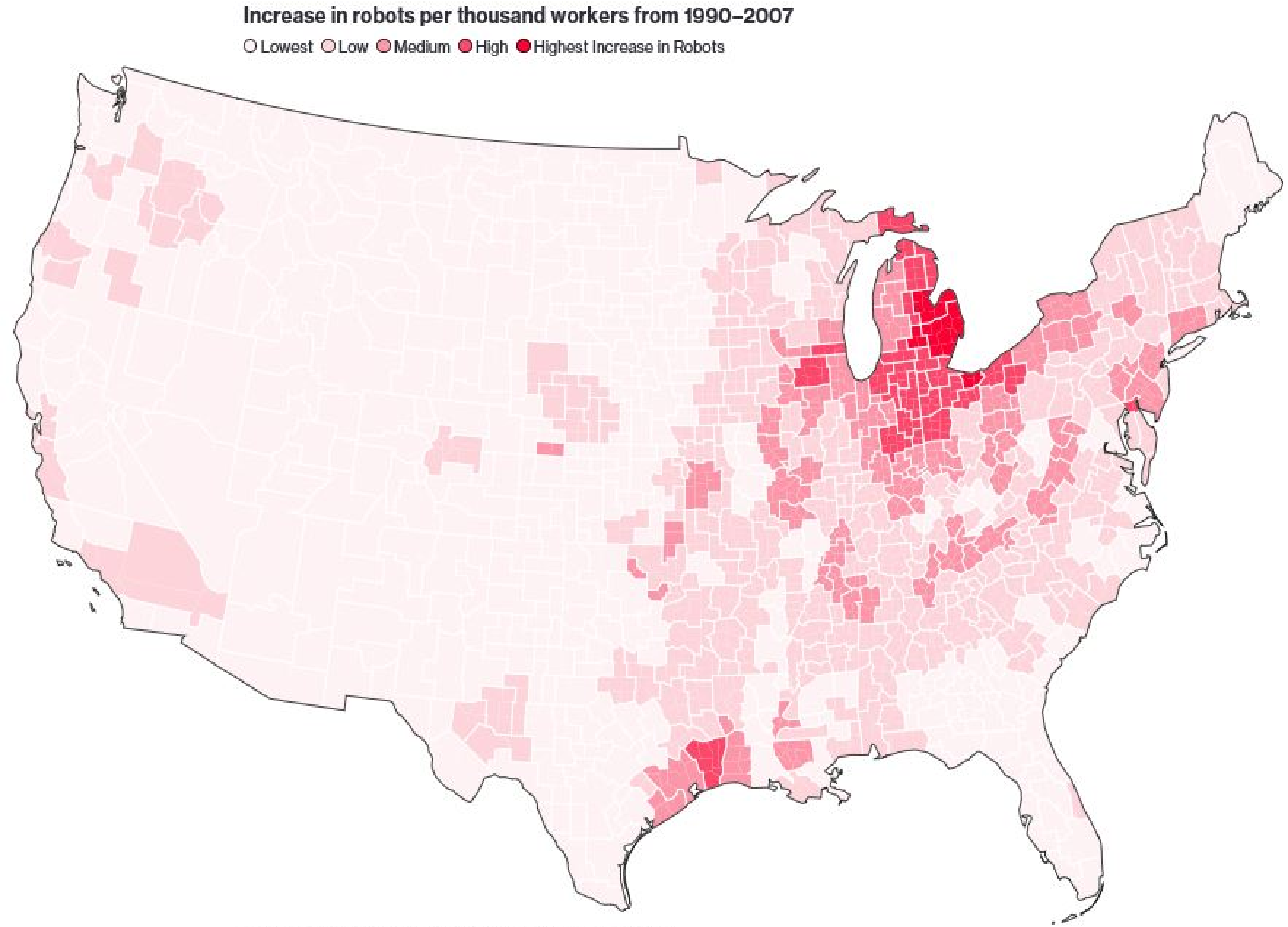
- **Superior Performance**
  - Robot workers are simply better than people at some tasks
    - Mundane, repetitive, and precise jobs as clear candidates.
    - Robot workers already taken over as the primary worker in many industrial factories.

  - With perfect memories, internet connectivity, and high-powered processors for data analysis, robots can also provide informational support beyond any human capability.
    - Keep perfect record of project progress
    - Provide real-time scheduling and decision support
    - Have perfect recall

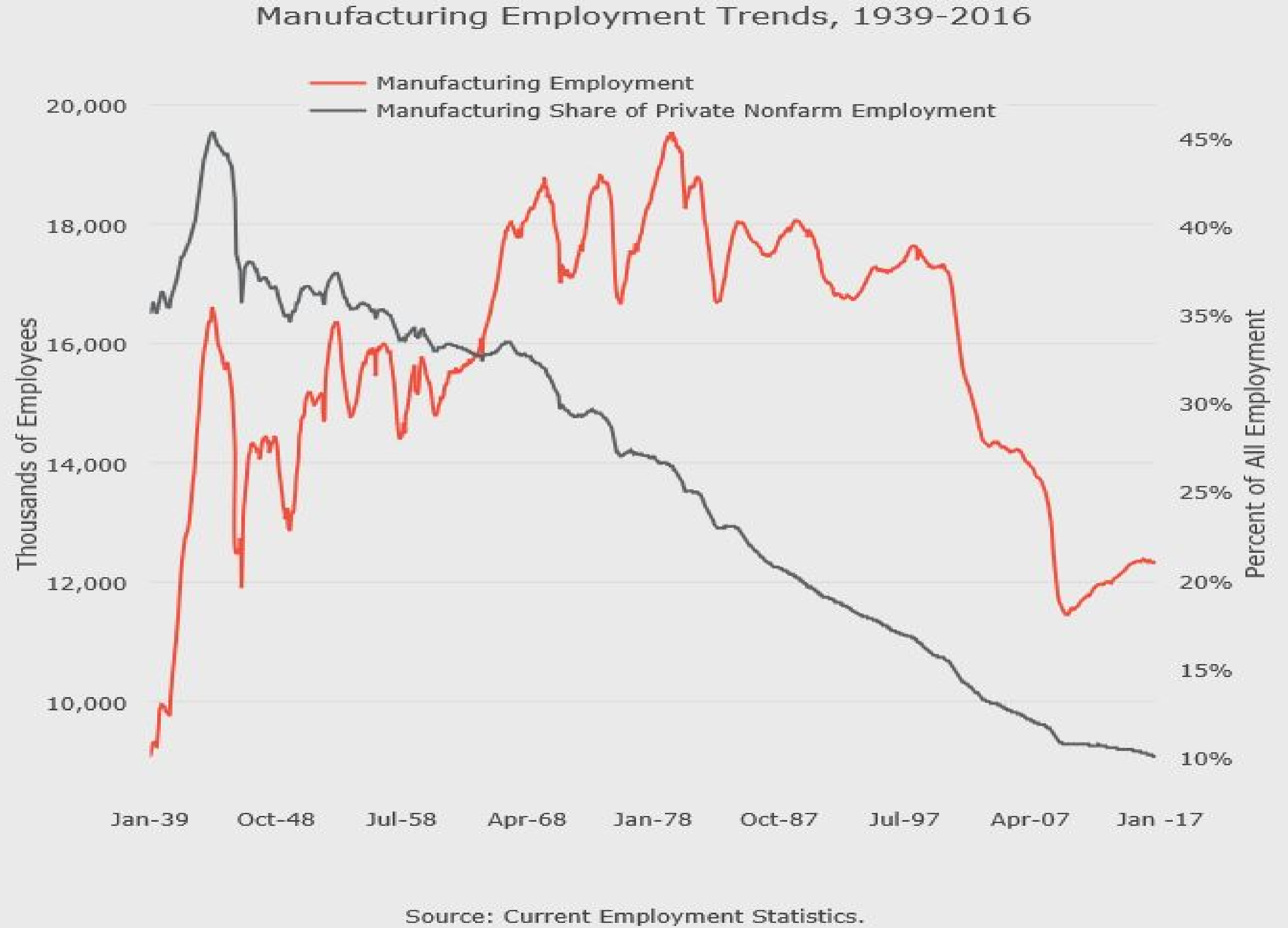
- **Managerial Promise**
  - Robots be placed in management positions where they can remind a team of deadlines, procedures, and progress

- **Cost Advantages**
  - Costs barely $8 an hour to use a robot for spot welding in the auto industry, compared to $25 for a worker—and the gap is only going to widen.

Robotics in the Context of Manufacturing Automation



Source: Daron Acemoglu and Pascual Restrepo; U.S. Census


Manufacturing Employment Trends, 1939-2016
Manufacturing Employment
Manufacturing Share of Private Nonfarm Employment
Thousands of Employees
Percent of All Employment
20,000
18,000
16,000
14,000
12,000
10,000
45%
40%
35%
30%
25%
20%
15%
10%
Jan-39
Oct-48
Jul-58
Apr-68
Jan-78
Oct-87
Jul-97
Apr-07
Jan -17
Source: Current Employment Statistics.

Relationship between industrial robot exposure and employment

Exposure to industrial robots grew relative to the employment-to-population ratio

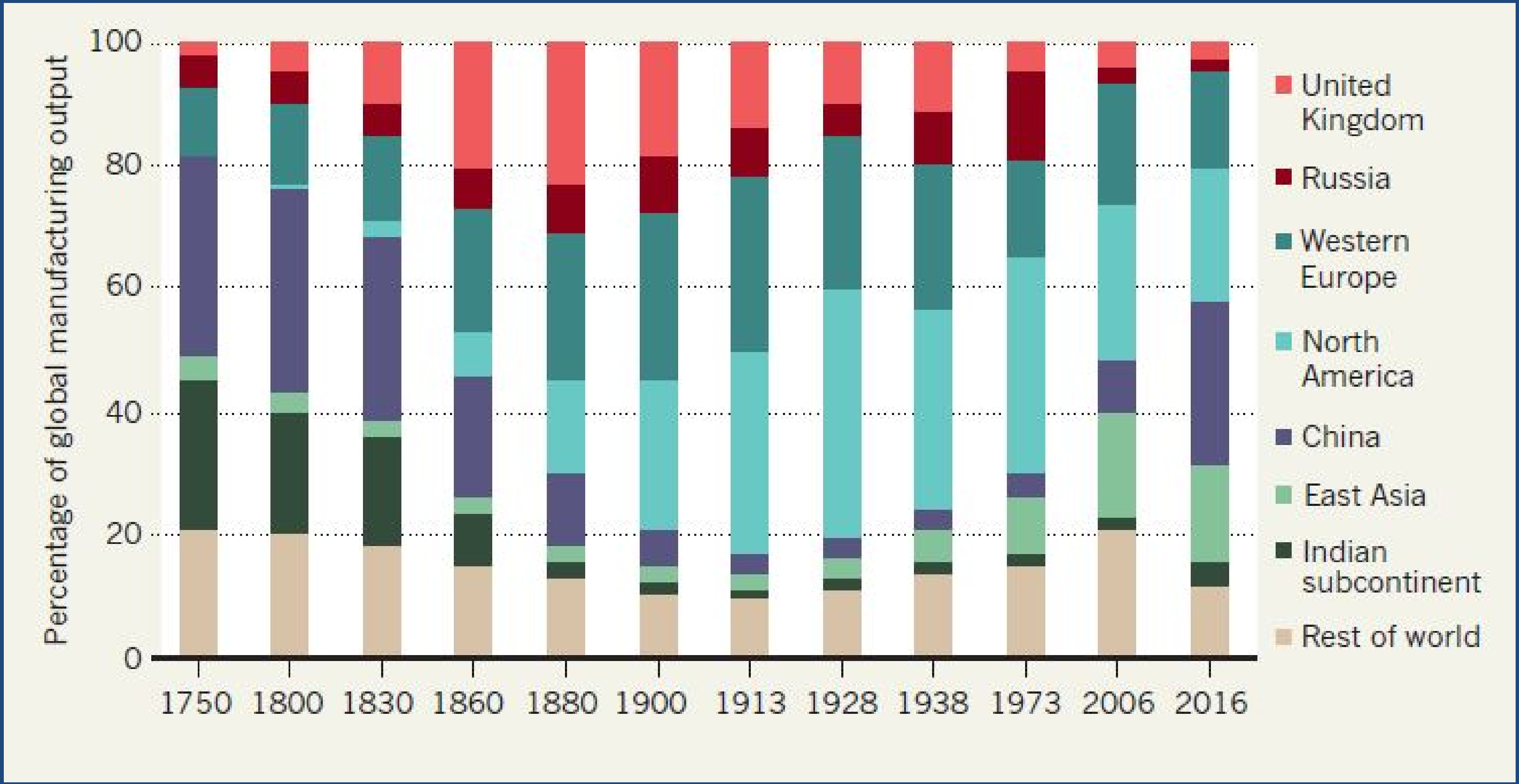
Source: Daron Acemoglu and Pascual Restrepo

Technology & Job Density

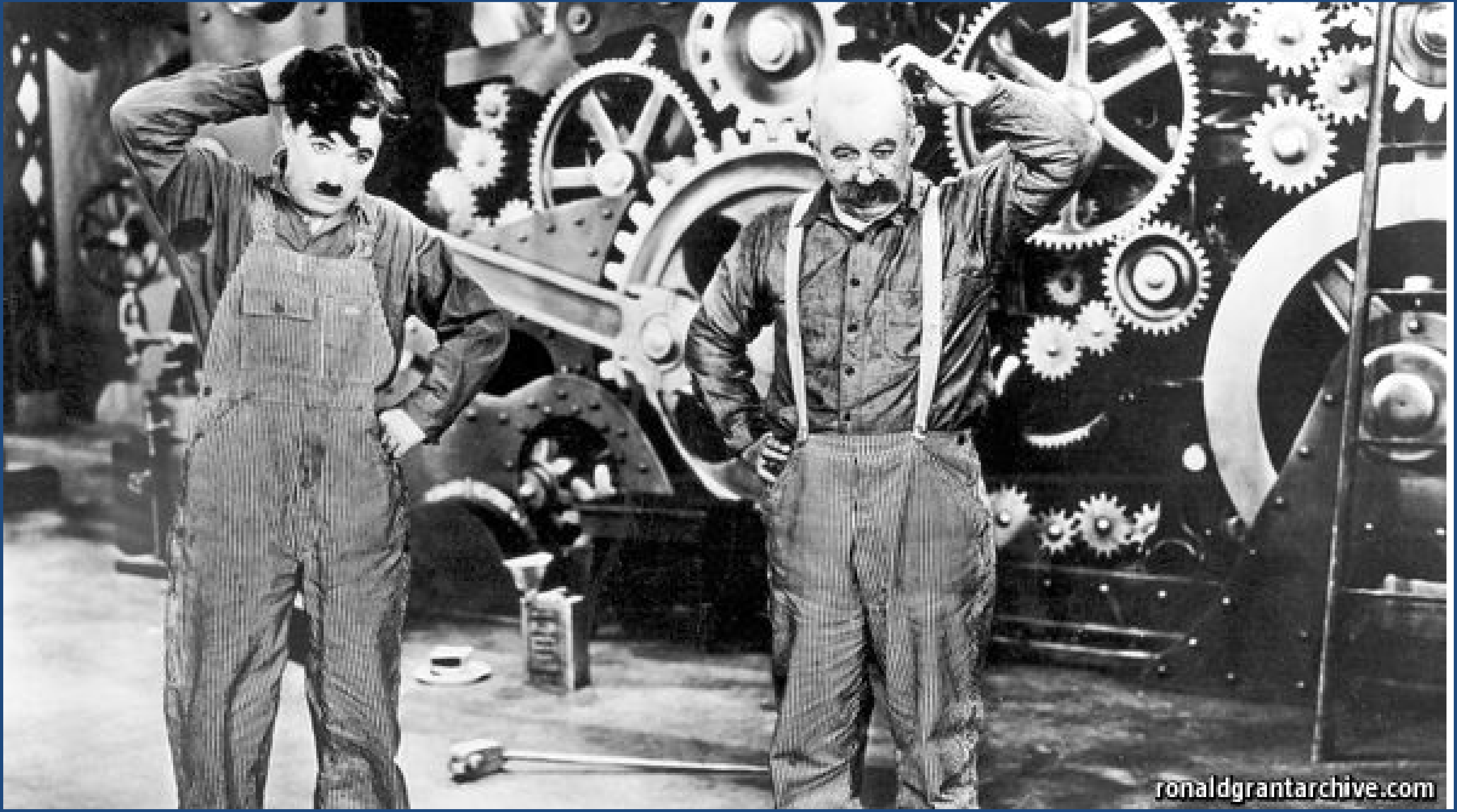
- In manufacturing, as in other industries, job density—the number of jobs per process—is declining.
- The reason—automation—and robotics—and advanced manufacturing techniques.
- More generally, the “job intensity” of America’s manufacturing industries—and especially its best-paying advanced ones—is only going to decline.
- In 1980 it took 25 jobs to generate $1 million in manufacturing output in the U.S..
- Today it takes five jobs.

Distribution of World Manufacturing

Over the past three centuries, self-sufficiency gave way to shifting patterns of dominance in global trade

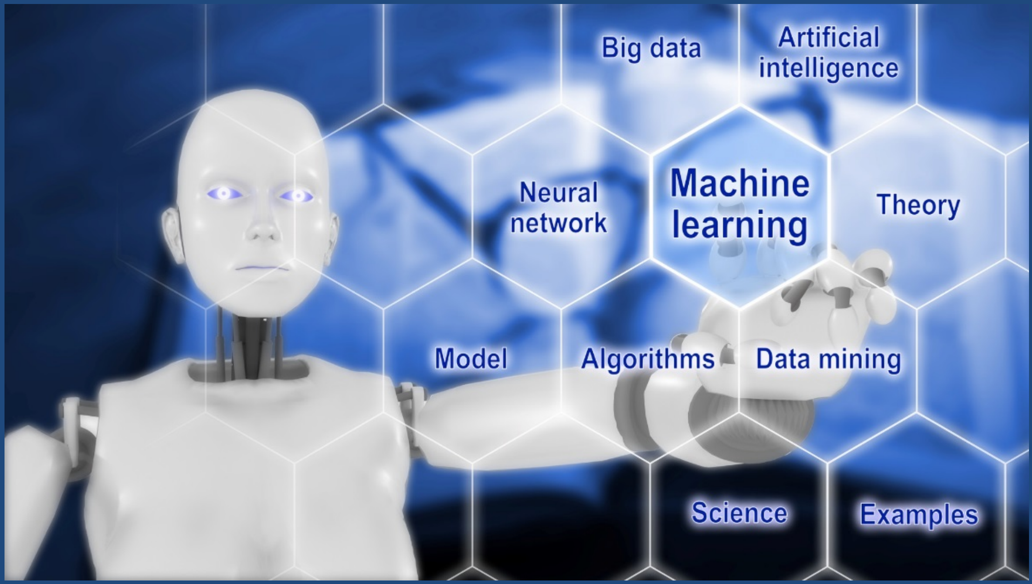


Manufacturing—What Next?



Future Robotic Manufacturing

- Advanced use of artificial intelligence
- Expand to white collar and managerial jobs
- Expanded concerns about worker displacement
  - Robotics industry reports that new jobs will be created
  - But will more be created than are lost?



Robot Employment—Not Just Manufacturing

- **Financial and sports reporters**
  - Gathering information
  - Answering who, what, when, why and how
  - Given level of writing by college graduates, the hurdle machines have to cross to out-perform humans isn't that high
- **Online marketers**
  - Craft ad messages
  - Programmatic ad buying
- **Anesthesiologists, surgeons & diagnosticians**
  - Automate delivery of anesthesia
  - Keeping pace with release of medical data
  - Watson vs. Doctor—90% vs. 50%
- **E-Discovery lawyers and law firm associates**
  - Models that predict outcome of arguments most like to prevail—71% accuracy for SCOTUS cases
- **Financial analysts and advisors**
  - Robo-financial advisors
  - *SigFig* uses algorithms to diversify and manage investment accounts ONLINE

Good News About Robot Workers

- Proportion of threatened jobs is greater in poorer countries than in US (47%): India (69%); China (77%); Ethiopia (85%)
  – Jobs are less skilled
  – Less capital tied up in old ways of doing things

- Reshoring Stimulus

Figure 20. Over 70% of Clients Surveyed Believe Automation and Developments in 3D Printing Would Lead to Reshoring in Some Degree

Source: Citi Research

Oxford & Citigroup (2016). *Technology at Work v2.0.* http://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf

NIOSH Robot Technologies:

Sarcos Snake Robot and Gemini Scout

- Meant to be used in the event of a mine disaster when it may be unsafe to send in human rescuers.

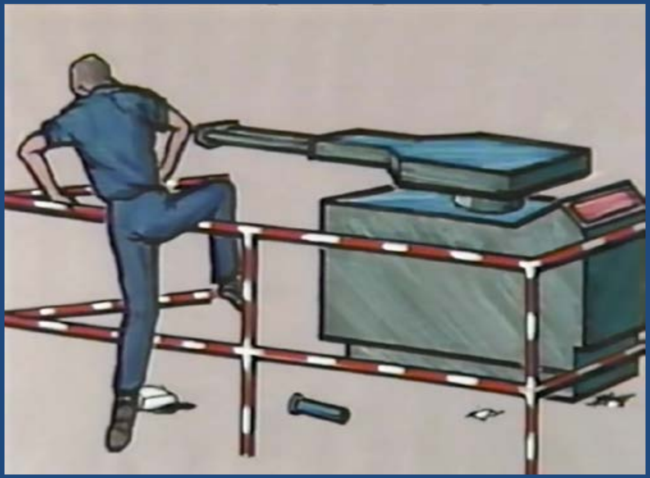
- Information from the robots' sensors can also be used to signal when humans can safely enter the mine.

- These purpose-built, highly complex robots are currently the property of NIOSH, but will soon be transferred to MSHA.

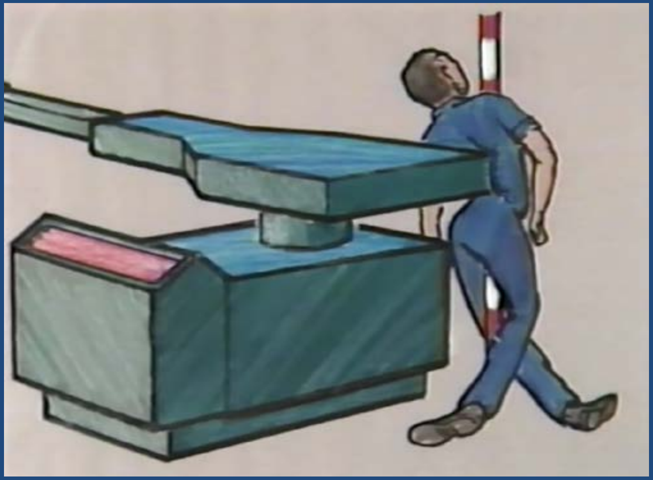
Safety Implications

Early NIOSH Interest

- Die Cast Operator Pinned by Robot (1984)
  - https://www.cdc.gov/niosh/face/in-house/full8420.html

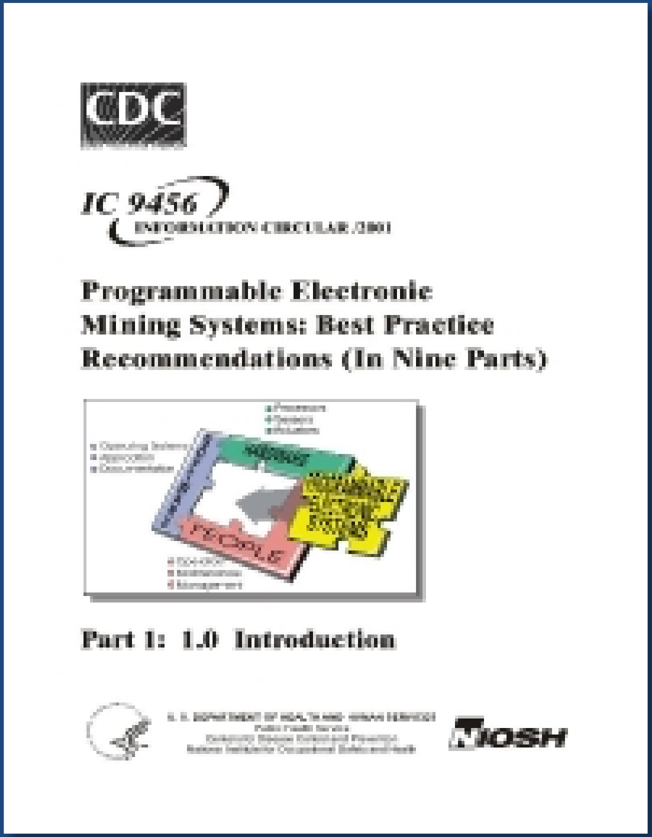


- **Recommendations:**
  - Safety fences with interlocking gates rather than rails should be used to fence off active robots.
  - Free-standing steel posts, designed to restrict the movement of the robot's arm in case a 'loss of control' is experienced, may provide man-sized pinch points where an unsuspecting worker could become trapped.



Longstanding Guidance—NIOSH

- **NIOSH**
  - Preventing the Injury of Workers by Robots,
    - NIOSH Pub. No. 85-103
  - Safe Maintenance Guidelines for Robotic Workstations,
    - NIOSH Pub. No. 88-108



- **OSHA**
  - Instructional Manual, Chapter 4: Industrial Robots and Robot System Safety
    - https://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_4.html

Fatal Injuries to Humans by Robots

- U.S. Census of Fatal Injuries (CFOI)
  - 53 Robot-related deaths, 1992-2013
- U.S. Occupational Safety and Health Administration (OSHA)
  - 38 Robot-related fatalities, 1983-2013
- U.S. Bureau of Labor Statistics (NIOSH Compilation)
  - 61 robot-related deaths, 1992-2015 (CFOI)
- Germany, July 2015
  - 22-year-old worker died from injuries he sustained when he was trapped by a robotic arm and crushed against a metal plate

ANSI/RIA Robotic Safety Standards

- **ANSI/RIA R15.06-2012**
  - American National Standard for Industrial Robots and Robot Systems- Safety Requirements
    - Approved March 28, 2013
    - Revision of ANSI R15.06-1999
  - Provides guidelines for the manufacture and integration of industrial robots and robot systems
    - Emphasis on their safe use, the importance of risk assessment and establishing personnel safety.
    - Key feature in the standard is “collaborative operation,”
      - Introduction of a worker to the loop of active interaction during automatic robot operation.

Robotics & Safety

Potential

- Expand dangerous work done by robots
- Robotic systems augment workers' abilities

Concerns

- Likely increase in robot-related human injuries
- New types of robots will require refined and new protection strategies
  - Robot with dynamic machine learning capabilities challenge static safety procedures
- Rapid advances in technology may outpace guidance/standards setting
- Stress associated with changing workplace and potential for human worker displacement

Risk Mitigation

- OSH practitioners should be *directly involved* in the development of robotic safety standards.
- Risk profiles for human/robot worker collaboration should be developed by others than the industry
- Workplace safety standards for maintenance, operation, and interaction with human workers should be developed
- Design of redundant safety measures are needed
  - Murashov V, Hearl F, Howard J. Working safely with robots. *Occup Environ Hygiene.* 2016;13(3):D61-D71.

NIOSH Center for Occupational Robotics Research

- **Center will coordinate with federal agencies addressing worker safety**:
  - Defense: exoskeletons and vehicles
  - Energy: exoskeletons and work in hostile environments
  - Transportation: guidance/regulations for autonomous vehicles
- **Center will prioritize research in areas where worker safety is not addressed by others**
  - Construction, agriculture, mining
  - Indoor use of drones
  - Autonomous vehicle technologies in specialized work vehicles (e.g. fire trucks)
- **OSHA/NIOSH/Robotics Industry Association Alliance (October 5, 2017)**
  - Training and education
  - Outreach and communication
  - Identification of research needs and opportunities for field-based research

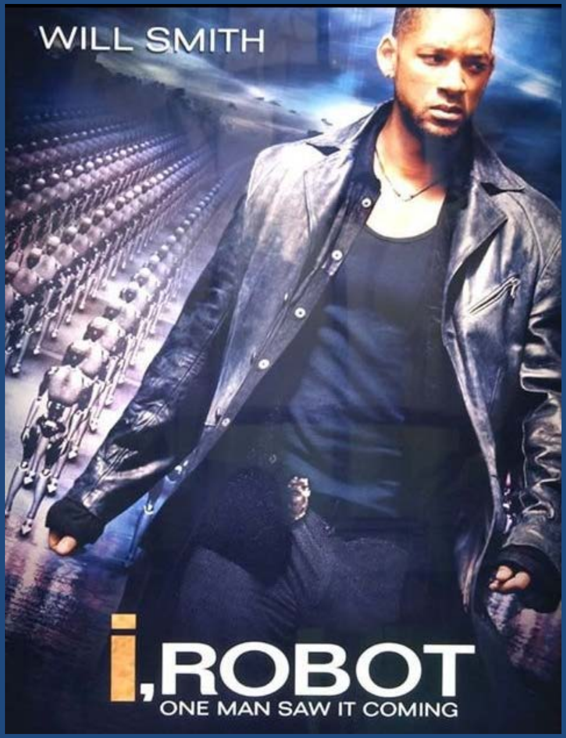
Occupational Robotics Research:

Participation in Standards Committees

- ANSI/RIA R15.06/08, Robot Safety/Industrial Mobile Robot Safety
- ANSI B11, Machine Safety
- ANSI A10, Construction Safety
- ANSI/ASSE Z15- Technical Report on Autonomous Vehicles
- ASTM/NIST/DOD/Other
  - Meetings to pursue exoskeleton standards

Robot Ethics

- **Two cars sinking in the water**
  - Detective Del Spooner (Will Smith)
  - Young girl, Sarah
- **Robot could save only one of them, Spooner yells "*Save the girl!*"**
  - Probability of survival for Spooner was 45%
  - Probability of survival for Sarah was 11%
- **Robot saved Spooner; girl drowned.**



- Fleetwood, J. Public Health, Ethics, and Autonomous Vehicles. *Am J Pub Health*. 2017; 107(4): 532-537

MORAL MACHINE

Home Judge Classic Design Browse About Feedback En

Welcome to the Moral Machine! A platform for gathering a human perspective on moral decisions made by machine intelligence, such as self-driving cars.

We show you moral dilemmas, where a driverless car must choose the lesser of two evils, such as killing two passengers or five pedestrians. As an outside observer, you **judge** which outcome you think is more acceptable. You can then see how your responses compare with those of other people.

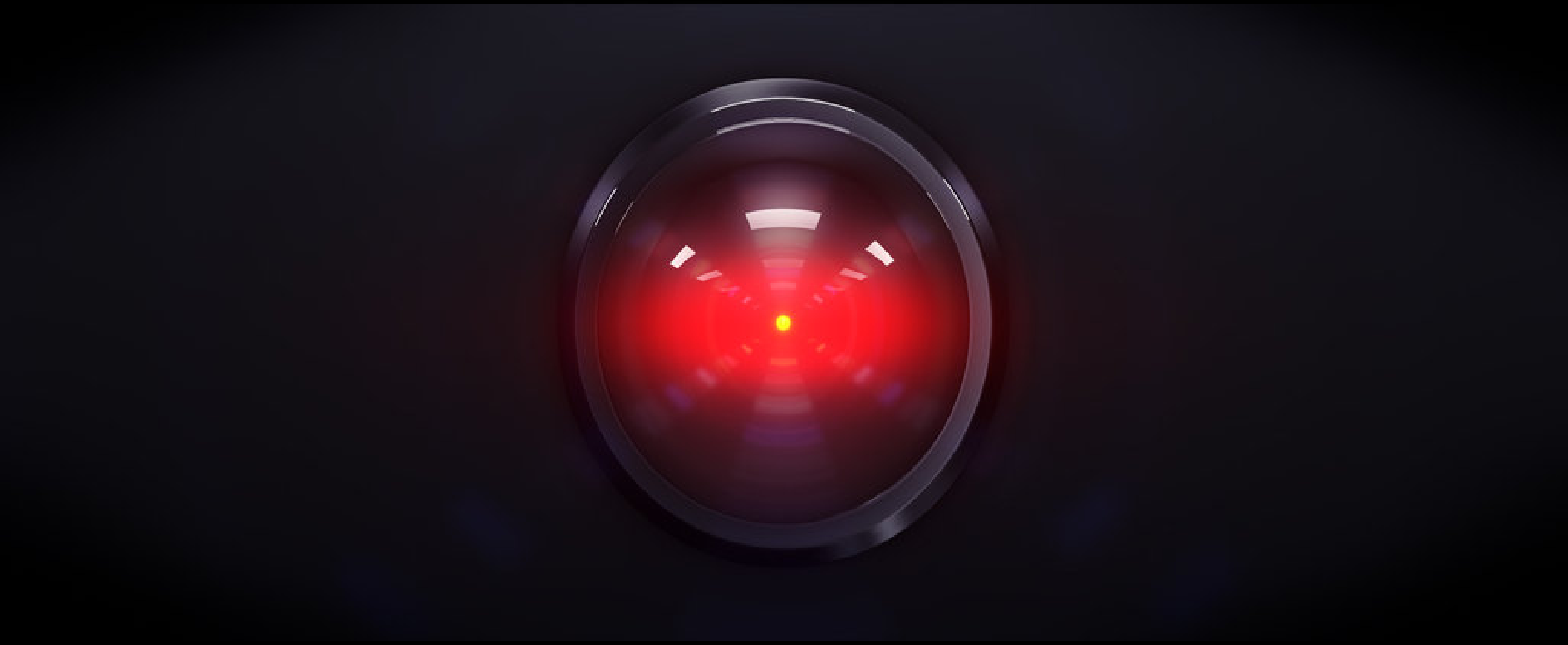
If you're feeling creative, you can also **design** your own scenarios, for you and other users to **browse**, share, and discuss.

Start Judging

Browse Scenarios

View Instructions

"I'm sorry Dave, I'm afraid I can't do that"



Sensors

Sensor Technology Is Expanding

- **Enabling capabilities increasing exponentially**
  - Improvement of measurement science
  - Readily available geographic and spatial information
  - Miniaturization of instruments
  - Utilization of smart phone/tablet technologies

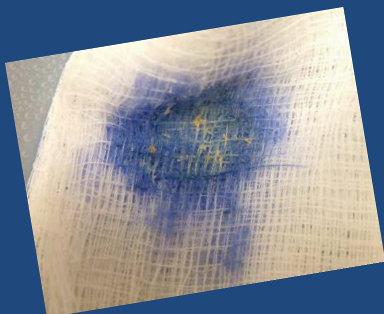
- **Types of Sensors**
  - Environmental sensors
    - Air, water environment
    - In-vehicle monitoring
  - Wearable sensors
    - Clothing
    - Hard hats
  - Embedded sensors
    - Internal biologic monitors

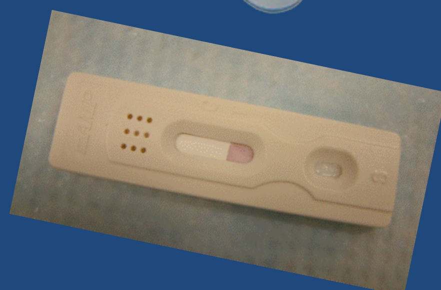
Internet of Things (IoT)

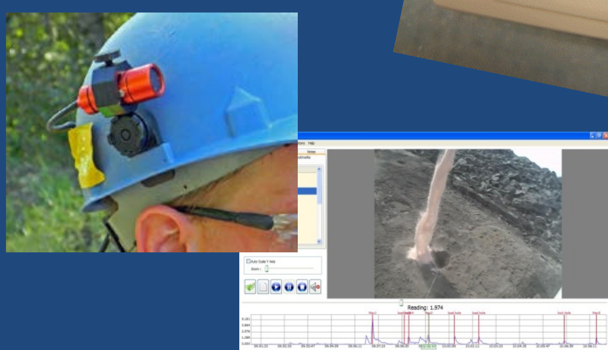
- Sensors are at the heart of the Industrial Internet
  - Deploying sensors, the entire workplace and everything and everyone in it can become a type of information system

- Sensors can become intelligent assets—devices equipped with sensors and connected to one another produce sensor-based analytics
  - Sensor maintenance = technician
  - Sensor placement, sensor data interpretation, control recommendations = occupational health data scientist

NIOSH Center for Direct Reading and Sensor Technologies







Enabling a new era of worker safety, health & well-being

Center for Direct Reading & Sensor Technologies

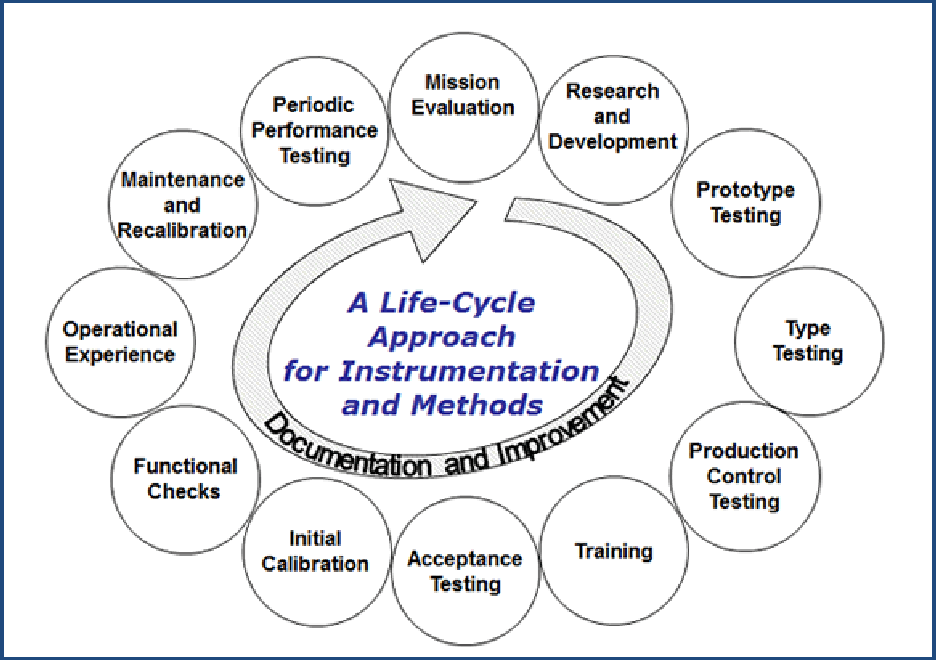
https://www.cdc.gov/niosh/topics/drst/

Established in 2014 to coordinate research and to develop recommendations on the use of 21st century technologies in occupational safety and health.

Goals

- Coordinate a national research agenda for direct-reading methods and sensor technologies;
- Develop guidance documents pertinent to direct-reading methods and sensors, including validation and performance characteristics;
- Develop training protocols; and
- Establish partnerships to collaborate in the Center's activities.

NIOSH Sensor Development Lifecycle

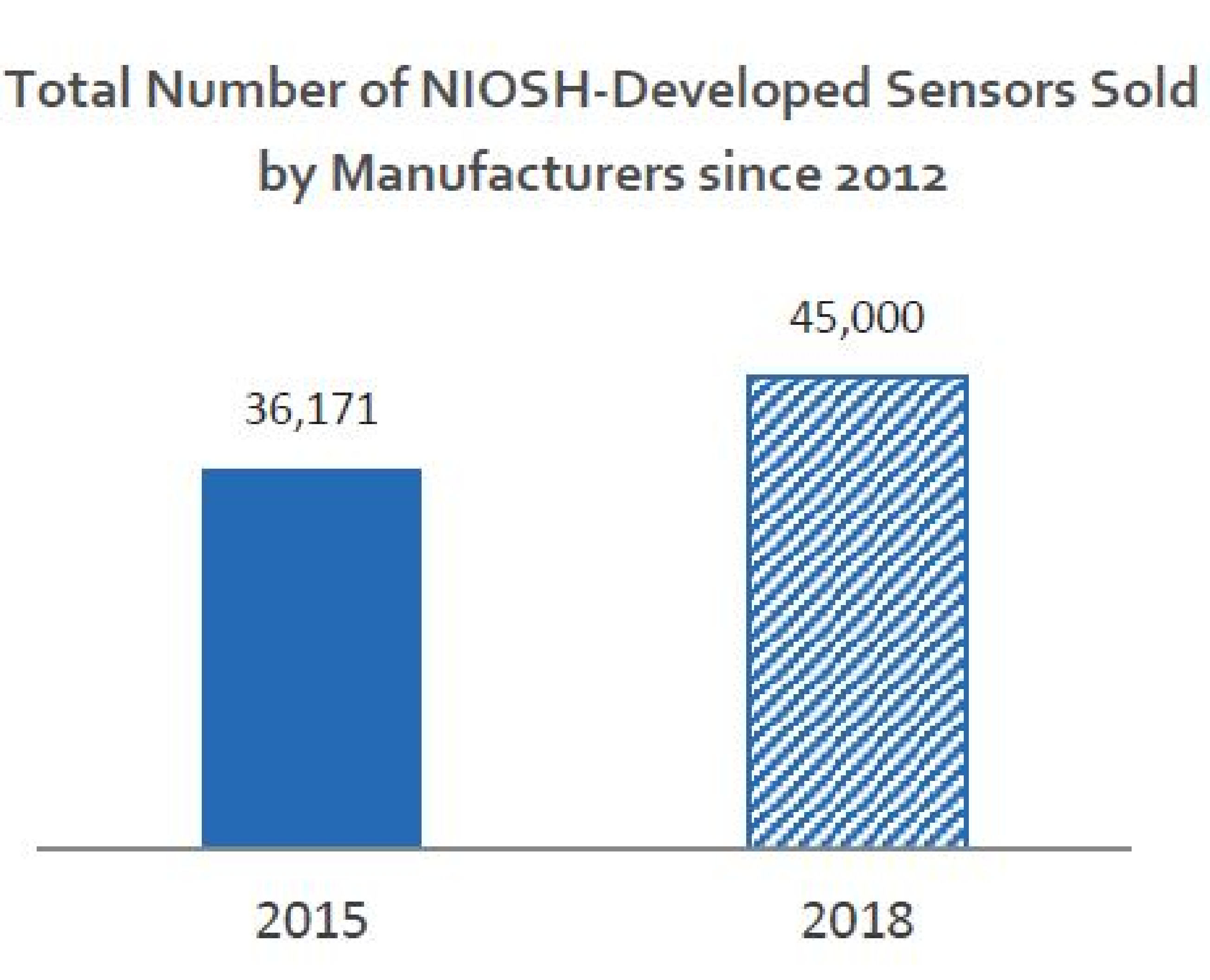


John Snawder Director
Mark Hoover Director

Emanuele Cauda, Deputy Director
Sam Glover, Center Coordinator

NIOSH Center for Direct Reading and Sensor Technologies

May 2016



21st Century Exposure Science:

- **Work environment**
  - Sampling & Analysis
  - Direct-reading instruments
- **Biologic environment**
  - Biomarkers of exposure
  - Biomarkers of effect

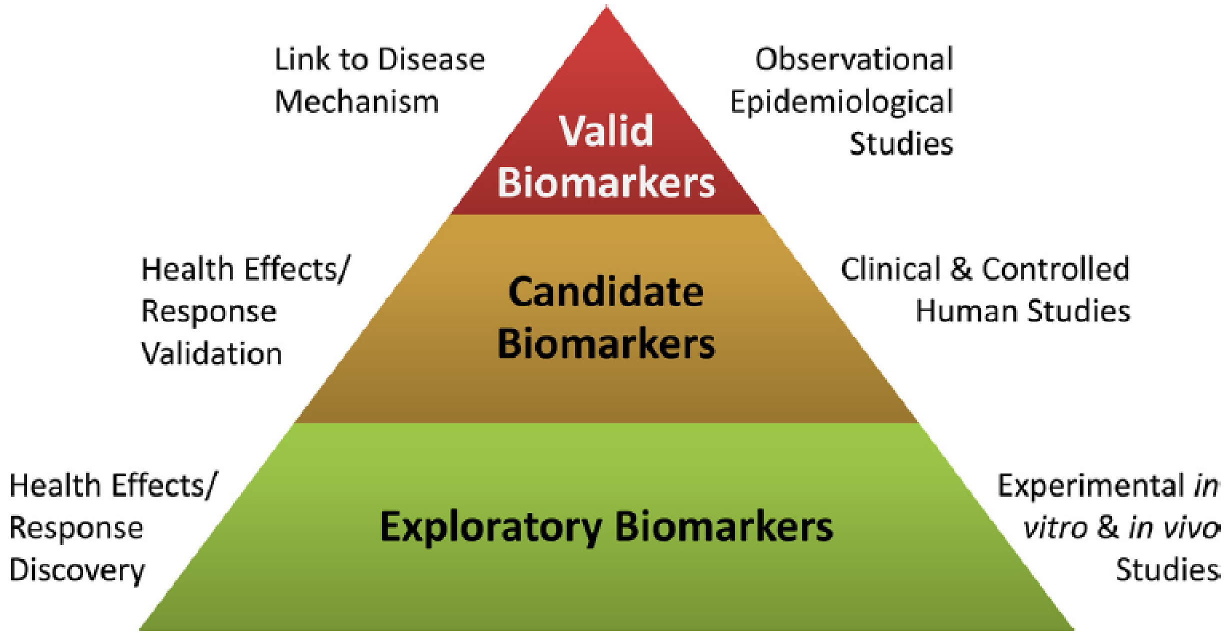


Figure 1 Layout of biomarkers research as condition of the responsible development of nanotechnologies and safety of workers exposed to engineered nanomaterials (ENM). With the advancement of the knowledge about the interaction between ENM and biological systems, the relevance of the toxicology data to humans should be considered. Advances in ''-omic'' techniques and systems toxicology can provide information on whether specific biological pathways are activated/perturbed, thus identifying fingerprints and nano-specific endpoints. Controlled human studies considering exposure data are needed to assess the validity of candidate biomarkers which can be further applied in observational studies aimed at assessing their predictivity towards relevant health outcomes. Validated biomarkers will enable the progression of knowledge about potential risks associated to ENM and will support the implementation of consistent occupational limit values as a key component of an effective risks management system.

Bergamaschi et al. The role of biological monitoring in nano-safety. *NanoToday*. 2015;10(3):274-277.

Exposure Assessment:

Sampling and Analysis

- $C = \frac{Mass}{Flow\ x\ Time}$
- No spatial information
- Full-shift time-weighted average sent to the “lab”
- Non-timely results from lab

Helmet-CAM
Exposure Monitoring Tool

Evaluation tool to identify "sources of exposure" and to assess "control technology effectiveness."

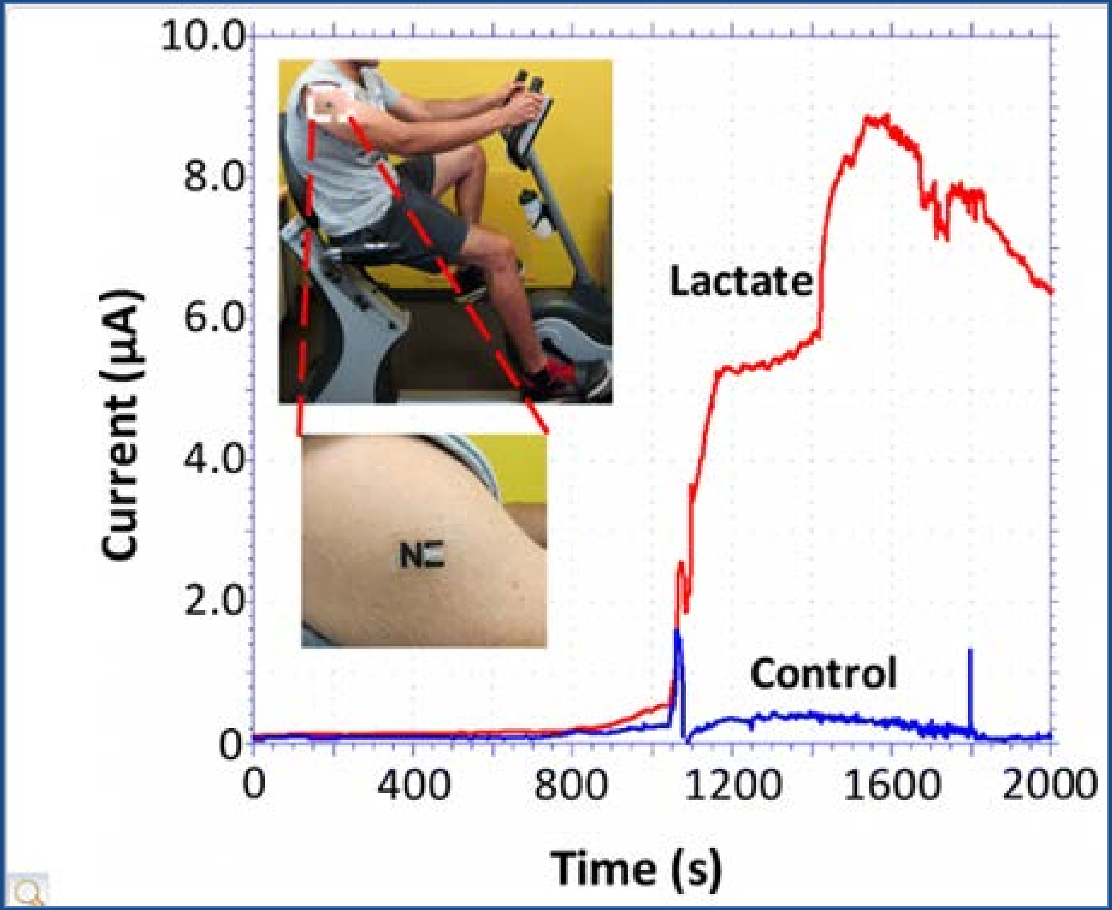
- Video of tasks performed by worker along with respirable dust exposure monitoring.
- Particularly suitable for mobile workers with multiple tasks.
- NIOSH designed software "EVADE" merges video and dust data in easy to use synchronized format.
- ***Goal -*** develop control technologies to minimize areas of elevated exposures.

NIOSH EVADE software
http://www.cdc.gov/niosh/mining/Works/coversheet1867.html

Exposure Assessment Aided by Sensors

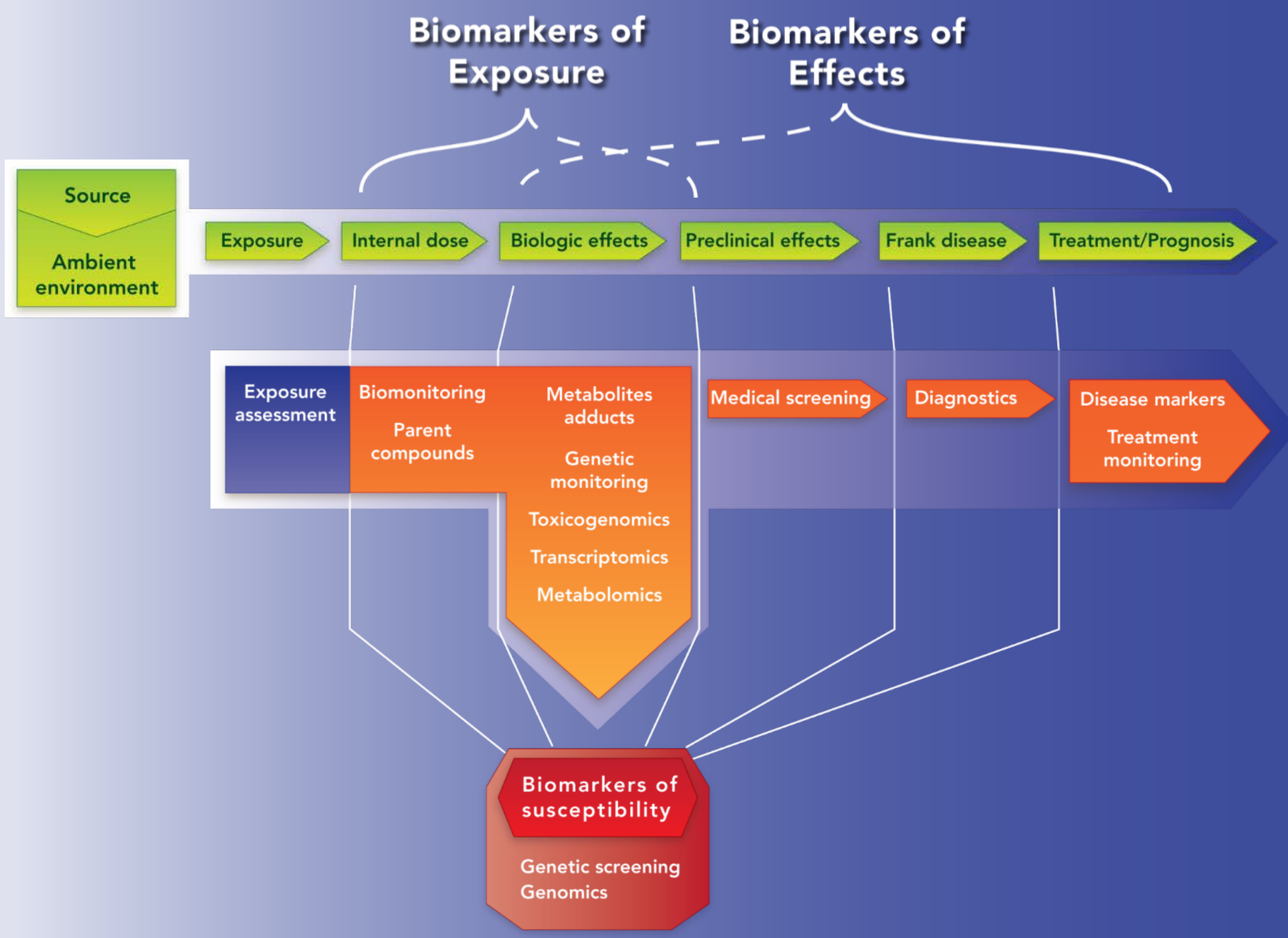
- Was the worker overexposed?
  - Concentration
- *Where* did the exposure occur?
  - Spatial positioning by satellite
- *When* did the exposure occur?
  - Timed exposure
- *Why* did the exposure occur?
  - Easier to analyze
- *How* do we remediate the situation?
  - NIOSH Continuous Personal Dust Monitor
  - Worker empowered to adjust exposure zone

Biomonitoring Sensors



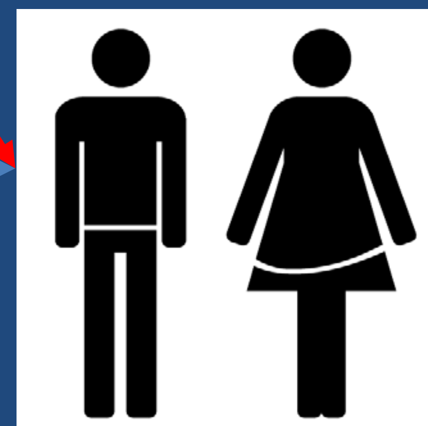
Jia, et al., Electrochemical Tattoo Biosensors for Real-Time Noninvasive Lactate Monitoring in Human Perspiration. *Anal Chem* 2013; 85(14);6553–6560.

DOSE = f (C, t, x, metabolism)



Biomarkers of Exposure
Biomarkers of Effects
Source
Ambient environment
Exposure
Internal dose
Biologic effects
Preclinical effects
Frank disease
Treatment/Prognosis
Exposure assessment
Biomonitoring
Parent compounds
Metabolites adducts
Genetic monitoring
Toxicogenomics
Transcriptomics
Metabolomics
Medical screening
Diagnostics
Disease markers
Treatment monitoring
Biomarkers of susceptibility
Genetic screening
Genomics

Tox21



https://wyss.harvard.edu/technology/human-organs-on-chips/

Alternative Toxicity Testing

- **REACH: Directive 2010/63/EU**
  - Member States shall ensure that, wherever possible, a scientifically satisfactory method or testing strategy, not entailing the use of live animals, shall be used instead of a procedure.

- **ICCVAM: 19 December 2000**
  - "To establish, wherever feasible, guidelines, recommendations, and regulations that promote the regulatory acceptance of new or revised scientifically valid toxicological tests that protect human and animal health and the environment while reducing, refining, or replacing animal tests and ensuring human safety and product effectiveness.“

- **Frank R. Lautenberg Chemical Safety for the 21st Century Act**
  - (A) not later than 2 years after June 22, 2016, develop a strategic plan to promote the development and implementation of alternative test methods and strategies to reduce, refine, or replace vertebrate animal testing …
  - (i) computational toxicology and bioinformatics;
  - (ii) high-throughput screening methods;
  - (iii) testing of categories of chemical substances;

TOX21

New Dimensions of Toxicity Testing

Tox21

- Since its establishment in 2008, the ***US Tox21*** inter-agency collaboration has made great progress in developing and evaluating cellular models for the evaluation of environmental chemicals as a proof of principle.

- Currently, the program has entered its production phase (Tox21 Phase II) focusing initially on the areas of modulation of nuclear receptors and stress response pathways.
  - During Tox21 Phase II, the set of chemicals to be tested has been expanded to nearly 10,000 (10K) compounds and a fully automated screening platform has been implemented.

- The Tox21 robotic system combined with informatics efforts is capable of screening and profiling the collection of 10K environmental chemicals in triplicate in a week.

  - Attene-Ramos MS. The Tox21 robotic platform for the assessment of environmental chemicals – from vision to reality. *Drug Discovery Today*. 2013;18:716-727

Tox21

- The Tox21 robotic system combined with informatics efforts is capable of screening and profiling the collection of 10K environmental chemicals in triplicate in a week.

- In a week, it can yield up to 2.2 million molecular data points derived from thousands of chemicals tested at 15 concentrations each with the goal of predicting human toxicity.

Tox21 Robotic Arm

https://ntp.niehs.nih.gov/results/tox21/index.html

Informatics

Worker Protection Informatics

Processing Procedures for Big Data

Courtesy of Mark Hoover, Ph.D., CHP, CIH

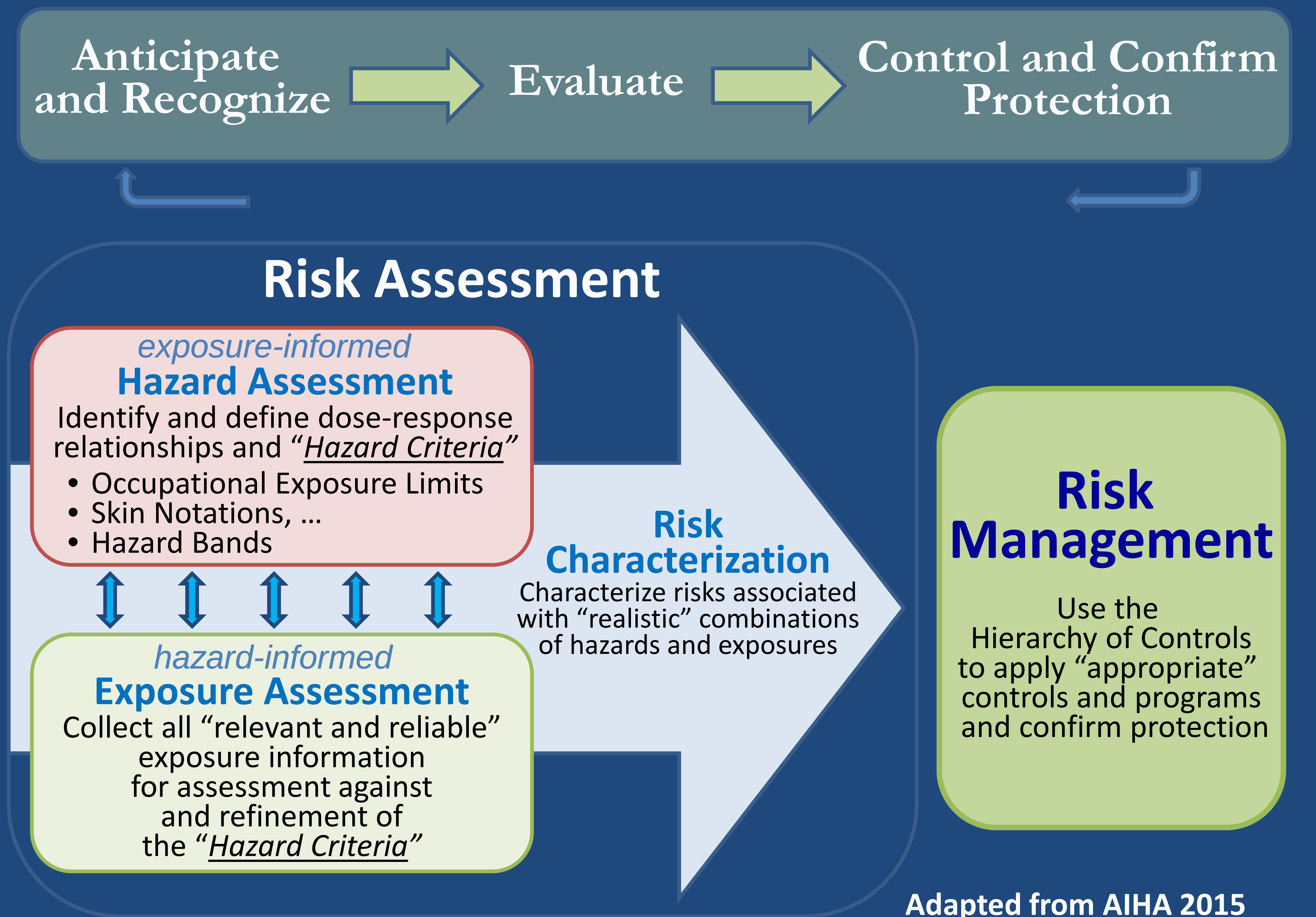
zij4@cdc.gov

Major Questions

- Do existing and proposed sensor methods **accurately measure** what they are supposed to be measuring?
- How can they be **adequately calibrated and validated**?
- When are they limited to use for screening and **when can they provide accurate characterizations** of specific hazards?
- Given the large to vast amounts of sensor data that may be collected, **how can those data be feasibly analyzed and interpreted by a occupational health data scientist**?

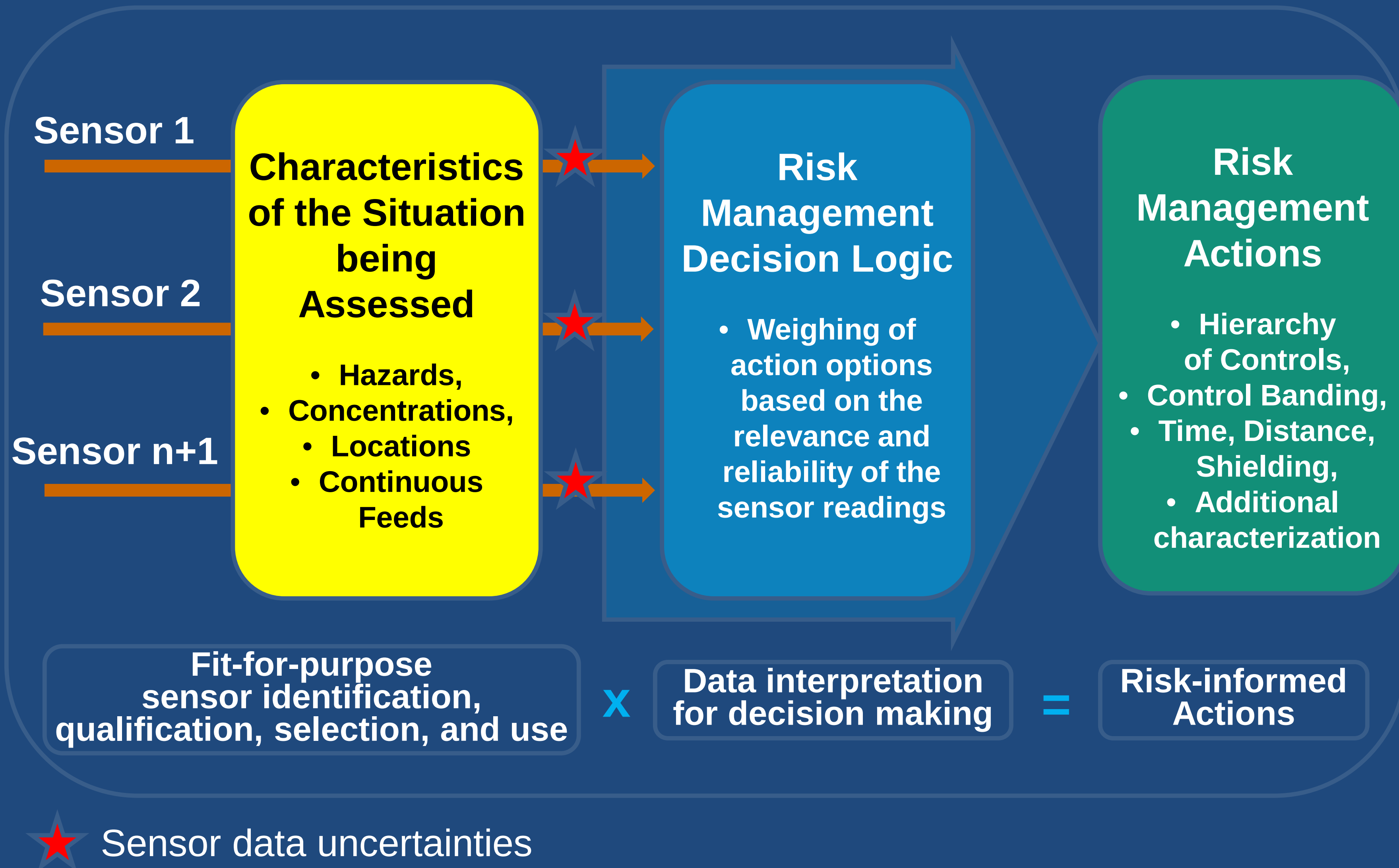






Adapted from AIHA 2015

Harnessing Sensors Data for Worker Safety & Health:
A Decision Logic for Risk-Informed Actions



Concept of BIG DATA for Worker Protection Informatics

If we begin by grouping the amount and complexity of the IH data we encounter, we may be able to define and develop a graded informatics approach to managing big data for worker protection.

Complexity of Data

Small amount needing complex assessment	Large amount needing complex assessment	Vast amount needing complex assessment
Small amount needing detailed modeling	Large amount needing detailed modeling	Vast amount needing detailed modeling
Small amount with obvious implication	Large amount with obvious implication	Vast amount with obvious implication

Amount of Data

What IH situations fit in which categories?

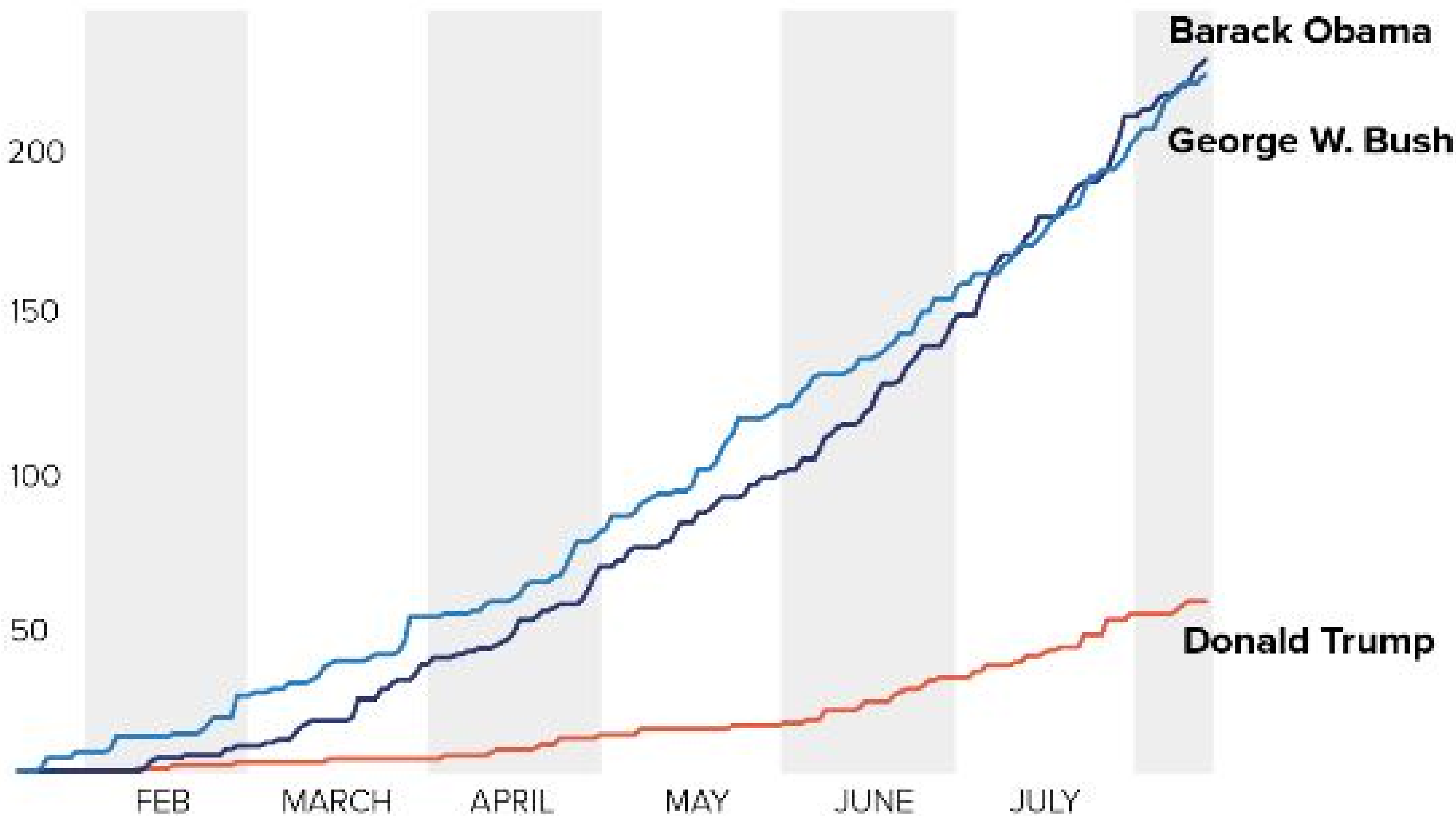
Worker Protection Informatics

- The ***science and practice*** of determining ***which sensor information is relevant*** to protecting worker safety, health, well-being, and productivity, and then developing and implementing effective mechanisms
  - to *collect, validate, store, share, analyze, model, and apply the information, and then to confirm achievement of the intended outcome* from use of that information,
  - and then *conveying experience to the broader community, contributing to generalized knowledge, and updating standards and training*.

Adapted from http://www.internano.org/nanoinformatics/ and Hoover et al. 2015

De-Regulating American Business

Major regulations approved by the Office of Information and Regulatory Affairs in the first seven months of each presidency.



Source: Office of Information and Regulatory Affairs

Climate Science Special Report

Fourth National Climate Assessment (NCA4), Volume I

This report is an authoritative assessment of the science of climate change, with a focus on the United States. It represents the first of two volumes of the Fourth National Climate Assessment, mandated by the Global Change Research Act of 1990.

Recommended Citation

The global, long-term, and unambiguous warming trend has continued during recent years. Since the last National Climate Assessment was published, 2014 became the warmest year on record globally; 2015 surpassed 2014 by a wide margin; and 2016 surpassed 2015. Sixteen of the warmest years on record for the globe occurred in the last 17 years (1998 was the exception). (Ch. 1; Fig. ES.1)

This assessment concludes, based on extensive evidence, that it is extremely likely that **human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century**. For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence.

https://science2017.globalchange.gov/

Thank You!