

Supply Chains: How the World is Interconnected & How “Black Swan Events” Can Leave us without Critical Supplies When we Need Them



Fred S. Roberts
Director of
CCICADA
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Credit: Wikimedia commons

Remember March 2020?

- When COVID-19 hit, we found the country short of Personal Protective Equipment (PPE)
 - Masks
 - Gowns
 - Ventilators



Credit: Wikimedia commons, Timely Medical Innovations, LLC



Credit: Wikimedia commons, [James Heilman, MD](#)

Remember March 2020?

- When COVID-19 hit, store shelves were empty.
- We couldn't get important items:
 - Hand sanitizer
 - Disinfectant wipes
 - Toilet paper



Hoarding Toilet Paper



Credit: Laurie Kolano

Remember March 2020?

- There were shortages of food
- Yet, farmers were burying crops and pouring out milk
- Our supply chains were thrown into chaos
- How did all this happen?



Despite shortages in grocery stores, some farmers had to destroy crops.

Photo Credit: Wikimedia Commons

Data-driven Supply Chains

- Supply chains have been dramatically changed in the digital age.
- *Artificial intelligence and machine learning have allowed the private sector and governments to minimize inventories.*
 - Due to extremely accurate knowledge of demand for goods or components.
 - Allowing for *”just-in-time” delivery.*
- COVID has demonstrated the problems with this approach.
 - Shortages of medical equipment (ventilators, masks)
 - Shortages of consumer goods (toilet paper, disinfectant wipes)
- AI/ML-driven supply chains worked great until there was a *“Black Swan” event* – an anomalous event, one that was totally unexpected.
 - Terminology stems from (Western) view that all swans are white.



Credit: Wikimedia commons, [Josephus37](#)

Supply Chains are Not Always Flexible

- Why did farmers plow under food and pour out milk when COVID hit and consumers couldn't get these products in the stores?
- Supply chains are not that flexible.
- There was more demand – people started hoarding. The supply chain didn't foresee this.
- Workers at different stages of the supply chain were out sick or in lockdown.
- It was difficult to change packaging, transportation routes, and contracts.
 - If you are used to delivering 50 lb. bags of potatoes to institutions such as schools or restaurants, you can't suddenly shift to 50 lb. bags.
 - Packaging is different. Transportation is different. New contracts have to be signed.



Supply Chains are Global & the World is Interconnected

- Supply chains are increasingly interconnected.
- The recent blockage of the Suez Canal by a grounded container ship continues to affect the world because 80% to 90% of the world's commerce continues to be moved by sea:
 - Supply and price of oil affected
 - Shortages of some food supplies
 - Shortages of microchips to make cars have caused some car makers to shut down
 - Vessels are backed up at ports for days – waiting at anchor
 - Empty shipping containers are in short supply in some ports and there is a glut of them in others.
 - Freight charges are going up fast and there is concern about resulting inflation



Moving Supplies by Air

- Moving supplies by sea can be slow.
- Especially when events like the Suez Canal incident force some ships to divert around the southern tip of Africa, adding several weeks to transit time.
- Air transport is faster, but can be more expensive.
- But to compete, some shippers have introduced special fast-transit shipping options by sea.

Image from Brandin Fried



Moving Supplies by Air

- COVID has really challenged both sea and air transport.
 - Seaports closed causing delays
 - Crews were sickened and vessels couldn't enter a port
 - Shortages of containers at some ports led to innovative solutions, like filling vessels with empty containers to take them where needed.
 - Airlines stopped flying because of lack of passenger demand
 - This resulted in loss of 50% of the world's cargo capacity
 - Innovative solutions led some airlines to carry freight in passenger compartments



Image from Brandin Fried

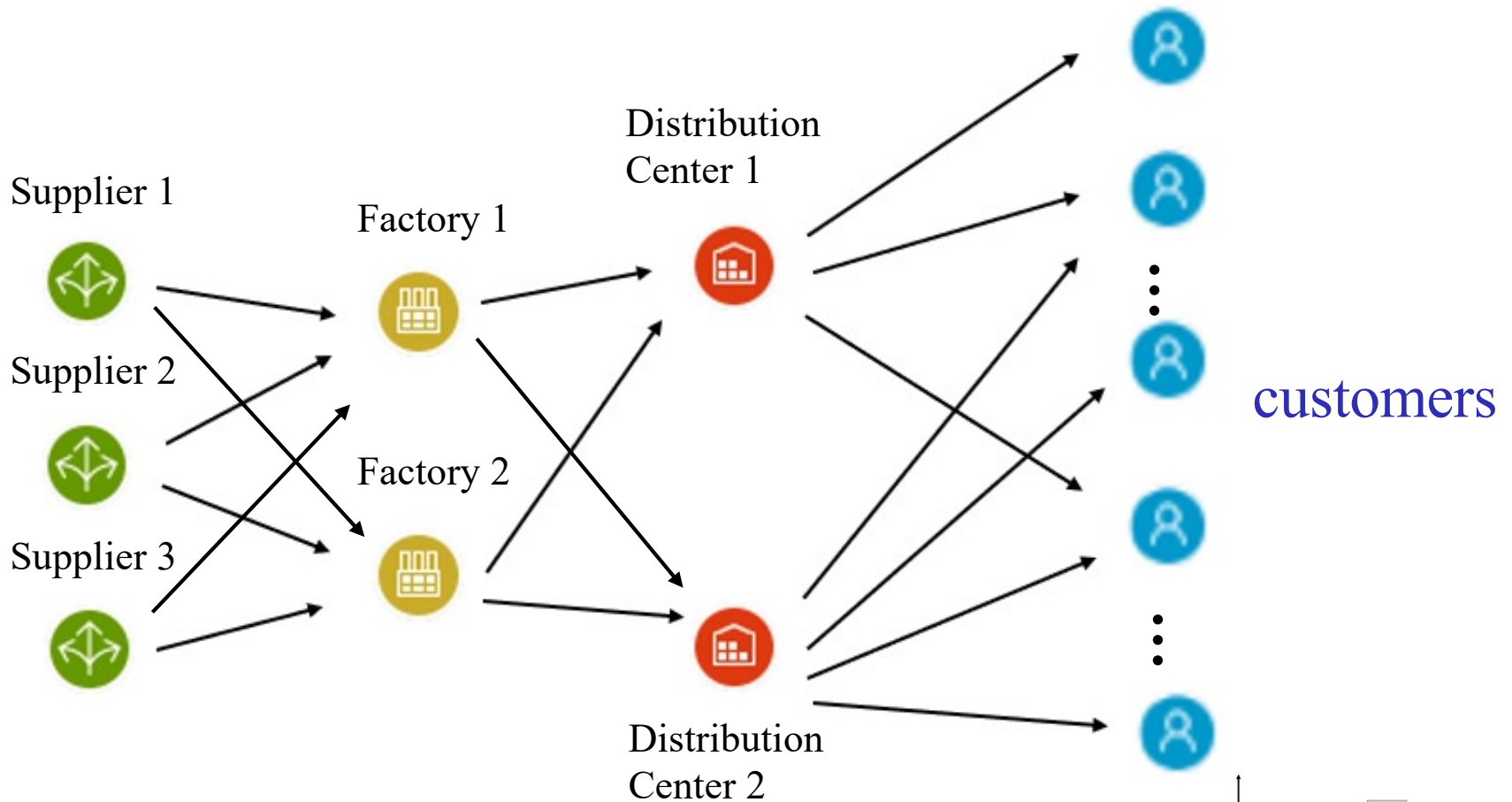
Supply Chains are Global & the World is Interconnected

- Consider the food supply for example.
- You can't deliver food unless you have the supplies for packaging (e.g., cans and paperboard)
- You can't process food without fuel for the electricity and gas used in producing food
- You can't clean and disinfect food processing plants if you don't have the needed chemicals and cleaning supplies
- You can't deliver food from farm to food processing to warehouses to markets without fuel for the means of transportation

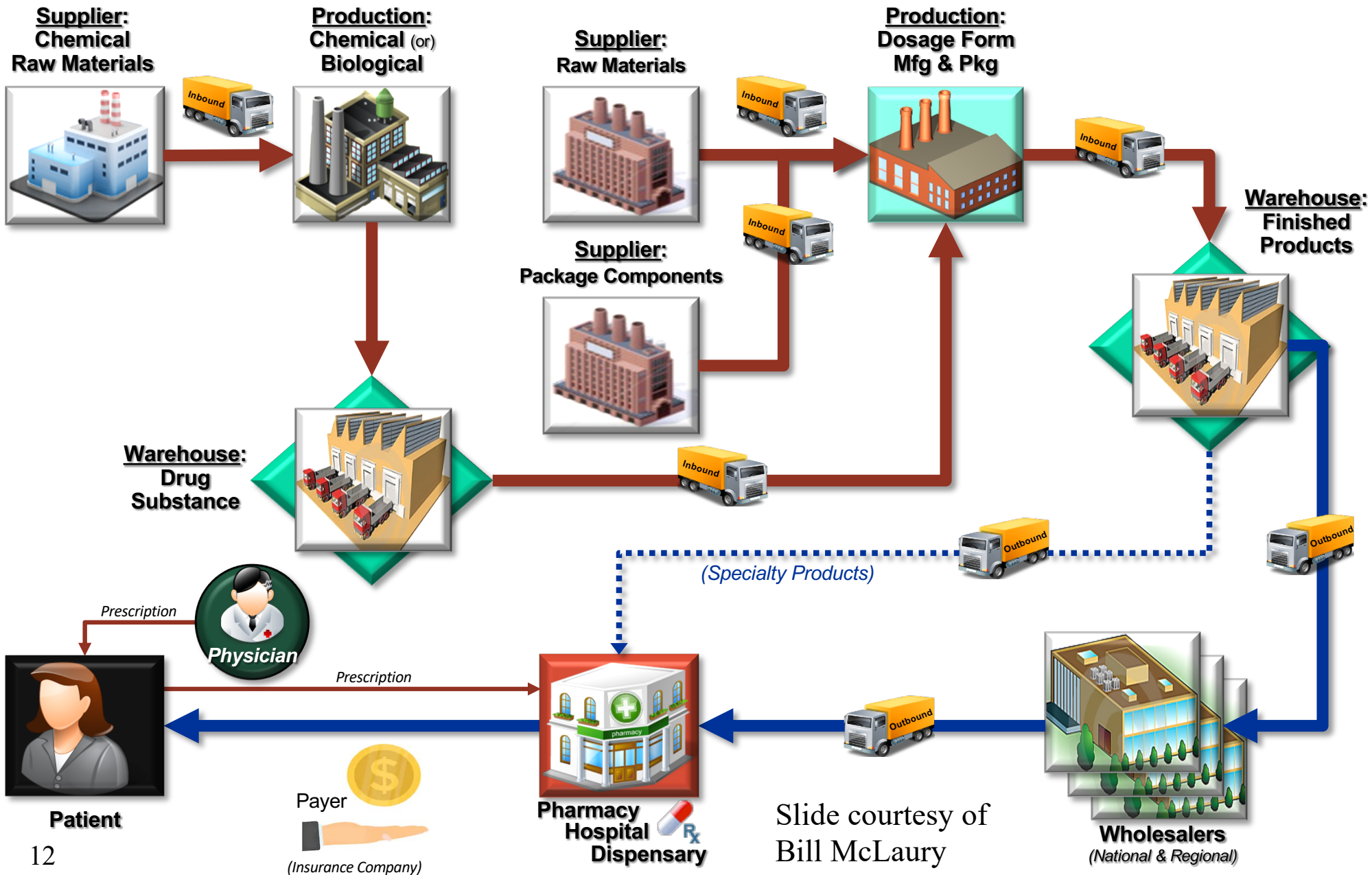
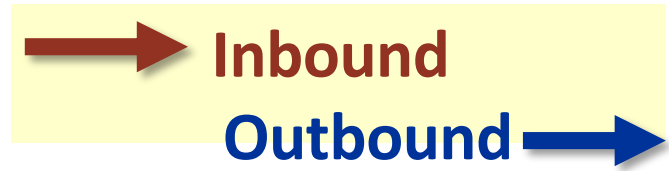


Images from John Hoffman

A “Toy” Supply Chain



A "Real" Supply Chain: Pharmaceuticals



Slide courtesy of Bill McLaury

Challenges for the Supply Chain for Food

- Economically motivated adulteration
- Loss of supply of key ingredients or a critical systems node
- Cyber attacks on facility operations or transportation systems
 - Cyber-based systems are ubiquitous in the food sector.
 - Few firms will share actual cyber attack impacts; yet, the available data show that the food sector is in the top 3-4 targeted sectors each year.
 - Cyber threats to the food sector have grown during the pandemic, from processors to transportation to distribution.
- Product theft
- Infrastructure failure: transportation failures, port closures
- Loss of access to workers
- Civil or political unrest



Risks and images from John Hoffman

Challenges for the Supply Chain for Food

- COVID-19 impact on the global system has demonstrated the problems associated with the availability and agility of packaging suppliers
- The need to surge retail food production and curtail food service supply systems resulted in packaging supply shortages as suppliers had difficulty responding
- This was exacerbated by disruptions in maritime transportation systems, closing of ports, and labor shortages in port facilities.
- Shortages in aluminum packaging as materials and production diversion to other critical response products further aggravated the shortages.
- ***Until COVID-19, food packaging was not seen as a critical strategic resource.***

Image credit: Wikimedia commons, US Department of Agriculture, Peggy Greb

Packaging risks from John Hoffman

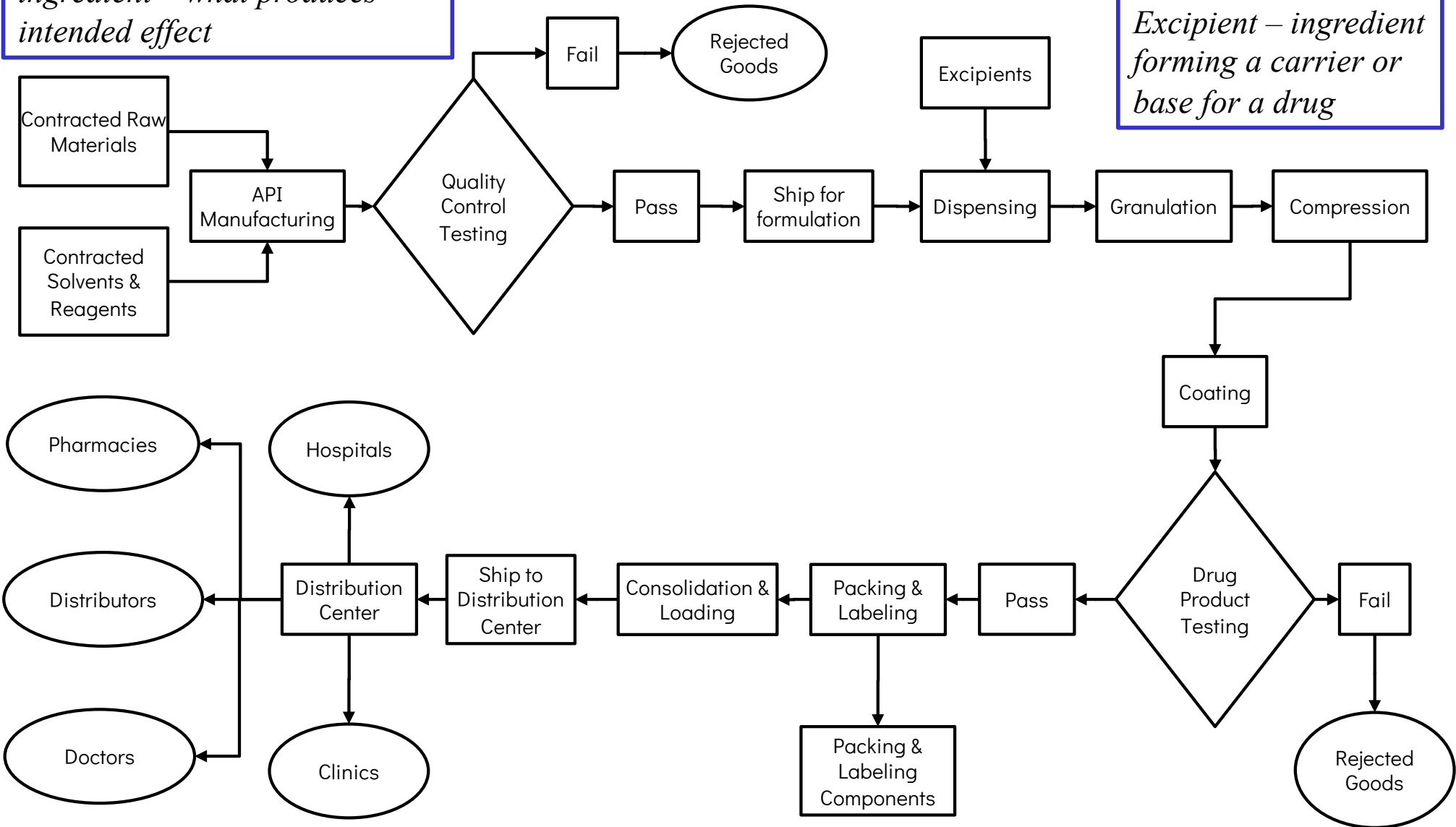


Challenges for the Pharmaceutical Supply Chain

Challenges at each step

API – active pharmaceutical ingredient – what produces intended effect

Excipient – ingredient forming a carrier or base for a drug



Challenges for the Pharmaceutical Supply Chain

- The ingredients* of several drugs, including antibiotics such as Azithromycin or Amoxicillin, use minerals such as chromium, cobalt, copper, magnesium, manganese, molybdenum, sodium, nickel and many others.**
- Increasingly, the key suppliers of such ingredients are in a small group of countries - creating some key threats.
- For example, phosphate is widely used in the pharmaceutical industry
 - Primary production facilities are concentrated in a few countries. China and a couple of countries in North Africa and the Middle-East accounted for over 70% of production of phosphate rocks in 2019, and about 80% of proven reserves.*
- A key is to identify alternative sources.

*Ingredients are API or “excipients” that form a carrier or base for a drug

**Source: <https://unece.org/circular-economy/press/securing-critical-raw-materials-supply-key-response-covid-19>

Challenges for the Pharmaceutical Supply Chain

- Potential shortages of medical glass vials and stoppers.
 - These are sourced primarily from suppliers in China. Shortages date back before the pandemic.
 - Potential shortage of the sand used to make glass vials.
 - Stoppers are heavily regulated as the rubber or latex components can't interact with the product inside the vial. A few manufacturers dominate the stopper business, and some of them also make the vials.
 - Glass vials are destroyed after use to prevent reuse by those who make counterfeit medicines/vaccines – adding to stress on the supply.
- Potential short-term shortage of syringes.
 - BD reported that there is not enough capacity in the industry to produce billions of syringes and needles in a significantly compressed time frame
- Foreign sources of raw materials and chemical ingredients needed to produce vaccines.



Challenges for the Supply Chain: Crime

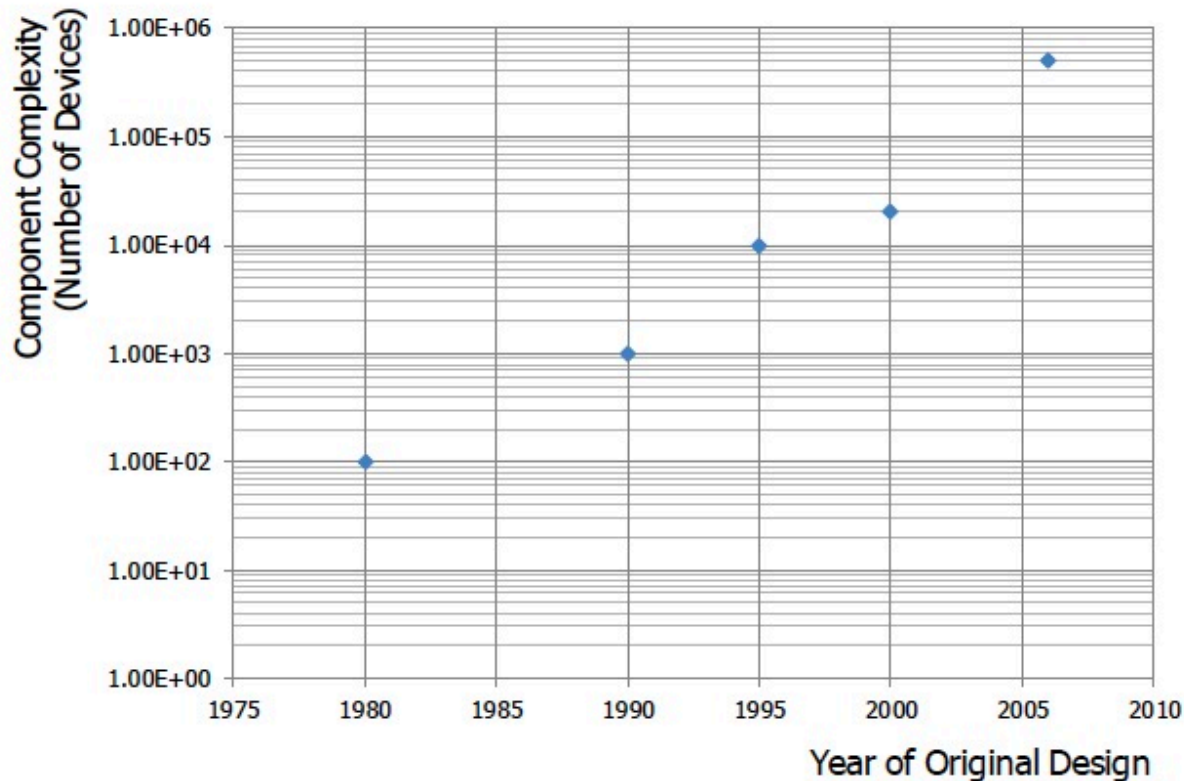
Crime has Gotten Worse During COVID

- *“Swindles, scams, and outright thefts have long been a feature of major disasters. The more catastrophic the event, the more active the fraudsters. However, the COVID-19 pandemic provides criminal opportunities on a scale likely to dwarf anything seen before. The speed at which criminals are devising and executing their schemes is truly breathtaking.”* – FBI, US Secret Service
 - Drugs are being marketed as “cures” or vaccines for COVID-19
 - Unapproved and counterfeit N95 masks, gowns, gloves, and other PPE
 - Unapproved and even dangerous sanitizing and disinfecting products
 - Debt relief scams are on the rise
 - Cyber attacks on the supply chain are increasing, including even ransom demands on hospitals treating COVID patients
 - Illegal hoarding and price gouging is on the rise
 - Fraud against the CARES Act
 - Donation schemes

The Challenge of Crime: Counterfeit Goods and Components



Growing National Security Exposure



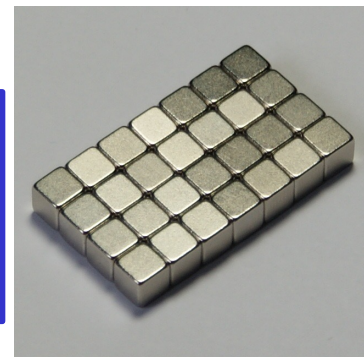
- Plot of selected counterfeit parts discovered in the DoD supply chain over past 2 years
- Evidence of growing capability in counterfeiting more complex components

Distribution A, Approved for Unlimited Distribution

Challenges for the Supply Chain: “Nexus Suppliers”

- Our supply chains are getting longer and longer.
- But all too often we are finding that at the beginning, there is one “*nexus*” *supplier* that provides a substantial portion of the components needed.
- That creates a serious vulnerability in case that supplier:
 - Suffers a natural disaster
 - Is politically unstable
 - Has a political agenda
- Pharmaceuticals. A few countries such as China are the source of key APIs and “excipient” ingredients.
- Advanced Technologies: Rare earth elements such as neodymium are mined almost exclusively in China.*

Neodymium magnet cubes for electric motors and generators



Challenges for the ICT Supply Chain

- All aspects of our lives are intertwined with *information and communications technology (ICT)*:

- Smartphones and tablets
- Laptops
- Servers running our power grid and our financial transactions

- Threats include:

- Counterfeit components
- Cyber attacks
- Introduction of malicious software
- Ransomware

- The counterfeit components might be introduced early in the supply chain and not noticed for years.



CYBERSECURITY AND INFRASTRUCTURE SECURITY AGENCY
National Risk Management Center
December 2018



Why are Supply Chains a DHS Issue?

- *July 2019: The Directors of the DHS university centers of excellence asked the Office of University Programs what the major problems facing DHS were.*
- *First Response: Supply Chains*
- Example: Great concern about counterfeit components in information and communications technology.

Counterfeits

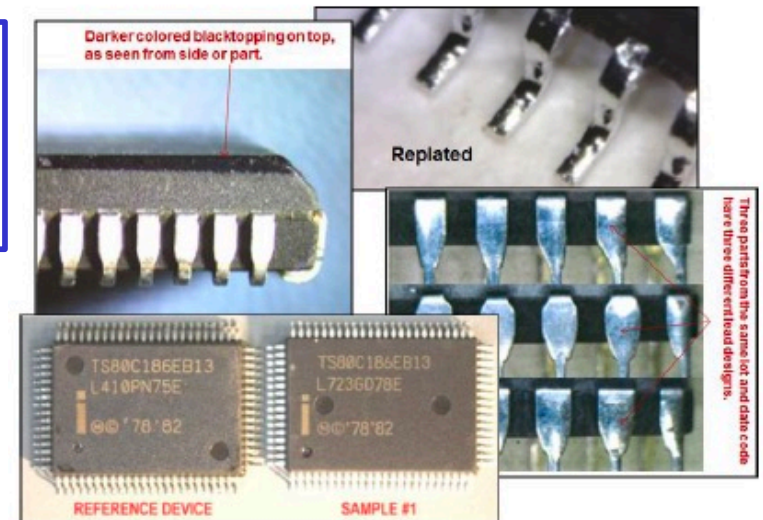
Still the original part from OEM:

- Recycled used components
- OEM's fab test failures sold on black market.
- Unlicensed fab overproduction

Electronic
Component
Counterfeits

Image credits: NSWC CRANE

DARPA Distribution Statement A:
Approved for Unlimited Distribution



Why are Supply Chains a DHS Issue? DHS Operation Stolen Promise

U.S. IMMIGRATION AND CUSTOMS ENFORCEMENT HOMELAND SECURITY INVESTIGATIONS OPERATION STOLEN PROMISE

Targeting Fraud and Illicit Activity

As the nation bands together to fight COVID-19, there are individuals and organizations operating around the globe that seek to exploit and profit from the pandemic.

Operation Stolen Promise will combine HSI's expertise in global trade investigations, financial fraud and cyber investigations with robust private and public partnerships to disrupt and dismantle this criminal activity and strengthen global supply-chain security.

Credit: Brian Weinhaus

Why are Supply Chains a DHS Issue? DHS Operation Stolen Promise

COVID-19 Health-Related Fraud

Counterfeit or Unapproved Personal Protective Equipment (PPE) and Life Safety Products include:

- N95 respirator masks
- Protective gowns
- Protective gloves
- Protective eyewear
- Full face shields
- Sanitizing products
- Hygiene products
- Medical and laboratory equipment

IPR Center Operation Body Armor targets counterfeit, unapproved or adulterated medical devices and personal care products



Why are Supply Chains a DHS Issue?

CISA

- DHS Cybersecurity and Infrastructure Security Agency (CISA) is heavily involved with supply chains.
- Specifically CISA's National Risk Management Center (NRMC)
- Example: CISA efforts in Information and Communications Technology (ICT) supply chain risk management.
- They have a series of ICT Supply Chain Risk Management Task Force Working Groups.
 - You can find their reports online.
 - These reports describe different supply chain disruption scenarios and identify useful countermeasures.
 - Can we tell which threats present the greatest risk and which countermeasures are most effective at reducing risk from disruptions?



ICT SCRM TASK FORCE: THREAT SCENARIOS REPORT

Sample ICT Supply Chain Disruption Scenario

6.3 Yokogawa Electric Corp. Counterfeit Equipment

- **Scenario:** Yokogawa Electric identified instances in which several customers received counterfeit high performance differential pressure transmitters used to measure liquid, gas, or steam pressure. The counterfeit products used the Yokogawa logo.
- **Threats:**
 - Counterfeiting originated at integrator.
 - At shipper.
 - At third party.
- Which presents higher risk?
- **Countermeasures:**
 - Does traceability/serialization to keep track of transactions reduce risk more than setting up product inspection and performance spot-testing processes with customers?
 - Does use of advanced techniques (e.g. machine learning) to detect counterfeit packaging, labeling, and logos reduce risk more than placing engineers in a vendor's location on a regular basis?

Sample ICT Supply Chain Disruption Scenario

14.1 Natural Disasters Causing Disruptions

- **Scenario:** A category 5 hurricane has hit in Savannah, GA, and has moved up the East Coast and inland in northern VA, damaging or destroying ports from Savannah, GA to Norfolk, VA, and washing out roads and bridges. This affects ABC Company.
- **Threats:**
 - Smartphones headed to ABC's Richmond, VA retail stores are delayed for a month because the port in Hampton Roads is closed.
 - The supply of components for high end servers manufactured at ABC in Hampton Roads, VA are delayed for a month, causing manufacturing to halt.
 - Screens for laptops manufactured at ABC in Atlanta are delayed for two weeks because the port of Savannah is closed.
- Which presents higher risk?
- **Countermeasures:**
 - Does developing emergency response procedures reduce risk/mitigate impact more than identifying mission-critical business functions and their interrelationships?
 - Does monitoring data on weather, port closures, traffic in real time reduce risk/mitigate impact more than exercising your recovery plan?

Sample ICT Supply Chain Disruption Scenario

10.2 New Vendor OnBoarding

- **Scenario:** American Service Co. is considering a new partnership with Chips, Inc., manufacturer of Chips. Chips, Inc. is based in Hong Kong and receives a government subsidy.
- **Threats:**
 - Intellectual property theft at Chips, Inc.
 - Government subsidy is lost, Chips, Inc. is sold and sensitive American Service info is transferred.
 - Spare parts/chips at Chip, Inc. production sites fall into American Service competitor hands.
- Which presents higher risk?
- **Countermeasures:**
 - Does phasing of onboarding services so that initially Chips, Inc. only does fabrication and not support services reduce risk more than having all deliveries from Chips, Inc. go to one American Services location (to hide internal operations)?
 - Does an agreement on a security measure for encryption, storage, retention, and destruction to prevent IP loss reduce risk more than monitoring of Chips, Inc. for financial and leadership changes?

Why are Supply Chains a DHS Issue?

- Other components of DHS involved with the supply chain are:
 - FEMA (supplies for emergency)
 - CBP (checking imports for violations and to collect duty)
 - Coast Guard (checking for smuggling, illegal supplies)
 - Secret Service (countering COVID-related crime)
 - Office of Health Affairs (effect of disease on the supply chain)

Why are Supply Chains a DHS Issue?

- Daniel Gerstein (former DHS Under Secretary (Acting) and Deputy Under Secretary in the Science & Technology Directorate): *We need to treat supply chains as a national security issue and need to develop a strategic national supply chain approach.*
- Gerstein: Our “just in time” delivery systems have been designed to optimize costs through prediction and minimizing inventories, but they lack resiliency in times of crisis.
 - 95% of companies will be impacted by COVID-19 and only 56% had a plan to address supply disruption from China, a source of many of the key active pharmaceutical ingredients.

Daniel Gerstein



Homeland
Security

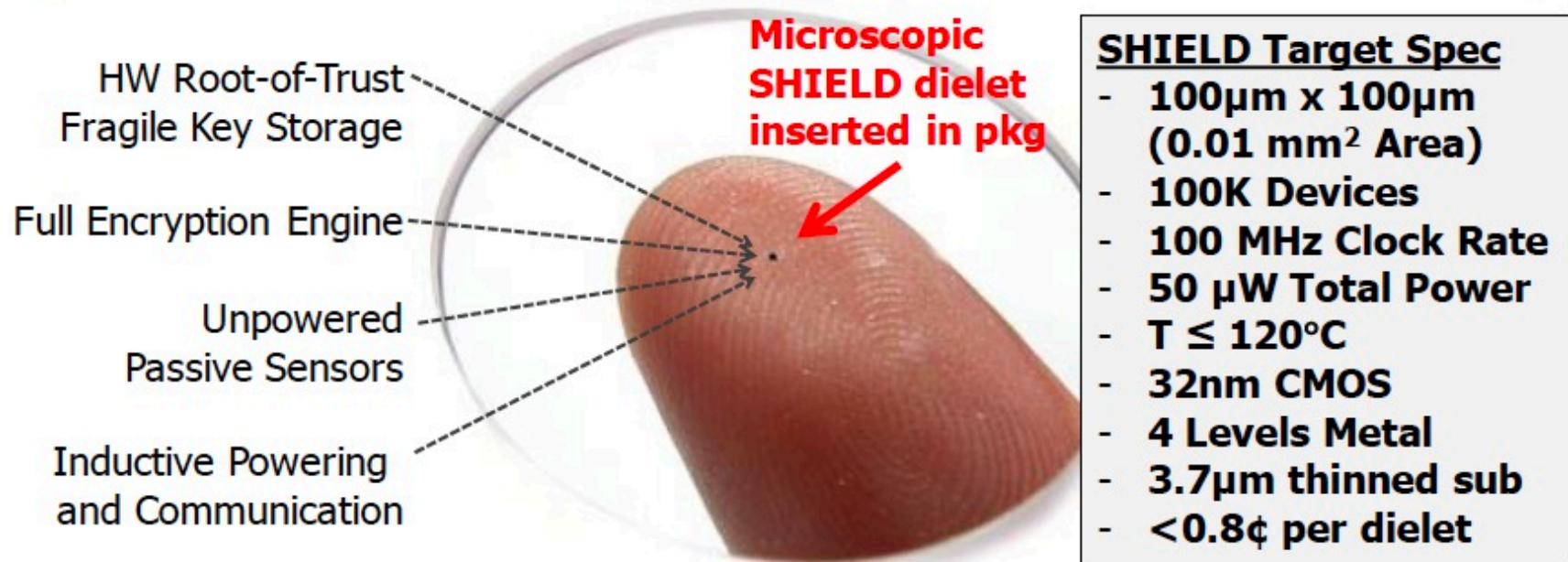
Why are Supply Chains a DHS Issue?

- Gerstein calls for the development of a methodology to:
 - Improve current supply chain visibility
 - Determine appropriate balance between efficiency and resilience
 - Develop principles, strategies, policies, and regulations for supply chains
 - Establish and validate the algorithms that will guide the supply chains
 - Model new risks and costs (network flow models or time series forecasting)
 - Improve situational awareness through use of advanced capabilities
 - Technology: Internet of Things, artificial intelligence, robotics, and 5G

Toward Solving Some Supply Chain Challenges: Identifying Counterfeit



SHIELD: The DARPA Supply Chain Solution



DARPA SHIELD will develop the ability to provide:

- 100% assurance against certain known threat modes;
- quickly, on demand, at any step of the supply chain; and
- essentially for *free*.

SHIELD makes counterfeiting too expensive and too hard to do.

Toward Solving Some Supply Chain Challenges: Identifying Counterfeit



Fab of Origin (ClearMark, Chromologic, IC Forensics)

- Fab-of-Origin looks for fab-signatures to identify origin of a component
- Idiosyncrasies associated with fab-specific tooling, recipe, sequence
- Needed to trace DoD, non-DoD clones and counterfeits to originating foundry (Smart Grid, Cyber Systems, Communications, etc...)

MTO SBIR SB133-03: Fab of Origin



Once SHIELD determines a chip to be a counterfeit, Fab-of-Origin will provide the insight needed to identify where it was made.

Toward Solving Some Supply Chain Challenges: Identifying Counterfeit

Fake drugs are a serious health risk globally



Interpol estimates about **one million people die each year from fake medicine**. Millions more get sick.



The counterfeit pharmaceutical industry is worth more than **\$75 billion annually** and producing and trading fake medicine is, reportedly **10 to 25 times more profitable than trafficking narcotics** (World Health Org.)



The anti-counterfeiting and piracy coordinator of the World Customs Organization, Christophe Zimmermann, stated there may now be “**more fakes than real drugs in the market**”.



The pharma industry **loses \$200B of gross revenues** to counterfeits – money that would otherwise reduce the cost of healthcare and increase R&D funding for new medicines.

Slide courtesy of Viswanath Narayan

Real and Fake Lipitor

Credit: FDA, Wikimedia commons



Toward Solving Some Supply Chain Challenges: Identifying Counterfeit

Ingredients Found In Counterfeit Medicines



Toward Solving Some Supply Chain Challenges: Identifying Counterfeit

- Consider packaging.
- Compare to an authentic sample for:
 - Print quality
 - Spacing and spelling
 - Differences in font style
 - Correct colors in the artwork
 - Correct size and shape of the packaging
 - Quality of packaging material
- Similarly with labeling on the pills themselves
- Now, moving to machine learning to be able to spot irregularities

Toward Solving Some Supply Chain Challenges: Identifying Counterfeit



- The authentic capsule is on the right.
 - Light blue packaging is wrong shade
 - No print on capsule body
 - Font is of a different type

Toward Solving Some Supply Chain Challenges: Information Sharing

- Information sharing is a key to enable organizations and individuals to work together while protecting their private information.
- Example: *Blockchain* is a decentralized recordkeeping system that enables disparate parties to transact safely without needing a middleman.
 - *A blockchain is a digital record of transactions.*
 - Individual records (*blocks*) are linked together in single list (*a chain*). Each transaction added to a blockchain is validated by multiple computers.
- Example: You would like to track your supplies at every stage of the supply chain, but not share your private information with other companies.
- Analogy with the vin number of a car. Every time it is sold, that vin number goes with it and so you can trace all transactions.

Information Sharing: MediLedger

- The FDA (Federal Drug Administration) put forward Drug Supply Chain Security Act (DSCSA) requirements related to the interoperable, electronic tracing of products at the package level that go into effect in 2023.
- MediLedger was designed to pilot an approach to this for prescription drugs, using blockchain.



Information Sharing: MediLedger

MediLedger FDA Pilot Report - Published February, 2020

Cross-industry effort to evaluate blockchain as a solution to DSCSA 2023 track and trace requirements

Manufacturers



Wholesalers



Dispensers

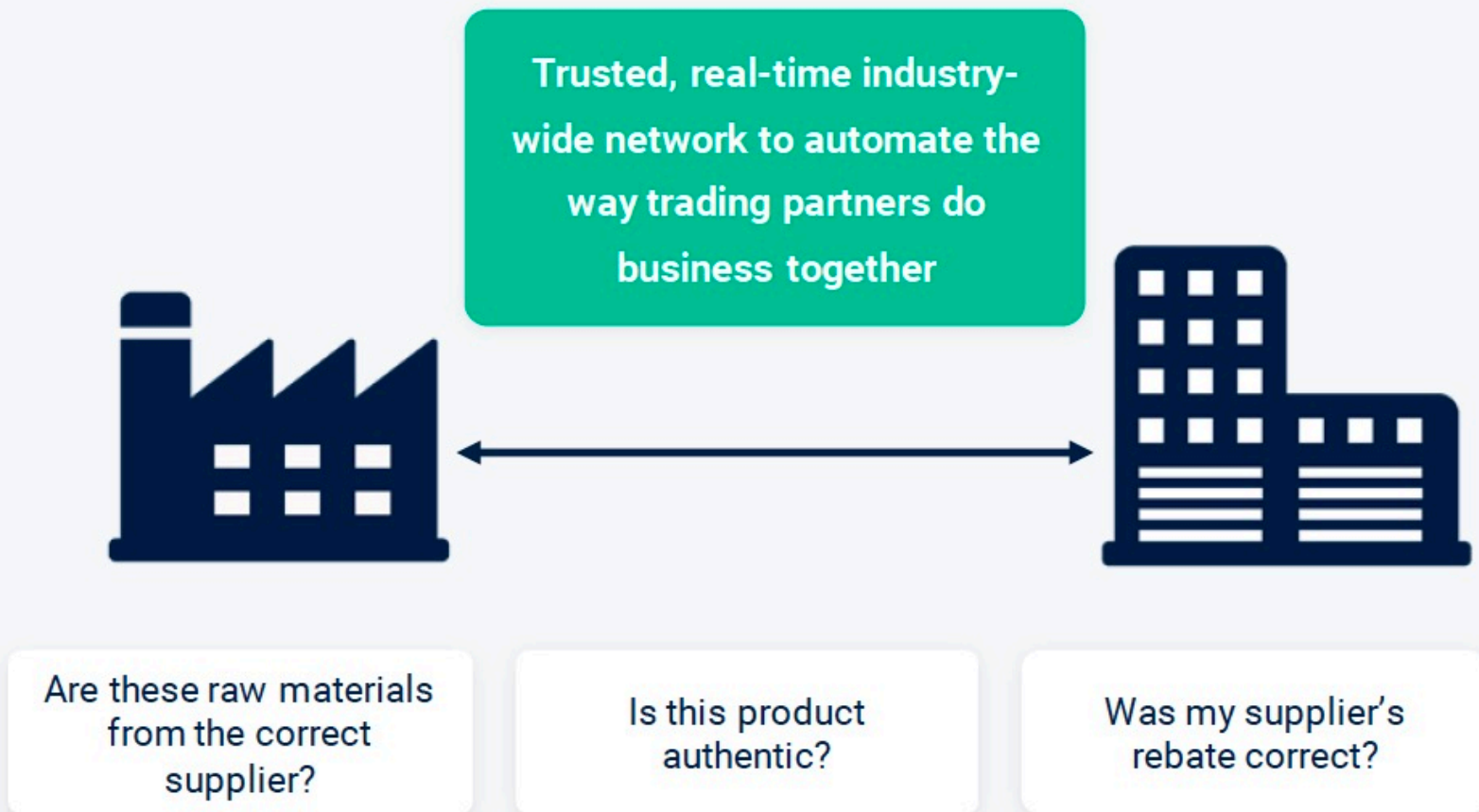


Others



Information Sharing: MediLedger

MediLedger Basics



Information Sharing: MediLedger

- MediLedger traces transactions, e.g., from manufacturer to wholesaler to dispenser and backwards with returns.
- By being able to track all of the transactions, one can hopefully defend against pharmaceutical fraud.
- MediLedger uses serialized data exchanges for prescription drugs using a blockchain/ledger-based system.
- Blockchain allows each player to maintain privacy over their private data while sharing information in a secure way.
- Proof of every update/transaction is published to blockchain.
- The pilot of MediLedger showed that business rules for each transaction can be enforced by blockchain smart contracts in real time while keeping each company's data 100% private.

Toward Solving Some Supply Chain Challenges: Stockpiles

- One way to prepare for an emergency or a shortage is to stockpile goods or components you might need.
- FEMA has an emergency stockpile of goods for emergencies:
 - Water, food, fuel, chainsaws
- There is a national strategic stockpile for medicines.
- Should companies have stockpiles too?
- There are many challenging research questions about stockpiles.



Credit: Wikimedia commons, [Nick Gray](#),



Credit: cdc.gov

Strategic Stockpile for Medicines

Toward Solving Some Supply Chain Challenges: Stockpiles

- Stockpile Questions

- How big should they be?
- What should be in them?
- Where do you locate them?
- Things spoil – how often do you replenish them?

Shipment of PPE
from Strategic
National Stockpile



- Special issues for pharma: API have longer shelf life than the drugs they constitute; once a drug is dosed, the expiration clock starts ticking toward the expiration date

- Distribution strategies

- What triggers distribution?
- How do you prioritize who gets what in case of shortages?

- How best to share information about what is in stockpiles

- Between federal government agencies
- Between federal and state government
- Incentives for information sharing

credit: National Guard, flickr

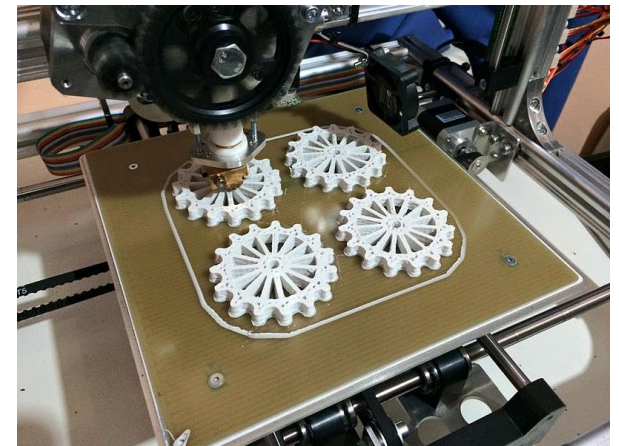
- 45 – Government incentives for private sector stockpiling?

Toward Solving Some Supply Chain Challenges: Stockpiles

- *FEMA has come to realize that sometimes it is better to utilize contracts with the private sector for stockpile items.*
- For instance, stockpiled water or food gets out of date.
- So do stockpiled masks and protective gowns – as we discovered during COVID.
- Large companies like Walmart usually move lots of water, food, etc. through regularly.
 - Rather than stockpile large quantities of such items, can FEMA make contracts with companies to provide certain amounts at a given price should there be an emergency?

Toward Solving Some Supply Chain Challenges: 3-D Printing

- 3-D Printing or Additive Manufacturing
 - During disaster: supply chain costs rise, resources are in short supply, and time is of the essence.
 - 3D printing can be used to make supplies more cheaply and faster.
 - A promising concept. May be more efficient than storing things.
 - **3D printing** is the process of using electronic data to make a three-dimensional object by depositing material successively, similar to 2D printing.
 - *Instead of maintaining an inventory of parts, the material used to print these parts can be stored and the parts can be printed rapidly as needed.*
- During COVID, FDA explored 3D printing of PPE (masks, gowns, etc.)
 - 3D-printed PPE may provide a physical barrier, but 3D-printed PPE are unlikely to provide the same fluid barrier and air filtration protection as FDA-cleared surgical masks and N95 respirators.



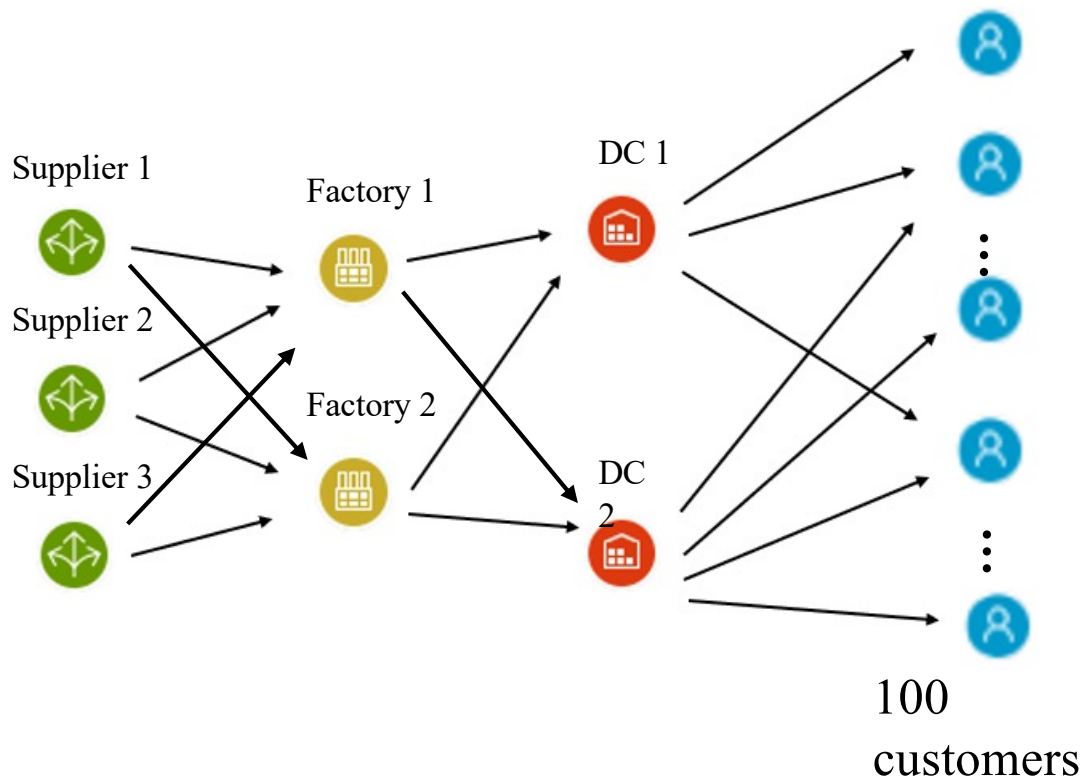
Toward Solving Some Supply Chain Challenges: Defense Production Act

- ***Defense Production Act (DPA)***: The primary source of presidential authority to expedite and expand the supply of materials and services from the U.S. industrial base needed to promote the national defense.
- Utilized by agencies such as FEMA
- Allows the president to:
 - Direct private companies to prioritize orders from the federal government.
 - Allocate materials, services, and facilities for national defense purposes
 - Bolster domestic production through loans/loan guarantees to companies
 - Install equipment in government or private factories
 - Authorize companies to coordinate with each other, which might otherwise violate antitrust laws
- The Biden administration has identified use of the DPA to fill 12 supply gaps, including in masks, gloves, and testing swabs, and to expand the Strategic National Stockpile.

Toward Solving Some Supply Chain Challenges: Technology

- Technologies such as artificial intelligence and machine learning are partly responsible for the supply chain problems during COVID.
- But they are also part of the solution (e.g., in identifying cases of counterfeit).
- Other relevant technologies include:
 - Blockchain, trustmarks
 - Optimization
 - Decision trees
 - Time series forecasting
 - Network flow modeling
 - Mathematical modeling and simulation
- Hopefully they can contribute to making supply chains more resilient.

Example: Building and Simulating a Hypothetical Supply Chain Network

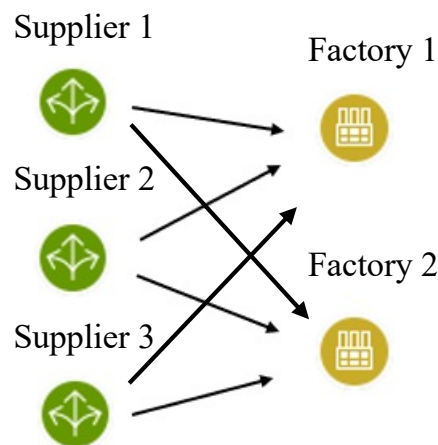


- Four-tier supply chain network
- Model built in AnyLogistix
- Suppliers provide parts to factories
- Factories assemble the parts into the final product: laptop

	Location	Part
Supplier 1	California	Screen, Keyboard
Supplier 2	Florida	Keyboard, Motherboard, Battery
Supplier 3	Texas	Motherboard, Battery, Laptop base

Parts Flow: Suppliers → Factories

- Factories assemble the parts into the final product: laptop
- Only laptops move forward to the Distribution Centers
- Factories have the RQ inventory policy (fixed replenishment quantity policy)

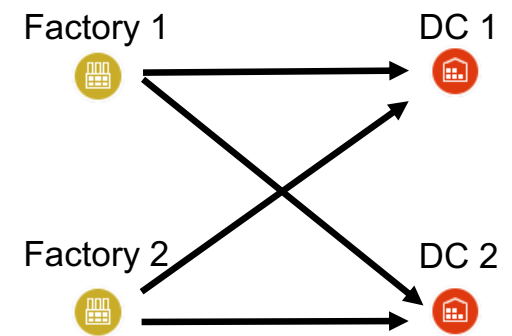


Factory 1	
Screen	100% from Supplier 1
Keyboard	50% from Supplier 1 50% from Supplier 2
Motherboard	62.5% from Supplier 2 37.5% from Supplier 3
Battery	100% from Supplier 2
Laptop base	100% from Supplier 3

Factory 2	
Screen	100% from Supplier 1
Keyboard	33.3% from Supplier 1 66.7% from Supplier 2
Motherboard	33.3% from Supplier 2 66.7% from Supplier 3
Battery	16.7% from Supplier 2 83.3% from Supplier 3
Laptop base	100% from Supplier 3

Parts Flow: Factories → Distribution Centers → Customers

- The final product is assembled in the factories and shipped to the distribution centers.
- Table shows the percentage of product shipped from each factory to each distribution center.
- DCs have the RQ inventory policy (fixed replenishment quantity policy).
- Customer has periodic demand
 - Order interval = 1 day
 - Demand quantity: Uniform (1,3)
- Demand is fulfilled by the nearest DC.



Distribution Center	Finished product supplied	
	Factory1	Factory2
DC1	50%	50%
DC2	40%	60%

Threat Scenarios

- Local natural disaster will shut down the factory.

Node	Factory 1
Location	Iowa
Disaster	Earthquake
Time Period	6/1/20 – 11/30/20
Severity levels	[1, 2, 3]
Probability (%)	[50%, 30%, 20%]

Node	Factory 2
Location	North Carolina
Disaster	Hurricane
Time Period	6/1/20 – 11/30/20
Severity levels	[1, 2, 3]
Probability (%)	[50%, 30%, 20%]

- Three severity levels

Hazard Severity	Low (1)	Medium (2)	High (3)
Impact duration (days)	30	45	60

Simulation Models

- ✓ Multiple threats
- ✓ Countermeasures
- ✓ Probabilistic input values
- ✓ Logical metrics

Sr No	Name	Details
1	Baseline	No risk event occurs
2	Threat + no countermeasures	Risk occurs but no countermeasures
3	Threat + countermeasure 1	Production capacity of remaining factory becomes 1.5 times
4	Threat + countermeasure 2	Outsourcing factory with 0.5 times production capacity supplies products

- **Threat + no countermeasures** model should keep the supply chain afloat because multi-sourcing policy is enabled. Therefore, the remaining factory which is still operating should provide to both DCs.
- We could classify **Threat + no countermeasures** as a **PASSIVE** model.

5 replications of the Baseline model are simulated to ensure that the policies chosen can maintain 100% service level during normal operating conditions without any threats

5 replications of all 4 models are simulated

Each replication period is 1 year long, for the year 2020, with 2 threats occurring in that year.

Threat + countermeasure 1 & Threat + countermeasure 2 are **ACTIVE** models as opposed to **Threat + no countermeasures**

Performance Measures

- We compare the models (**Threat + CM1**) and (**Threat + CM2**) with (**Threat + no CM**).
- Performance metrics:
 - 1) **Mean Delivery Time**
 - 2) **Total Time to Recovery (TTR)** – total amount of time the supply chain was running below the specified *Failure Service Level*
 - 3) **ELT Service Level by Product** – ratio of products delivered on time to the overall number of products shipped
 - 4) **Service Level by Product** – ratio of products in successfully fulfilled orders to the sum of products in all orders placed for a facility

Results

*Average values from 5 replications are shown

	Mean Delivery Time		TTR
	DC1	DC2	
Threat + CM1	0.8047	1.0146	5.4
Threat + CM2	0.8047	1.0101	2.2

365-day average			
ELT Service L.		Service Level	
DC1	DC2	DC1	DC2
1	0.9979	0.9999	0.9918
1	0.9959	1	0.9941

Threat period average			
ELT Service L.		Service Level	
DC1	DC2	DC1	DC2
1	0.9874	0.9993	0.9514
1	0.9758	1	0.9660

- **Mean Delivery Time** and **Total Time to Recovery (TTR)** metrics alone are **NOT** the best indicator of performance.
- Both of these metrics should be used along with **ELT Service Level** and **Service Level** to gauge the effectiveness of a countermeasure.

Keeping **Mean Delivery Time**, **TTR**, and **Threat Period Averages** in mind, **Threat + CM2** is a better countermeasure.

For all 3 models, the metrics do not show a significant difference in performance of DC1. This is because DC1 serves fewer customers than DC2, therefore its inventory lasts longer and service levels are higher.

- Therefore, let's observe only DC2 for gauging the countermeasures.
- **The countermeasures do increase the performance of the DC2.**

Taking the average over **threat period** shows the **actual increment** in performance due to these countermeasures.

- **Threat + CM1** results in a higher **ELT Service Level** for DC2.
- **Threat + CM2** results in a higher **Service Level** for DC2.

- **ELT Service Level** – ratio of products delivered on time to the overall number of products shipped
- **Service Level** – ratio of products in successfully fulfilled orders to the sum of products in all orders placed for a facility

Questions?

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