Rethinking the Design of the WHO-EPI Vaccine Distribution Chain

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Background

Immunization programs worldwide (over the last 40+ years of EPI and 15+ years of GAVI):

The good news:

- Huge reductions in vaccine-preventable disease occurrences

The not-so-good news:

- We still have millions of deaths annually from vaccine-preventable diseases

Background

Something to think about:

- Steady expansion in the WHO-EPI suite of vaccines with new vaccines being regularly introduced
- Many technological advances in vaccine cold chain technology
  - Storage devices
  - Temperature monitoring
  - Cold transport
  - Et cetera
- Improvements to infrastructure
- More global awareness

BUT

- The structure of the vaccine supply chain is essentially unchanged!

Distribution (cold) chain

Clearly, the essential link between procurement and delivery. It must…

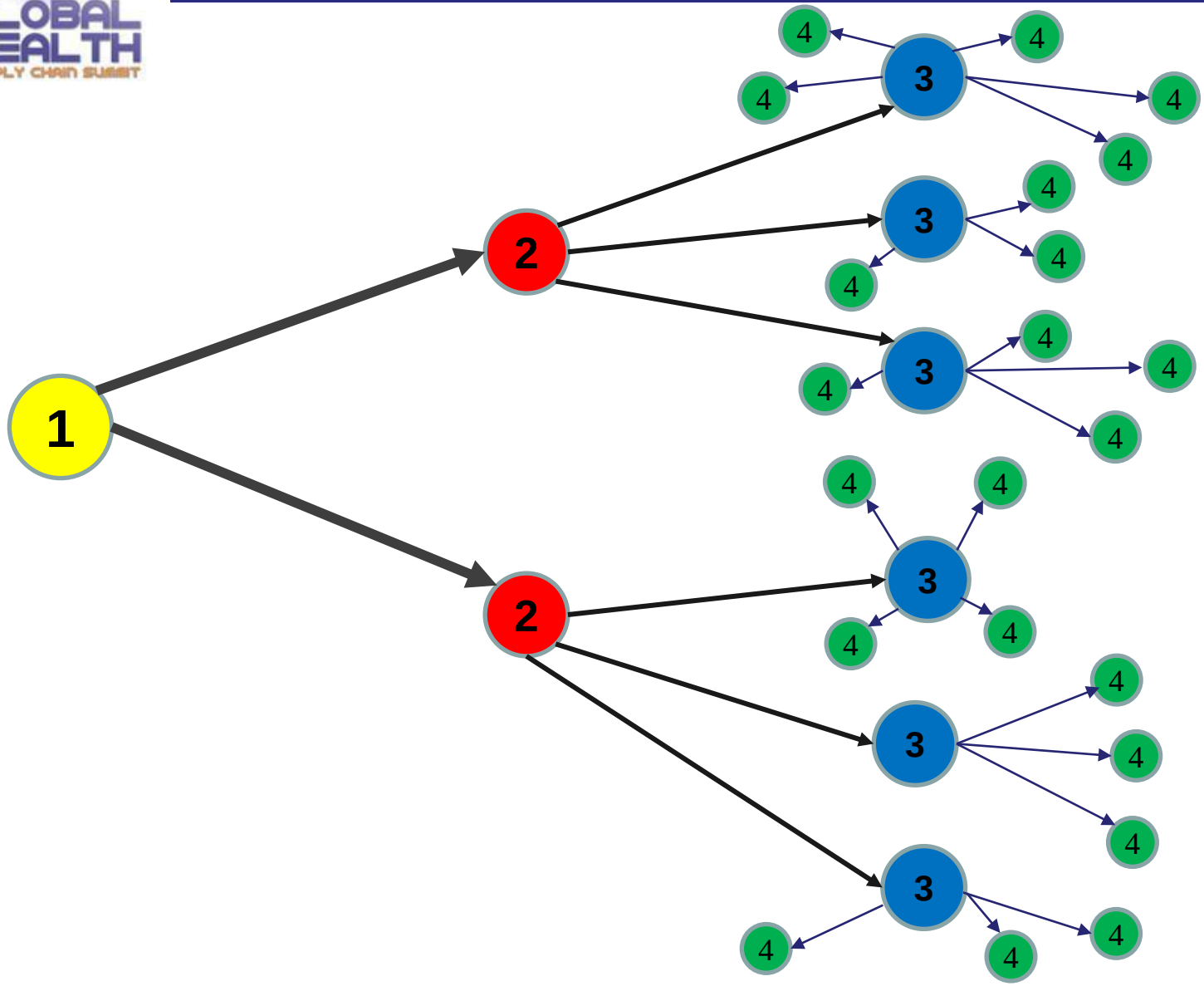
- …move vaccines from central store to final points of delivery
  - Remote locations
  - Progressively poorer infrastructure as we move down the chain
- …while keeping vaccines in correct temperature range (2-8 °C)
- …and dealing with uncertain demand, inadequate resources, unreliable equipment and infrastructure, shortages of trained personnel, wasted vaccine, etc., etc., etc.

Distribution chain

The vast majority have the same, very typical structure:

- Four levels (occasionally three or five…)
- Hierarchical structure
- Arborescent flow of vaccines
- Often, identical storage/transport by level
- Often identical vaccine replenishment frequencies (by level)
- Supplemented by outreach (of a mostly *ad hoc* nature)

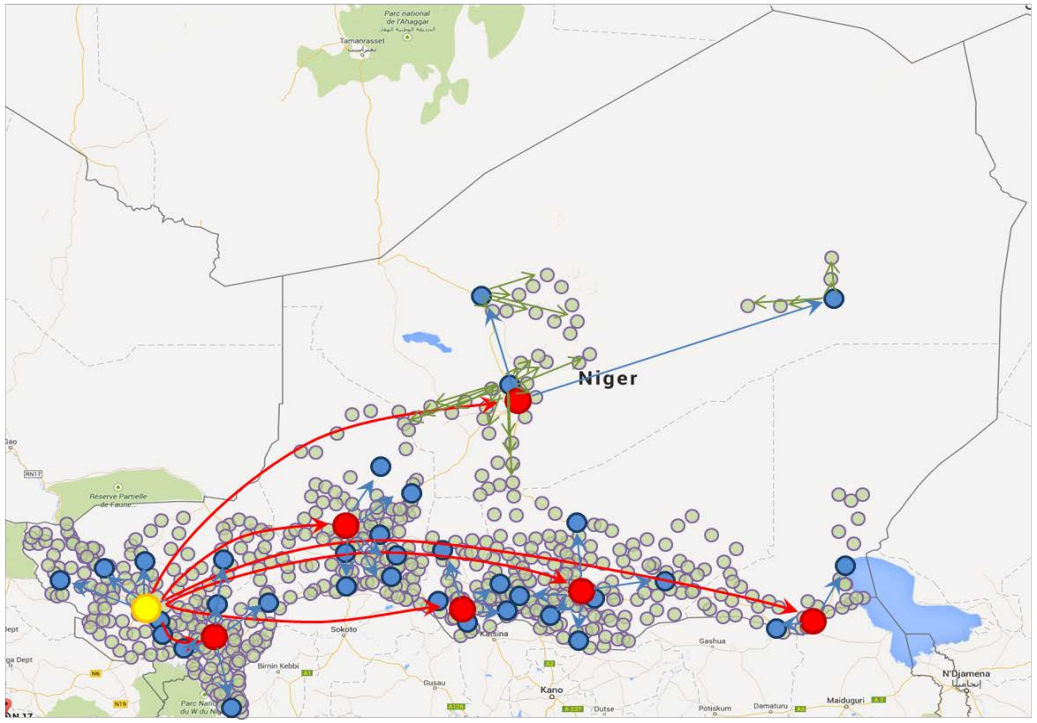
Hierarchical, arborescent flows



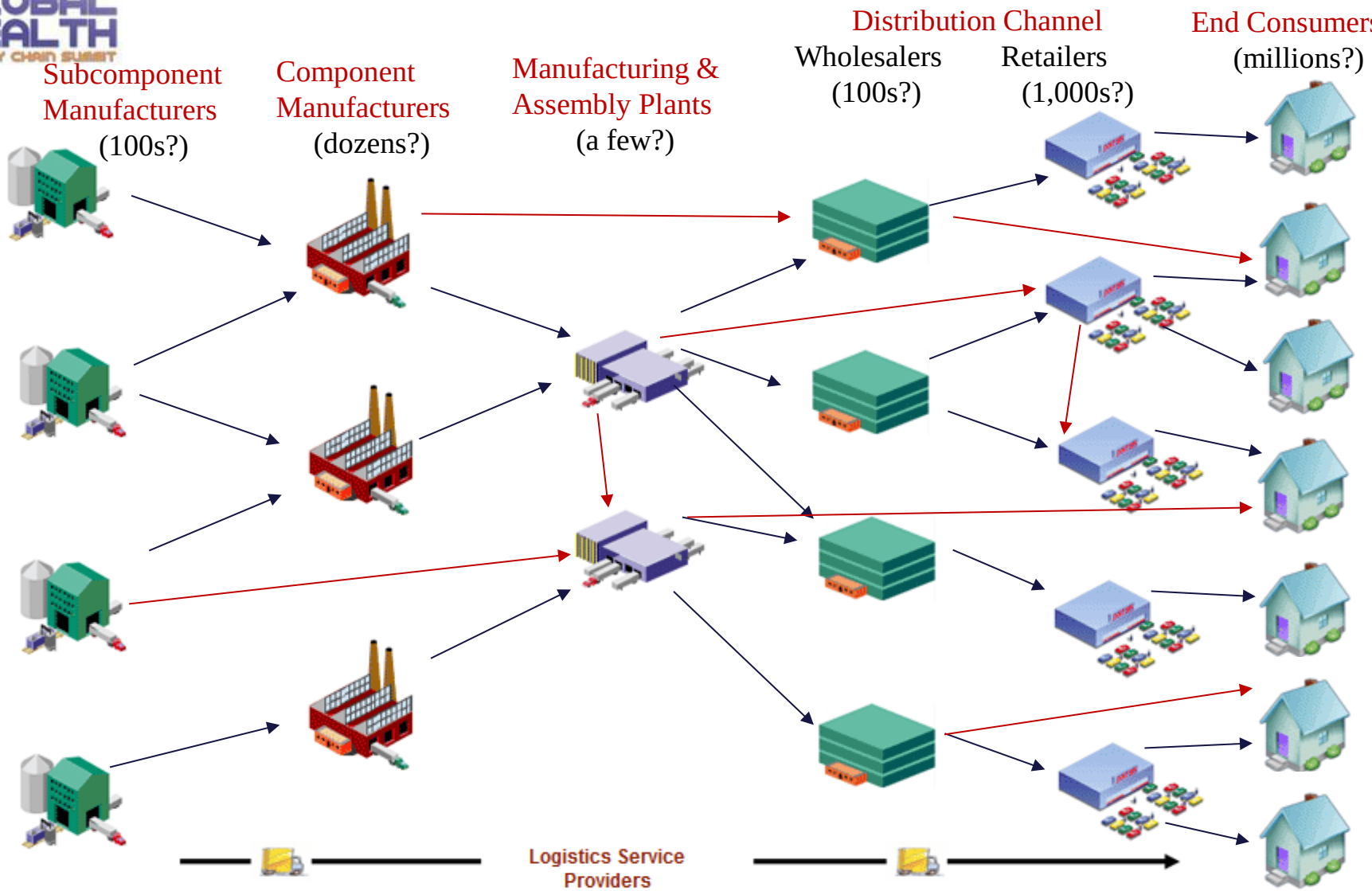
An example: Niger

- Four tier hierarchical network

Central	
Regional	
District	
IHC	



Traditional supply chains



Adapted from careersinsupplychain.org

Questions of interest

- Should we be rigid about this overall structure of the distribution chain?
- Can we do better by adapting the structure to the characteristics of a specific country?
- Can the benefits of flexibility outweigh the benefits of standardization?
- How about outreach and its role within the structure?

Current distribution dtructure

	Kenya	Niger	Benin	Chad
	1 Central	1 Central	1 Central	1 Central
	9 Province	8 Regions	7 Departments	21 Regions
	132 Districts	42 Districts	80 Communes	60 Districts
	2733 Health Centers	695 IHCs	658 Health Posts	851 Health Centers
Area	581,309 km^2	1,267,000 km^2	114,763 km^2	1,284,000 km^2
Population (2014 from world bank)	44,863,583	19,113,728	10,598,482	13,587,053

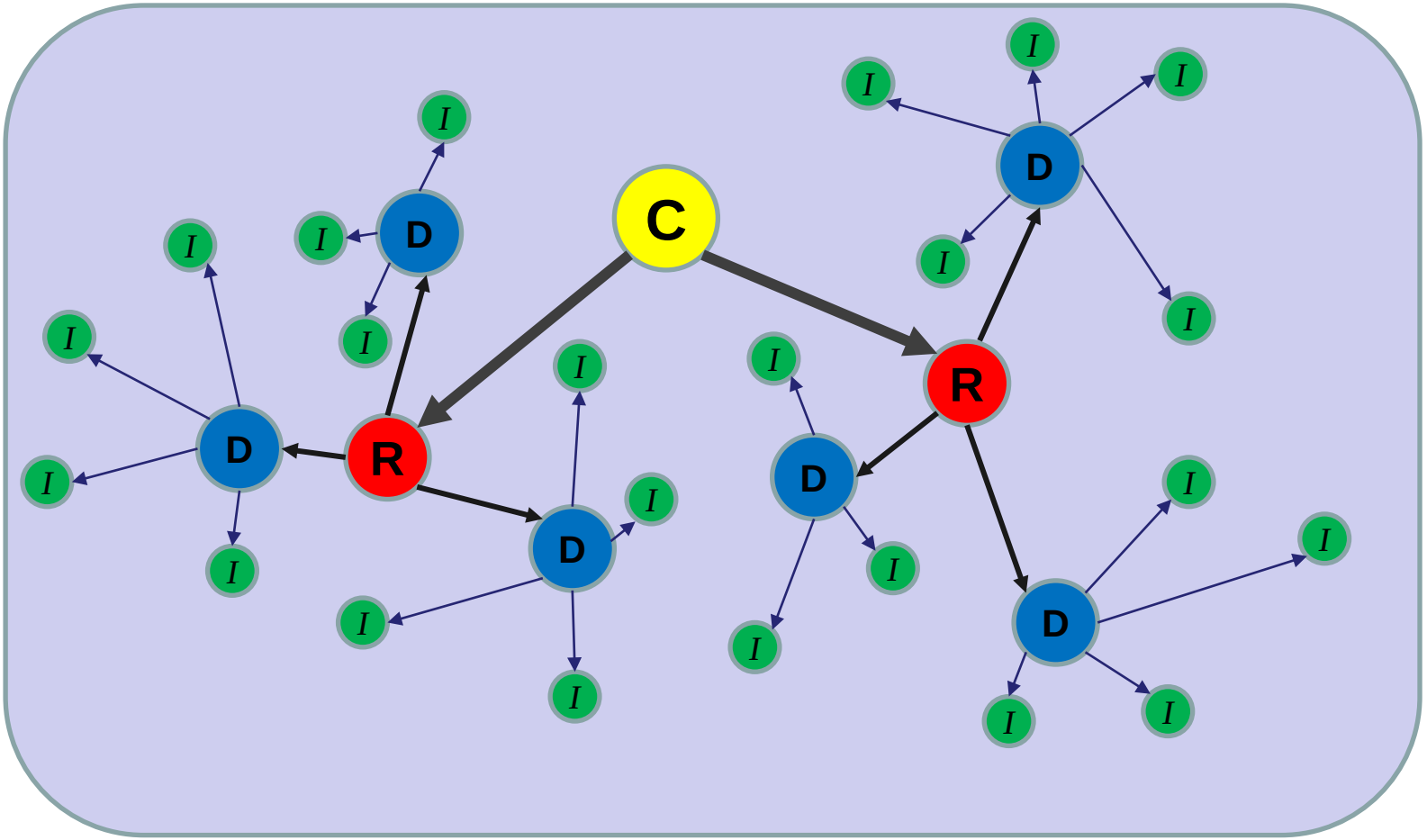
Prior Work

- Approach: Computer simulation (*HERMES*)
- Assi et al., *Vaccine*, 2013
  - Go from 4 to 3 levels (Niger)
  - Significant improvement in vaccine availability as long as transportation policies are also suitably modified
- Brown et al., *Vaccine*, 2014
  - Redesigned structure and shipping loops needed to ensure availability after new vaccine introduction (Benin)
- Lee et al., *Vaccine*, 2015
  - Segmenting chains for 57 countries and simulating simplified structures for some examples

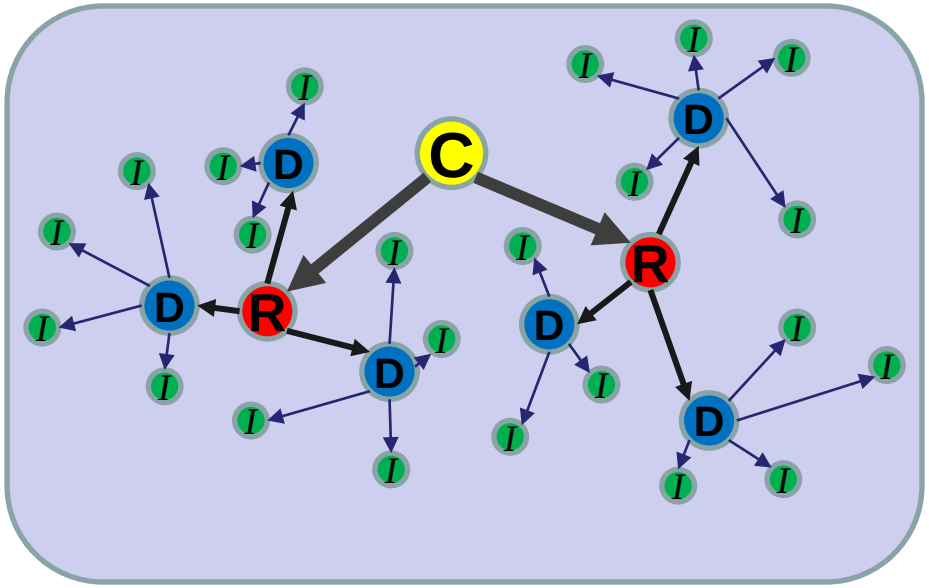
Alternatives

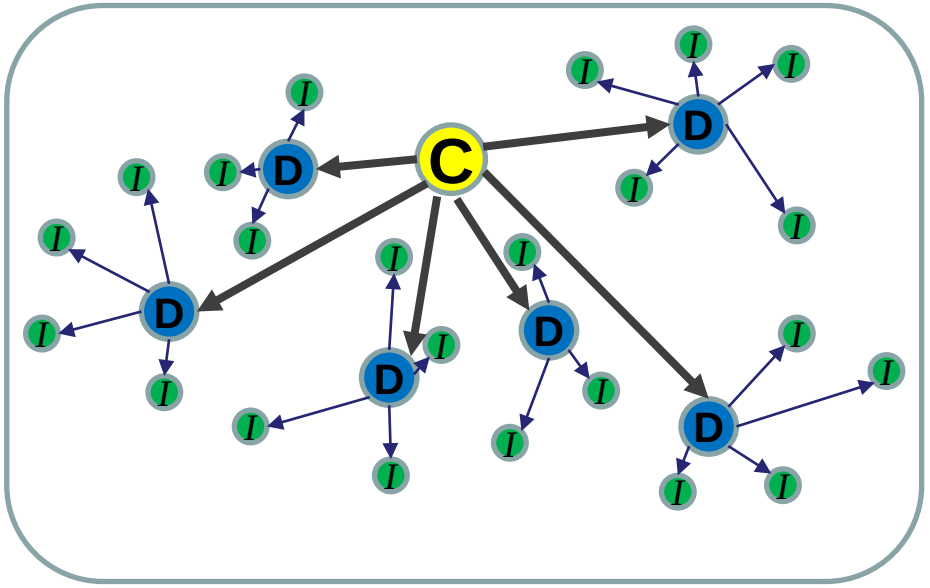
- Vaccines are typically distributed through a legacy medical supply chain
  - Locations and connection have typically been determined based on political boundaries or an existing administrative hierarchy
- Cold supply chain
  - Can the vaccine supply chain be separated from the medical supply chain?
- Redesign the vaccine supply chain for efficiency
  - Mathematical modeling

For example...

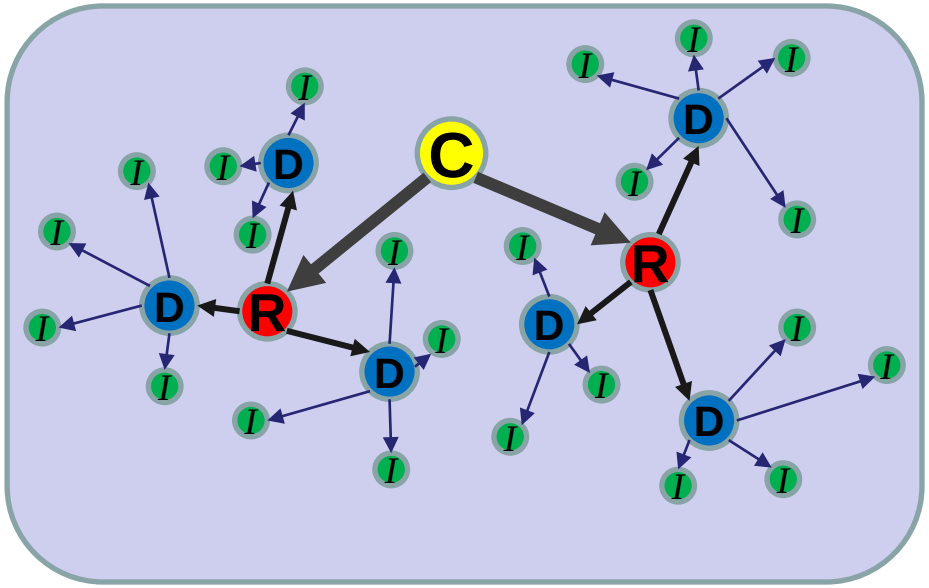


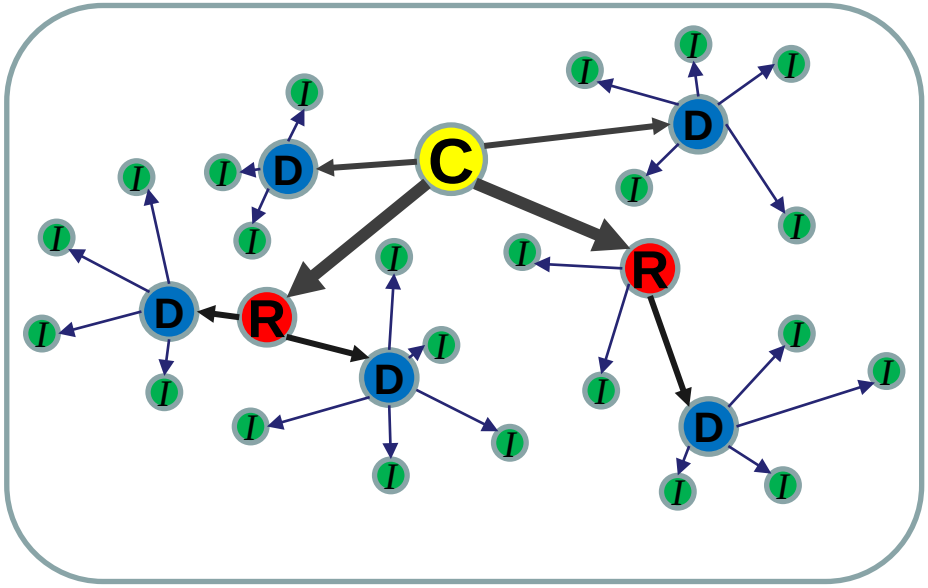
Level removed



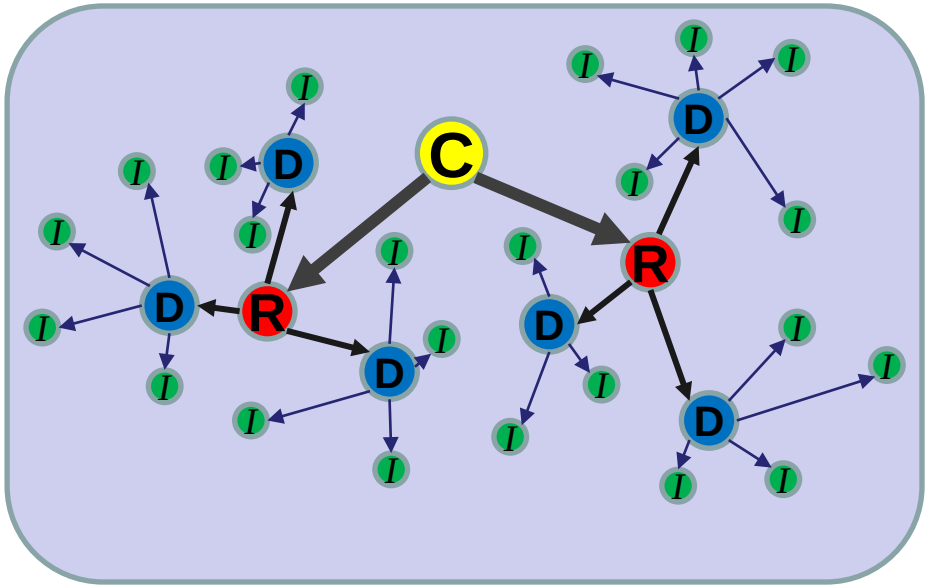


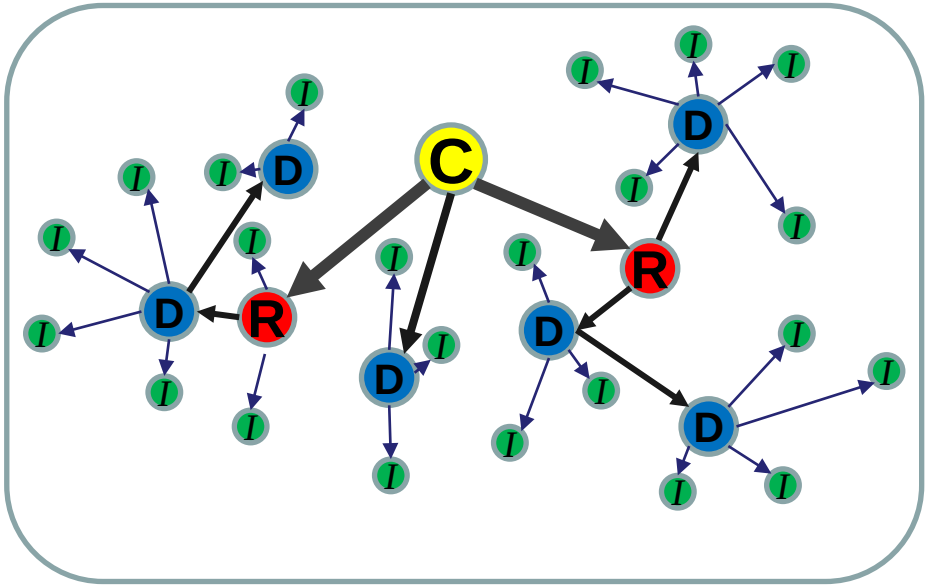
Non-hierarchical flows





Lateral flows





Proposed approach

- Mathematical framework to optimize how an EPI vaccine distribution network is designed
  - Mixed Integer Programming Model
- Considerations
  - Facility costs – labor, building
  - Cold storage: costs and capacities
  - Transportation: costs and capacities
  - Replenishment frequencies
  - Travel distances between locations
  - Shipping loops

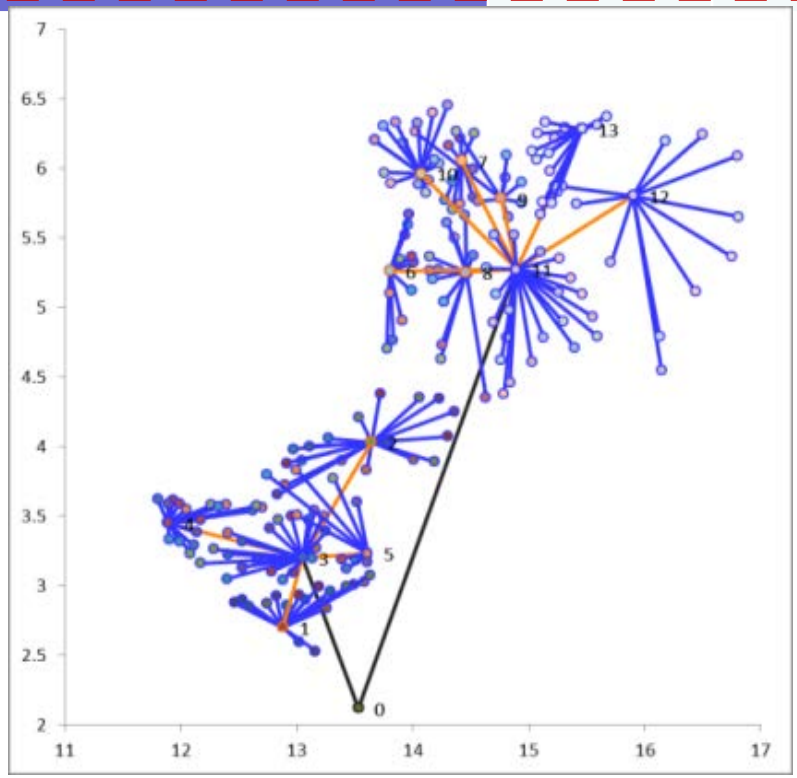
Goal

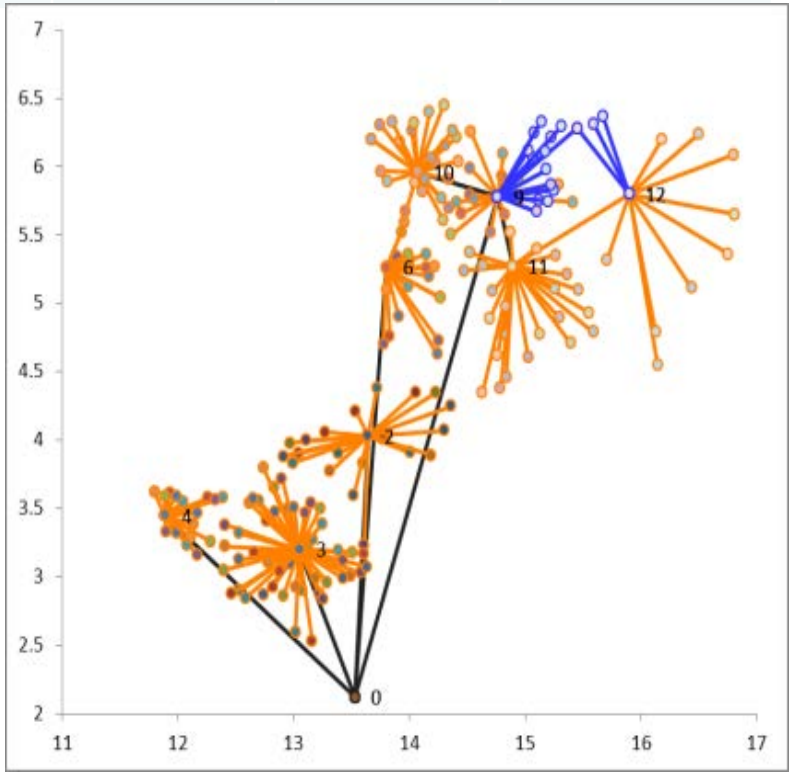
Main goal is to obtain insights on redesigned structures - it's a MODEL not an exact depiction of reality!

- How many levels?
- Skipping levels, i.e., non hierarchical flows?
- Lateral shipments; i.e., non-arborescent flows?
- Differing replenishment frequencies?
- What is the best storage/transport device by location?

Numerical example – Niger (2 Regions)

Network	Total cost	Transportation cost	Storage cost	Facility cost	Computation time
Original Network	**961,014**	394,852	293,862	272,300	
Optimized Network	**605,193**	135,107	237,286	232,800	**196 hours**





Further numerical examples

	Niger (2 regions)	Benin (1 region)	Kenya (1 region)	Chad (3 regions)
Original Network	961,014	158,330	771,290	294,739
Optimized Network	605,193	142,543	593,326	213,422

Conclusions

- Standardization is simpler, but flexibility has its benefits
- Network redesign has the potential to significantly reduce vaccine supply chain operating costs and improve vaccine availability

Further research

- Better solution methodologies
- Applying a looping factor
  - Current assumption is a point to point travel between two facilities, but a cold truck can visit several facilities in one route
    - Decreases travel distance and cost and affects network structure
- Conduct sensitivity analysis
  - With respect to cost elements and demand
- Incorporate outreach into the design

Acknowledgment

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