# NSF OE Program's Future Directions – Supply Chain Systems


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# *Outline – supply chain systems*

**NSF Workshop at SMU on Future Directions in Service, Manufacturing, and Operations Research**

*Sponsored by the NSF Operations Engineering Program, March 29-31, 2019*

- Introductory comments
- Trends affecting supply chain design and operations
- Topics potential interest (far from exhaustive)
- Example
- Questions to NSF

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# Framework

- *Purpose*: To identify promising future SC research directions (challenges & opportunities) with significant impact on *theory* and *practice*
- *Recognize*: dramatic increases in availability of data and computational capabilities
- *Connecting*:
  - Societal impact
  - Interface of OR/MS/Analytics with human behavior and organizational behavior and change

# What the OE Program supports

- *Fundamental research:* on advanced analytical methods for improving operations in complex decision-driven environments; e.g., deterministic and stochastic modeling, optimization, decision and risk analysis, data science, and simulation
- Must be motivated by problems that have potential for high impact in *engineering applications*; e.g.,
  - commercial enterprises
  - public sector/government
  - public/private partnerships

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# *Models & projects that consider:*

- Variety, velocity, and volume of real-time data
- Understanding the interplay between information and control
- *=> Monetizing data*

- Address the human-technology partnership and augmenting human performance
- Real-world, behavioral and organizational *implementation* challenges
- *Incentive structures* – university researchers versus real-world problem solvers

# *Domains – manufacturing & service*

- Healthcare
- Energy
- Manufacturing
- Supply chain
- Security
- Revenue management
- Autonomous vehicle control
- Driver safety performance
- Cooperative enterprise control

Picture: Bio cell manufacturing facility for CAR-T cell therapies

# A brief history of tools & techniques

- *1950's – 1990's*: Exact DP, optimal control, LQG problem, centralized & decentralized control, DES, information theory, MDPs, POMDPs, MIPs, game theory, heuristic search (e.g., A*, AO*)
- *1990's - mid 2000s*: approximate DP, neuro DP, reinforced learning, machine learning, BIG data, robotics, deep neural networks
- *2016, 2017*: AlphaGo, Alphazero, DeepMind

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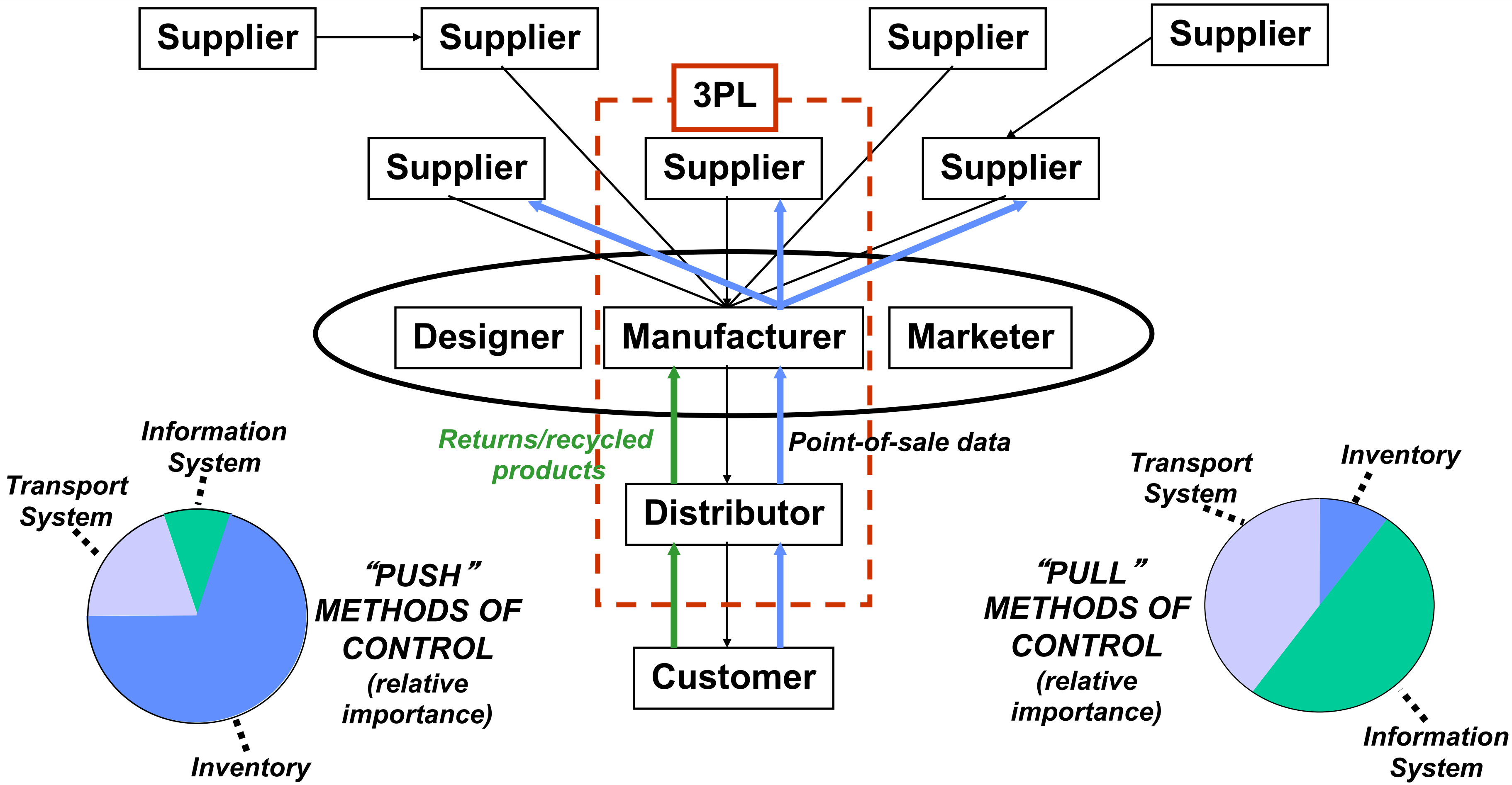
# Supply chain systems

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# Trends affecting supply chain design and operations

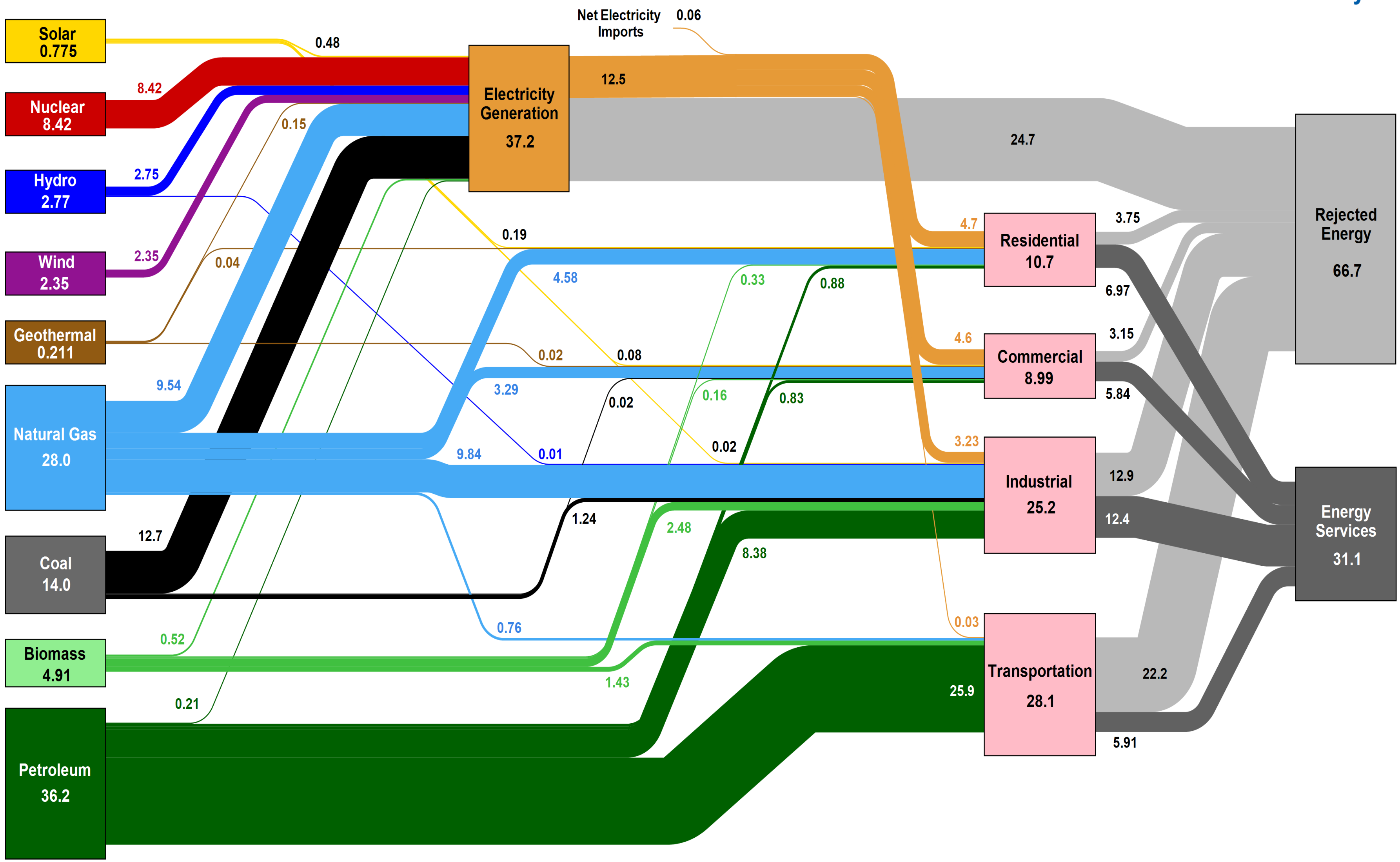
- BIG data – how to monetize congestion, consumer preference, weather, etc., data
- Automation – automated vehicles, warehouses, ports, bio cell manufacturing
- Globalization
- New forms of manufacturing – additive, additive-subtractive, 3D/4D printers
- New business/contract models – e-commerce, fast fulfillment, the sharing economy
- Security/Trusted supply chains – intelligent, adaptive adversaries; blockchain
- Demographic changes – urbanization
- Other chains – the development chain
- Energy/environmental implications

# *Supply chain implications of additive manufacturing*

- Products made closer to customer => shorter lead-times; portable manufacturing capacity
- Supports build-to-order, mass customization
- Supports postponement, modular product architectures
- Dramatic increase in information transmission, decrease in ton-miles (implications for LTL)
- Possibly versatile feedstock (risk pooling)
- Less finished goods & WIP transport & inventory (warehouse implications)
- Less packaging and handling
- Fewer stock-outs; less obsolescence
- Ideal for small batches & uncertain demand
- Negatives: cost, economies of scale

# Estimated U.S. Energy Consumption in 2017: 97.7 Quads

Lawrence Livermore National Laboratory




Source: LLNL April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

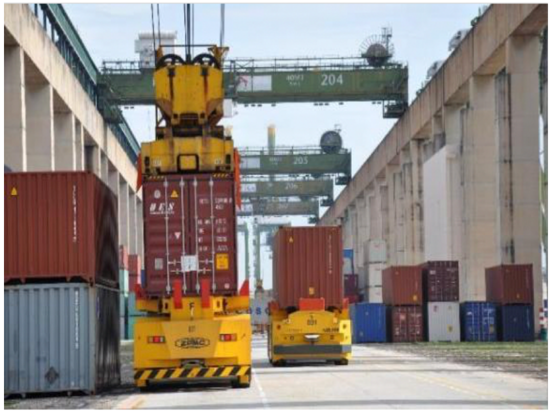
# The Sharing Economy – Main Players

| People/Labor | Health | Logistics | Financial Services |
|---|---|---|---|
| Rover<br>Bellhops Moving | Circle Medical<br>zipdrug | FLEXE<br>DOFT | LendingClub<br>PROSPER |
| **Household Goods/Food** | **Education** | **Transportation** | **Accomodation** |
| eatwith<br>peerby | Chegg The Student Hub | lyft<br>CAR2GO | airbnb<br>couchsurfing |

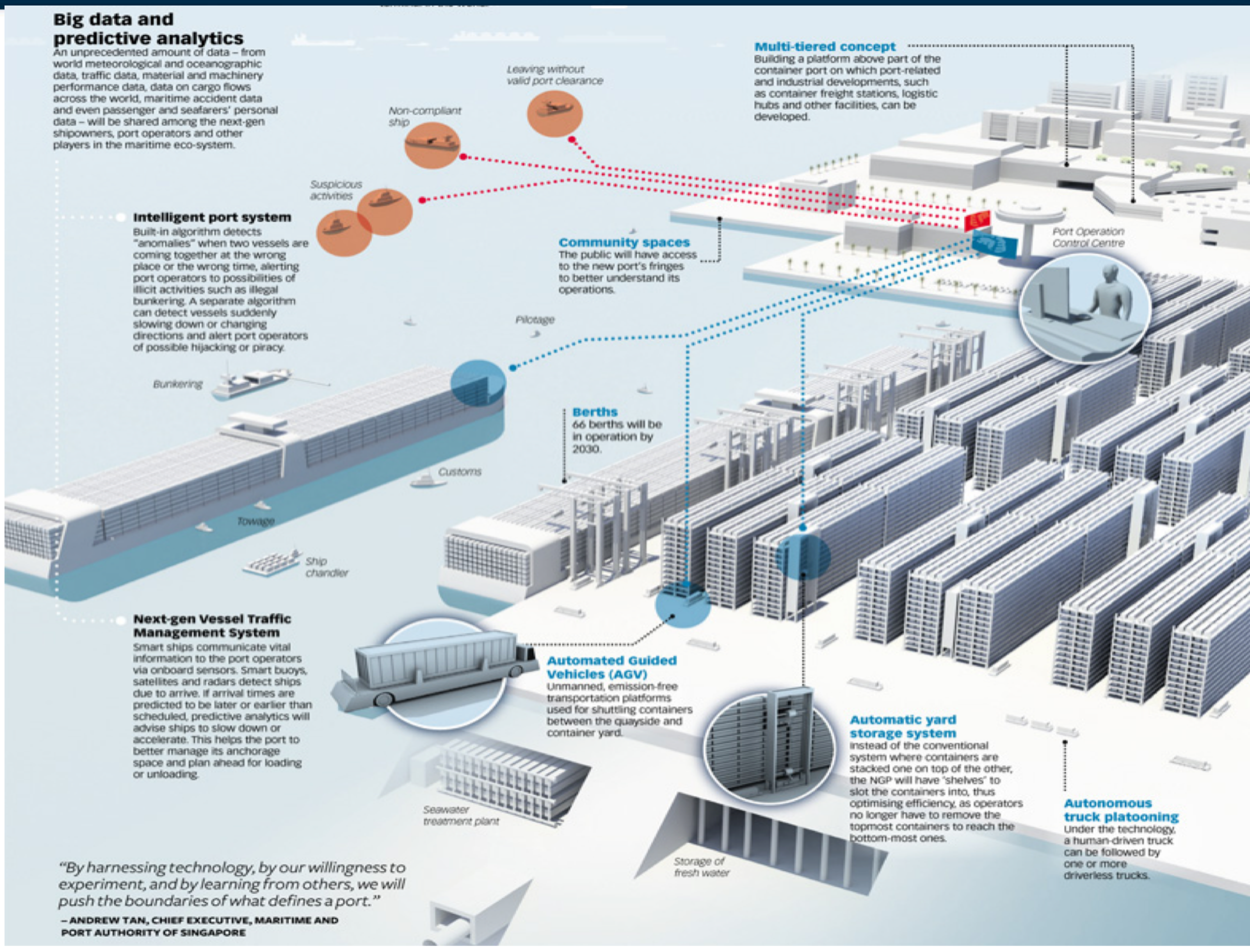
*Source : BofA Merrill Lynch Global research*

# Automation

- Continued automation in manufacturing; e.g., auto assembly, CAR-T cell therapy to assure consistent quality
- Self-driving vehicles, truck platooning (reduced manpower demand), robotics for loading and unloading (UPS, DHL, FedEx, Amazon)
- In Rotterdam & Singapore: AGVs at the wharf, in the yard, moving haulage to off-peak hours



# Next Generation port & warehouse automation




Next generation port:

- Intelligent port system
  - Intelligent planning system to optimize ships' turnaround time at the port and anchorages
- Vessel traffic management system
- Automated guided vehicles
- Automatic yard storage system
- Automatic yard crane
  - load and unload containers with precision, aided by computers, intelligent sensors and cameras
- Autonomous truck platooning
- Troubleshooting
  - Drones to inspect port equipment and assist in troubleshooting with remote video streaming
- Community spaces
- Multi-tiered concept
- One Sea autonomous maritime ecosystem



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# Data-driven inventory, storage, & production relocation

Relocation of mobile/modular resource capacity or local transshipment based on data-driven demand forecasting can result in the:

- Fast fulfillment of a *distributed* system
- Reduced buffer resource & cap ex of a *centralized* system

Without compromising *service level*


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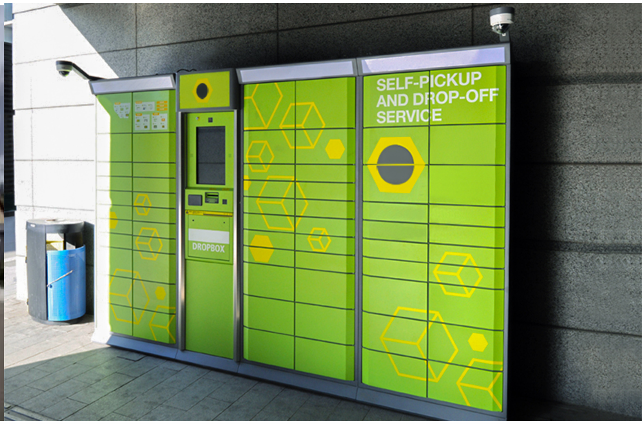
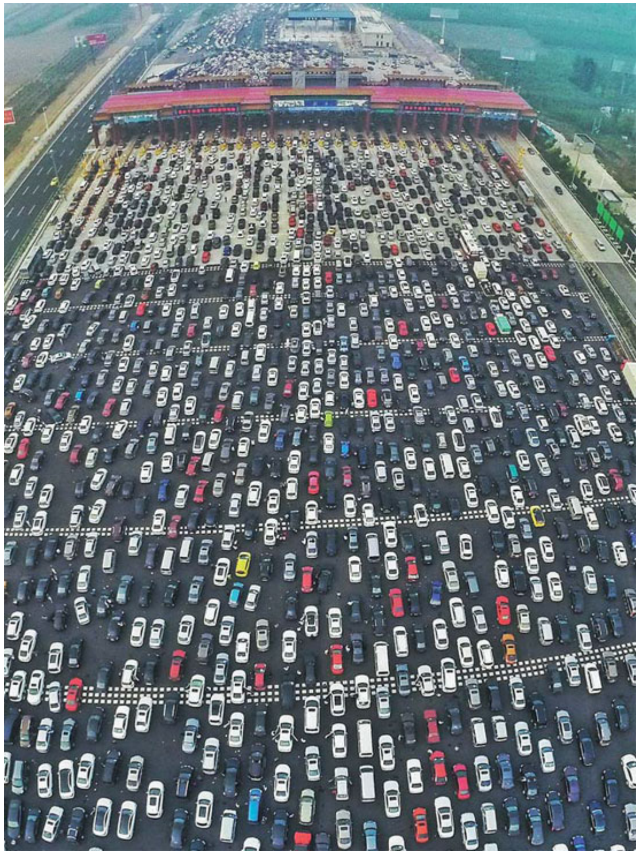
Without compromising *service level (or come close – conjecture)*

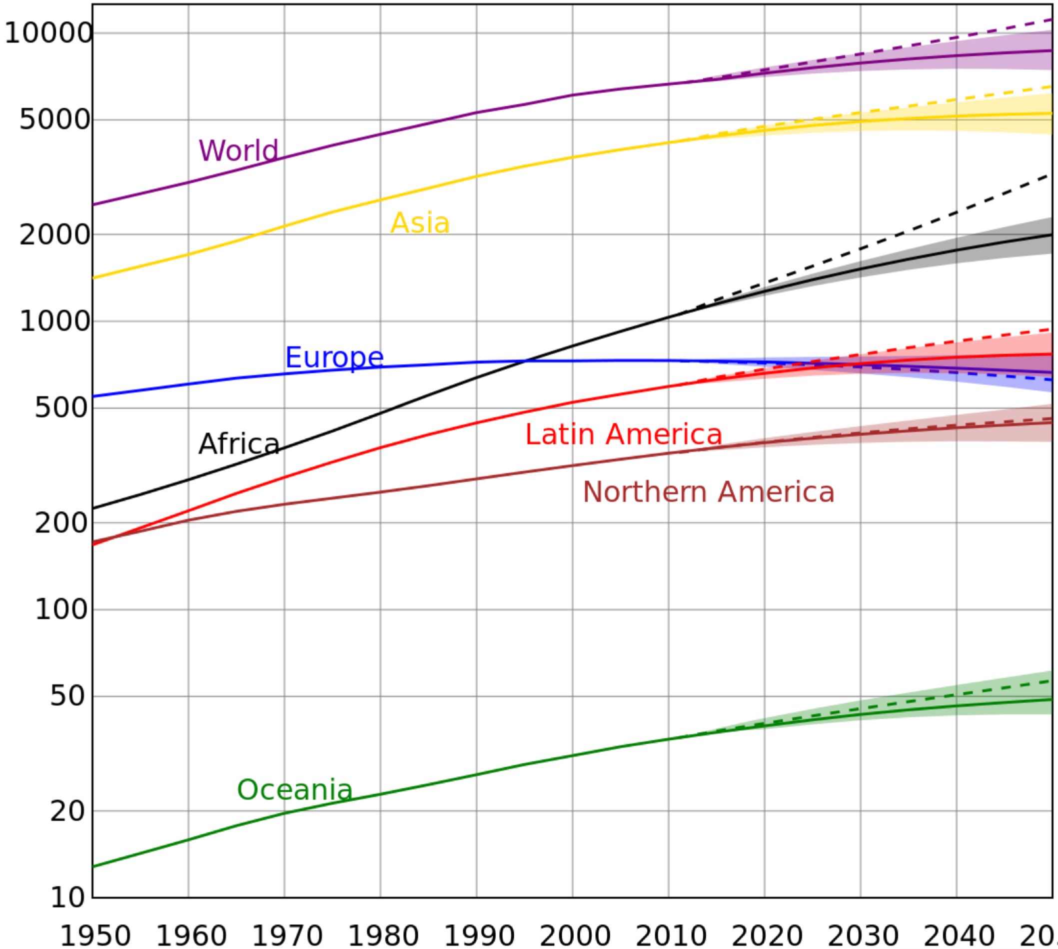



# ***Economic & demographic trends***

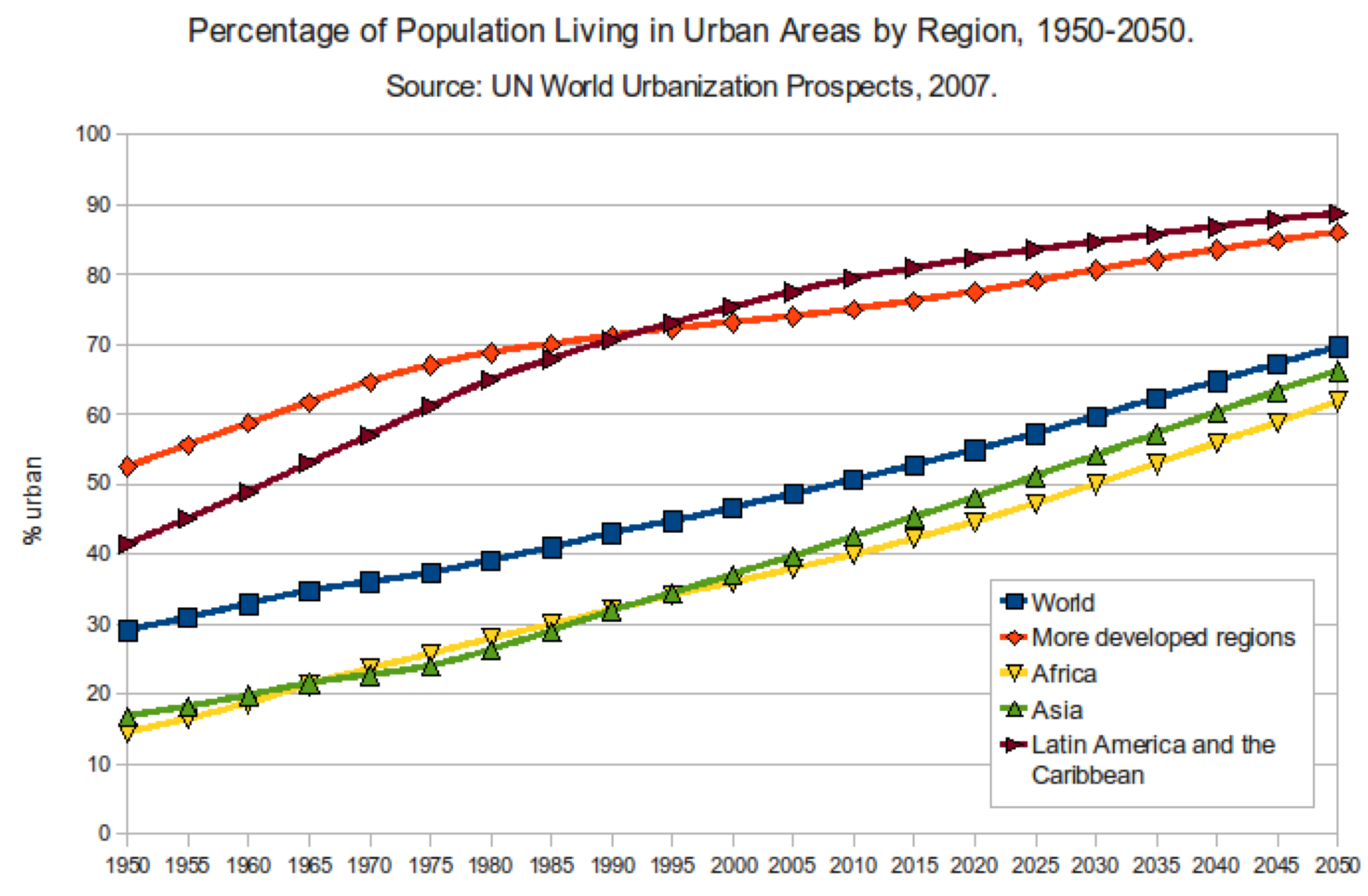
- Population movement into urban environments.  Mega city (slum) growth, infrastructure and *supply chain stress* greatest in Asia.  Congestion ('Big City Disease') magnified.
- Fast growth of middle class, particularly in Asia; emerging markets.  More discretionary income.  Growing income inequality
- Coupled with growth of older population, *health care logistics* of rapidly increasing importance; *cold supply chains*



# World population growth (UN)



# Global urban population growth



# Megacities

| Rank | City | Country | Continent | Population |
|---|---|---|---|---|
| 1 | Tokyo | Japan | Asia | 34.8M |
| 2 | Guangzhou | China | Asia | 31.7M |
| 3 | Shanghai | China | Asia | 28.9M |
| 4 | Jakarta | Indonesia | Asia | 26.4M |
| 5 | Seoul | S. Korea | Asia | 25.8M |
| 6 | Delhi | India | Asia | 24.0M |
| 7 | Mexico City | Mexico | N. America | 23.8M |
| 8 | Karachi | Pakistan | Asia | 22.7M |
| 9 | Manila | Philippines | Asia | 22.2M |
| 10 | New York City | USA | N. America | 21.6M |
| 19 | London | UK | Europe | 15.5M |
| 27 | Moscow | Russia | Europe | 11.5M |
| 28 | Paris | France | Europe | 10.7M |

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# Topics of potential interest

*New forms of manufacturing/medicine*

- Advanced manufacturing & materials, additive and additive-subtractive manufacturing, Production unit: 3D printer. 3D printers are portable. Impacts on other industries, e.g., of additive manufacturing on the trucking/LTL industry. How do they impact the design and operation of the supply chain?

- Bio cell manufacturing. Production unit: bioreactor. Bioreactors are portable. New class of supply chains supporting autologous cell manufacturing. Example: chimeric antigen receptor (CAR) T cell therapy has demonstrated complete responses rates of 69% - 90% in pediatric patients with relapsed or refractory acute lymphoblastic leukemia*. Novartis now has an FDA approved commercial product.

* *NSF supported research through GT ERC on Cell Manufacturing*

# *A deeper dive – bio cell manufacturing*

Before autologous therapy manufacturing can begin, we need:

- A patient's *specimen*
- An idle *bioreactor*
- A sufficient amount of *reagent* (a necessary manufacturing intermediate)

**Objective:** Insure the reagent is rarely the bottleneck but is not overstocked, where the number of patient therapies to begin to manufacture: min(p, b, r)

- Reagent replenishment penalty term: $(\min(p, b) - r)^{+}$
- Holding cost considerations: $(r - \min(p, b))^{+}$

**Challenge:** to model the idle bioreactor process, where completion time is stochastically dependent on:

- Current state of the manufacturing and QC processes
- Current state of patient health

# Topics of potential interest

*New business models & supply chain designs*

- Having direct contact with the e-customer as a competitive advantage. Amazon versus traditional systems integrators, e.g., UPS, FedEx, DHL; Alibaba and JD.com versus SF Express).
- Sharing economy
- How to design and operate data-driven supply chains *having relocatable inventory, storage capacity, and/or manufacturing capacity* that without customer service level reduction blend the advantages of *distributed* systems (e.g., fast fulfillment) and *centralized* systems (e.g., economies of scale, risk pooling, less total buffer inventory, and reduced capital expenditures)

# Topics of potential interest

*Security & cooperation*

- Quantifying the value of *cooperation/trust* – cooperative games – sequential, partially observed
- *Secure/Trusted* supply chains – dealing with intelligent, adaptive adversaries (lead to the development of the partially observed Markov game (POMG), an extension of the POMDP); blockchain

# Topics of potential interest

*Better demand forecasting versus better product & SC design*

How to best incorporate data (ML/RL) for improved *demand forecasting*, from exogenous forces, e.g., macro-economic conditions. *The value of better demand forecasts (* => *w*eather-dependent logistics & transportation)

How to decide between:

- **I**mproved demand forecasting
- Product and SC redesign for shorter lead times, less reliance on demand forecasts

We note: shorter lead times lead to better demand forecasts

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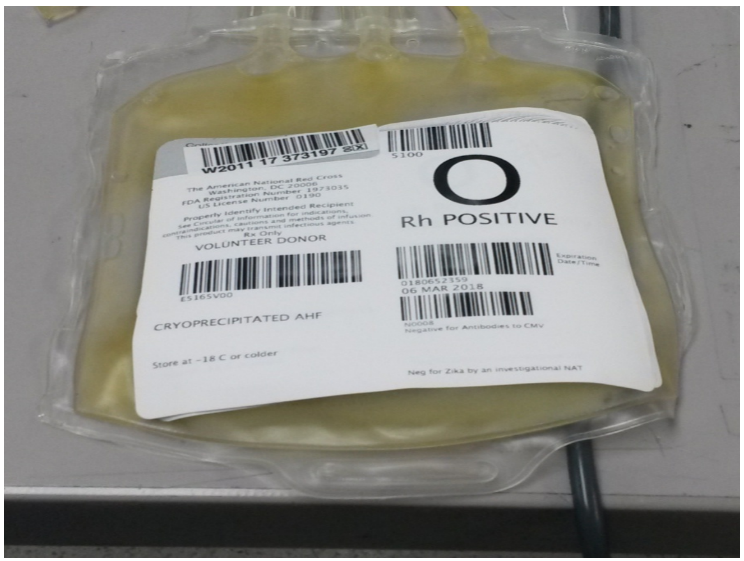
# *Example - cryoprecipitate collection**
## *Co-authors: Turgay Ayer, Can Zhang*




- Cryoprecipitate is a critical whole blood product that plays a key role in clotting and controlling hemorrhaging
- At most *8 hours* can pass between the time of collection and the beginning of the cryo production process
- Other blood products have a 24 hour window, different bag requirements
- => Cryo requires special collection logistics involving ‘mid-day’ ($) pick ups

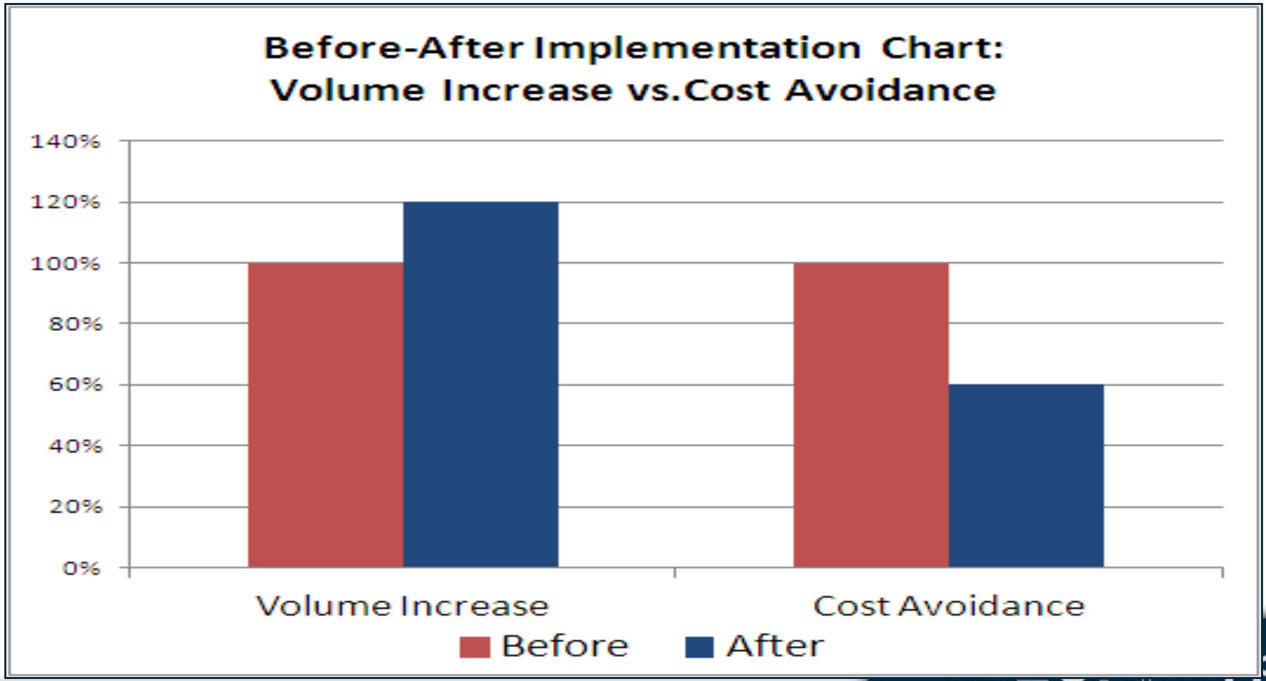
American Red Cross

- *NSF supported research*

  *Edelman Finalist*

# Example - cryoprecipitate collection

- *Challenge*: how to choose collection sites and adjust through the week to meet weekly collection target and minimize mid-day collection costs
- Two solution approaches: Greedy heuristic, MDP (the benchmark)
- Solving the MDP required several foundational advances (e.g., action elimination results)



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# Questions to NSF

- *Searching for synergies*. What is the partnering/coordinating strategy within NSF and with other organizations (e.g., NIH, USDOT, DOE, DOD, foundations, NGOs) to identify and remove domain and foundational *interdisciplinary* research area gaps?
- *Premise*: using applications for discovery of foundational research topics is an excellent approach for expanding the state of knowledge in important directions. How does NSF insure support for foundational research that is not driven by a specific mission; e.g., foundational research useful across multiple domains?

# Thank you!

# References


- Ayer, T., Zhang, C., Zeng, C., White, C., V. Roshan Joseph, Mary Deck, Kevin Lee, Diana Moroney, Zeynep Ozkaynak, “American Red Cross Uses Analytics-Based Methods to Improve Blood-Collection Operations”, Interfaces, Volume 48, Issue 1, January-February 2018, pp. 24-34 (Finalist, 2017 Edelman Prize)
- Ayer, T., Zhang, C., White, C., “Analysis and Improvement of Blood Collection Operations”, Manufacturing & Service Operations Management, published online 22 June 2018, (first prize winner, 2017 MSOM Practice-Based Research Competition)