Introduction to Vaccine Supply Chains:
A Systems Approach & Systems Modeling

TVEE
TEACHING VACCINE
ECONOMICS EVERYWHERE

Module Objectives

1. Identify each of the components of a vaccine supply chain
2. Understand the complexities of the supply chain and how each component interacts with each other
3. Describe common vaccine supply chain system issues
4. Identify and assess the critical efficiency and costs measures of a vaccine supply chain's health
5. Understand the benefit of modeling in assessing the vaccine supply chain system, and testing changes to the system

What is a complex system, anyway? Examples?

Examples of complex systems

Transportation systems

Ecological systems

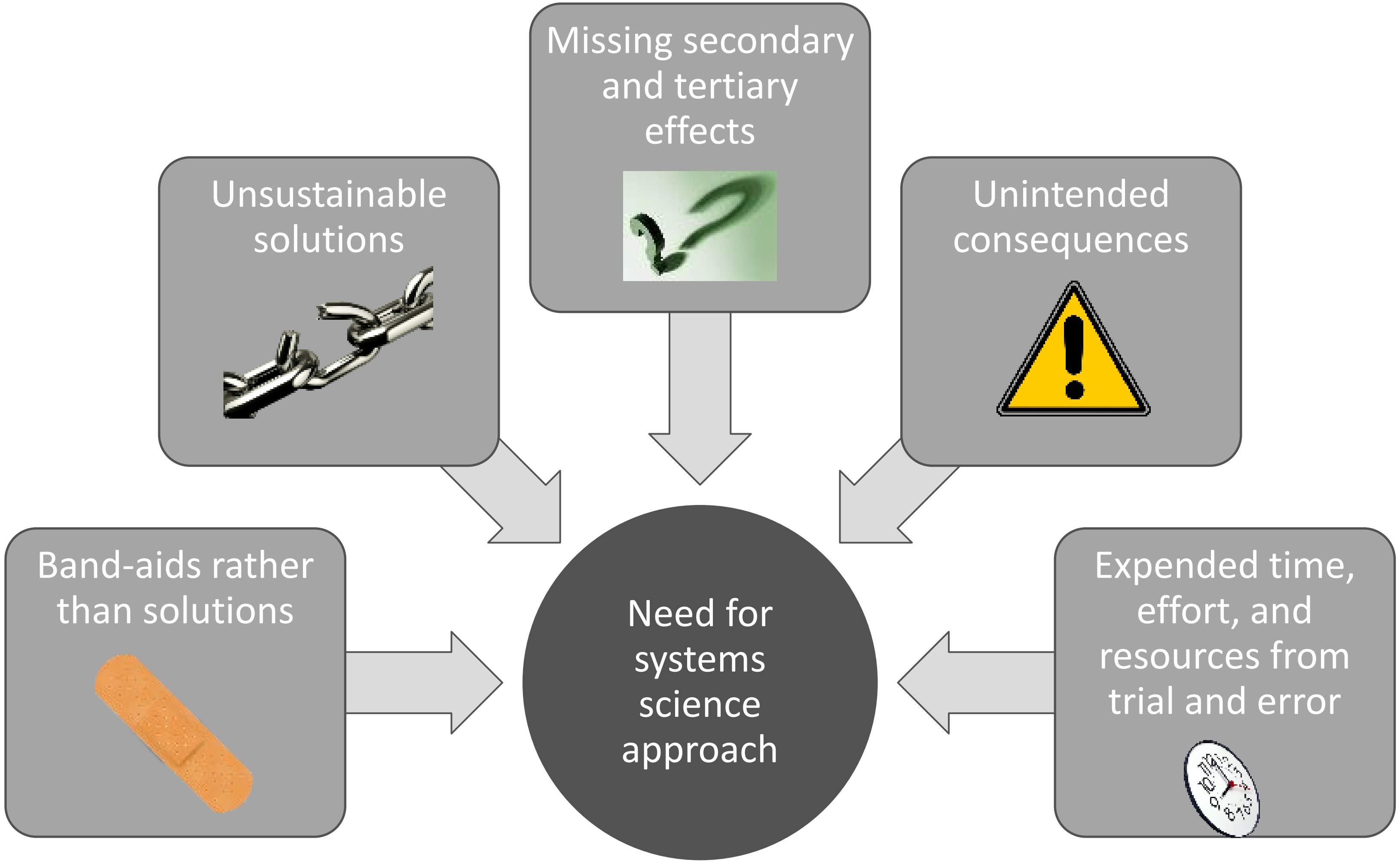
Manufacturing systems

Meteorological systems

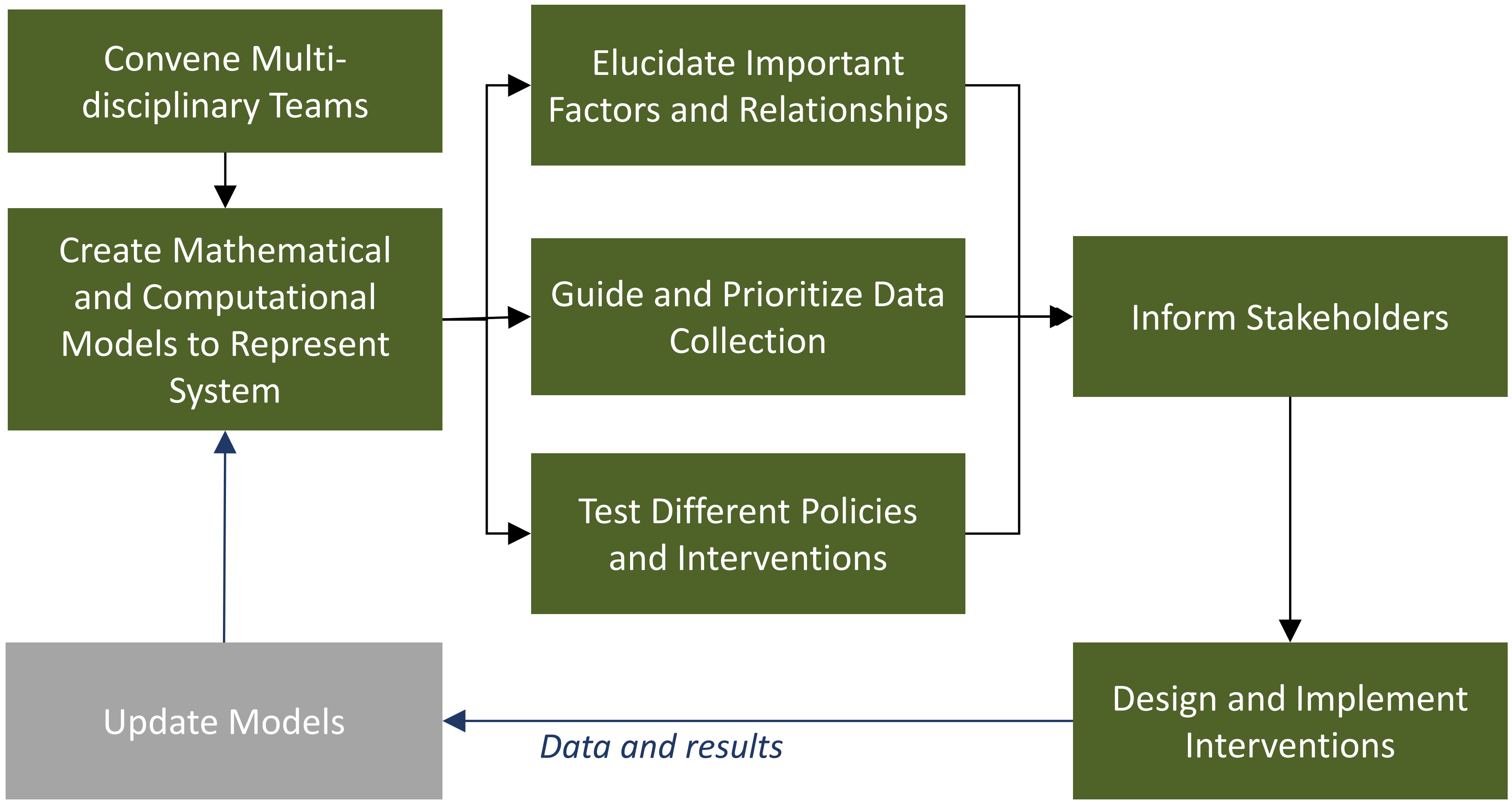
Financial systems

Aerospace systems

Why do we need a systems approach?



What is a systems approach?



Why focus on the supply chain?

Forbes

Are Vaccines Getting To Where They Need To Go?

Bruce Y. Lee, CONTRIBUTOR

I cover the intersection of business, health and public health. FULL BI

Opinions expressed by Forbes Contributors are their own.

Health Affairs

By Judith R. Kaufmann, Roger Miller, and James Cheyne

DOI: 10.1377/hlthaff.2011.0368
HEALTH AFFAIRS 30,
NO. 6 (2011): 1113–1121

ANALYSIS & COMMENTARY

Vaccine Supply Chains Need To Be Better Funded And Strengthened, Or Lives Will Be At Risk

ELSEVIER

Contents lists available at ScienceDirect

Vaccine

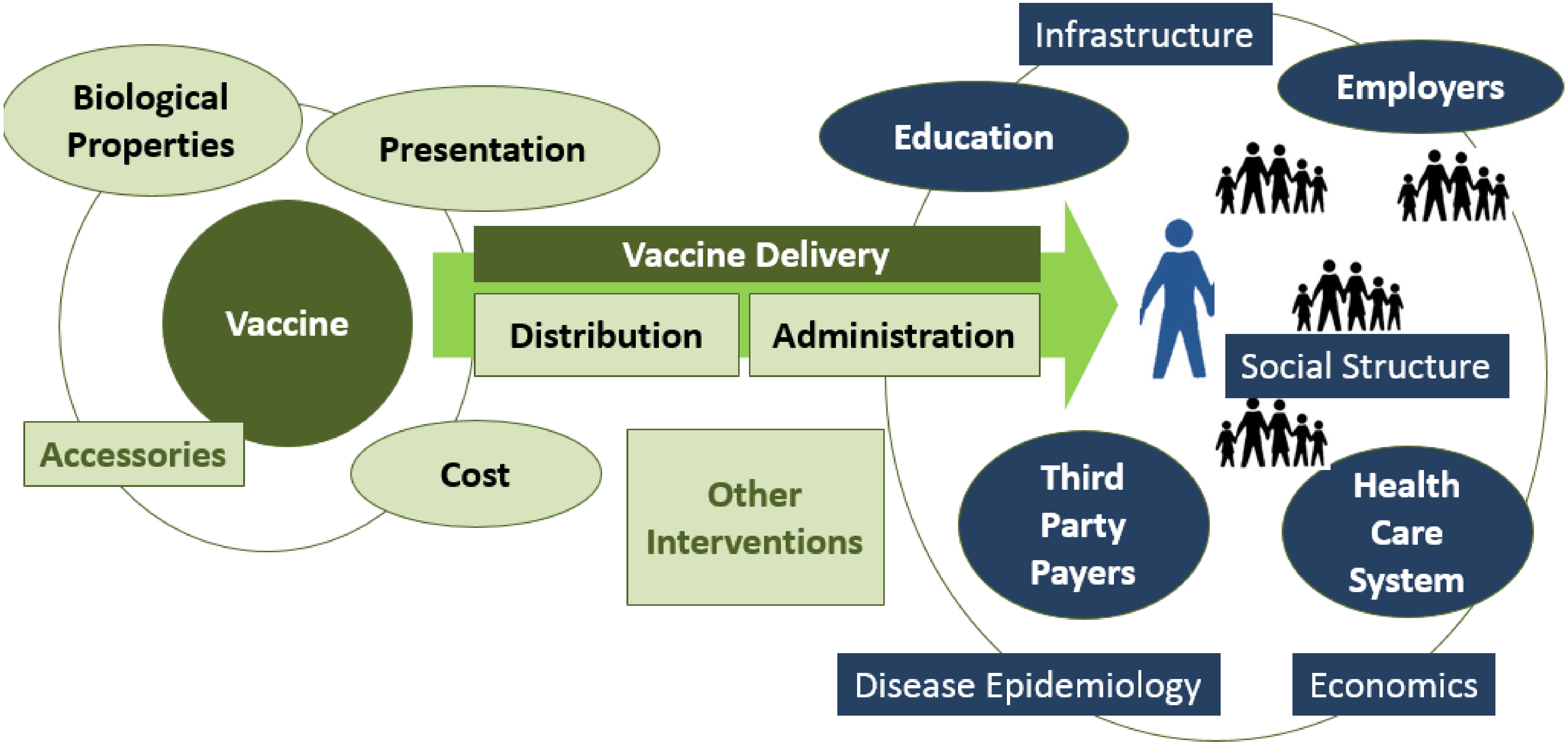
journal homepage: www.elsevier.com/locate/vaccine

Editorial

No product, no program: The critical role of supply chains in closing the immunization gap ☆

CrossMark

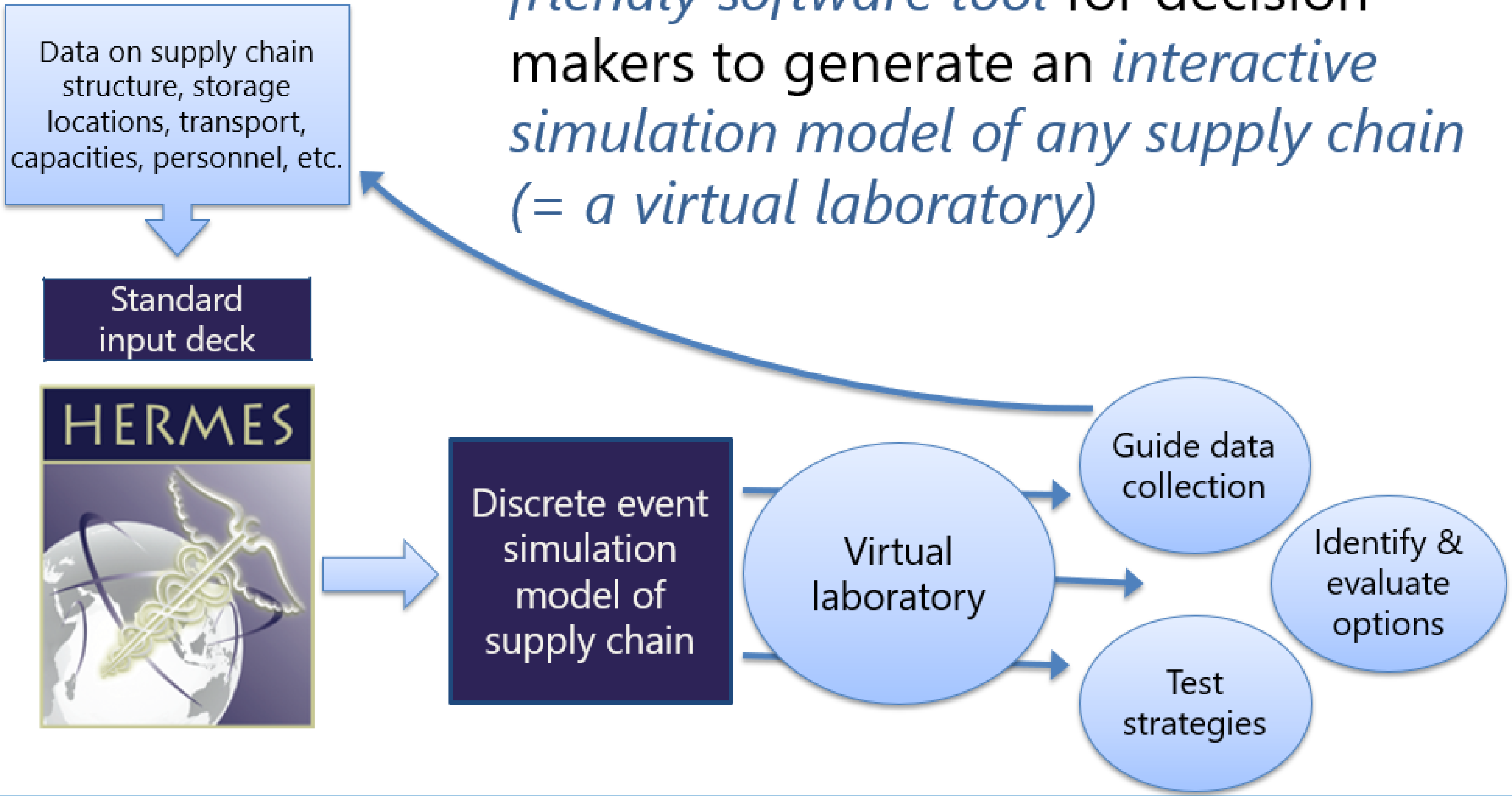
Vaccine delivery is a complex system



HERMES is a Systems Modeling Tool for Decision Support

HERMES vision

Create a *freely available* and *user-friendly software tool* for decision makers to generate an *interactive simulation model of any supply chain (= a virtual laboratory)*



Hands-on Learning Using Systems Modeling

1 Creating a New Vaccine Supply Chain Model

2 Running Your New Model & Viewing Results

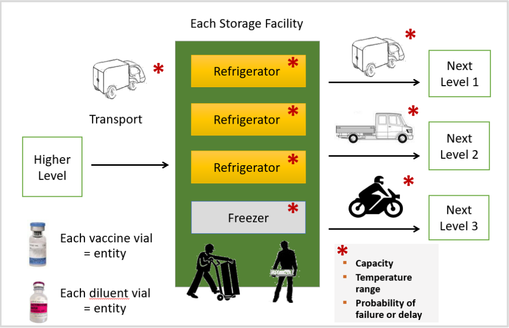
3 Introducing or Changing Vaccines

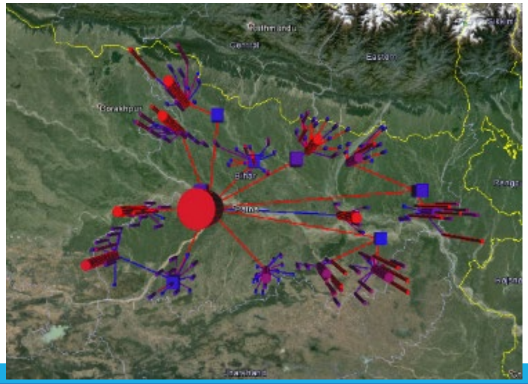
4 Adding, Removing, and Changing Storage Devices

5 Removing a Level From the Supply Chain

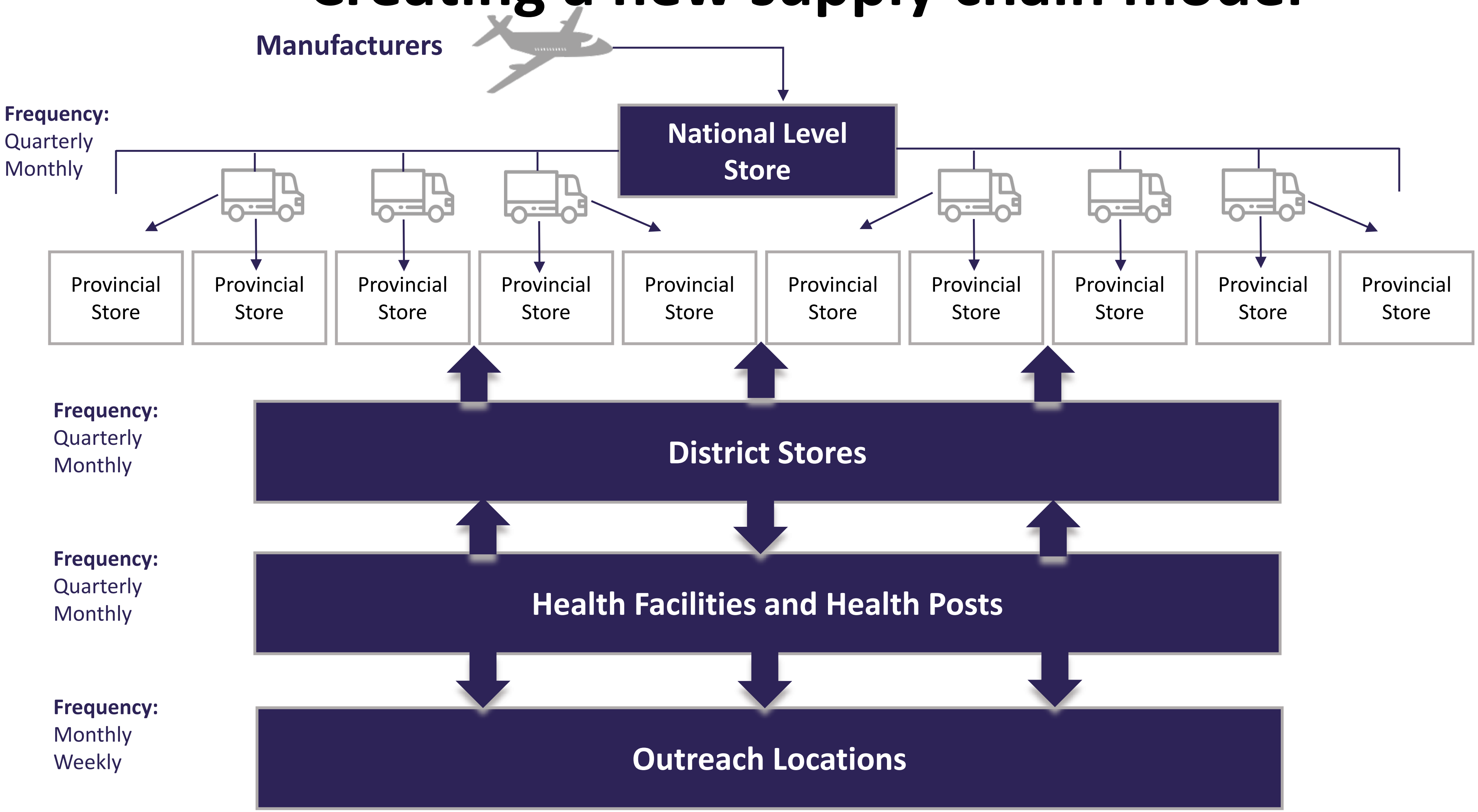
6 Modifying Transport Characteristics by Level

7 Introducing Transport Loops

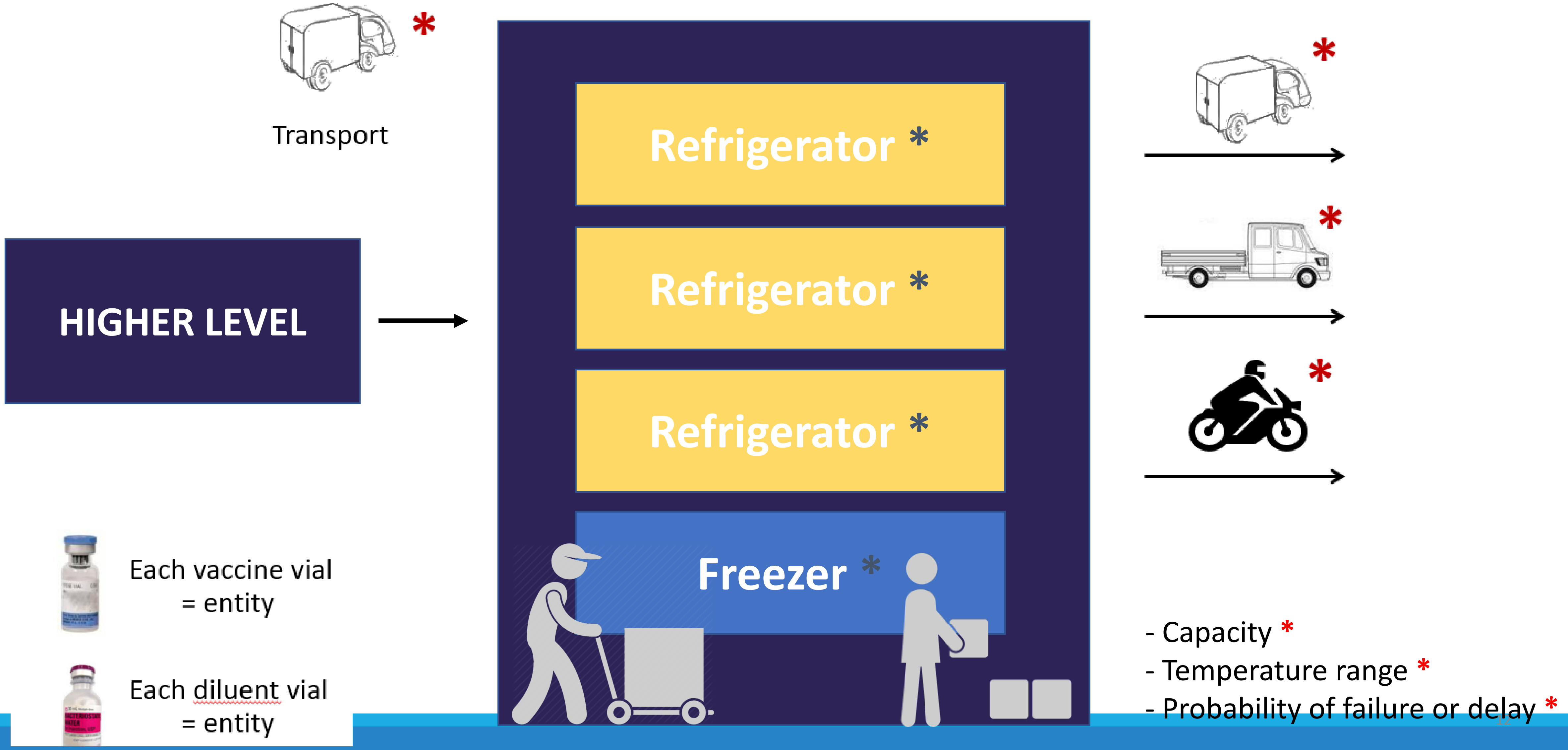




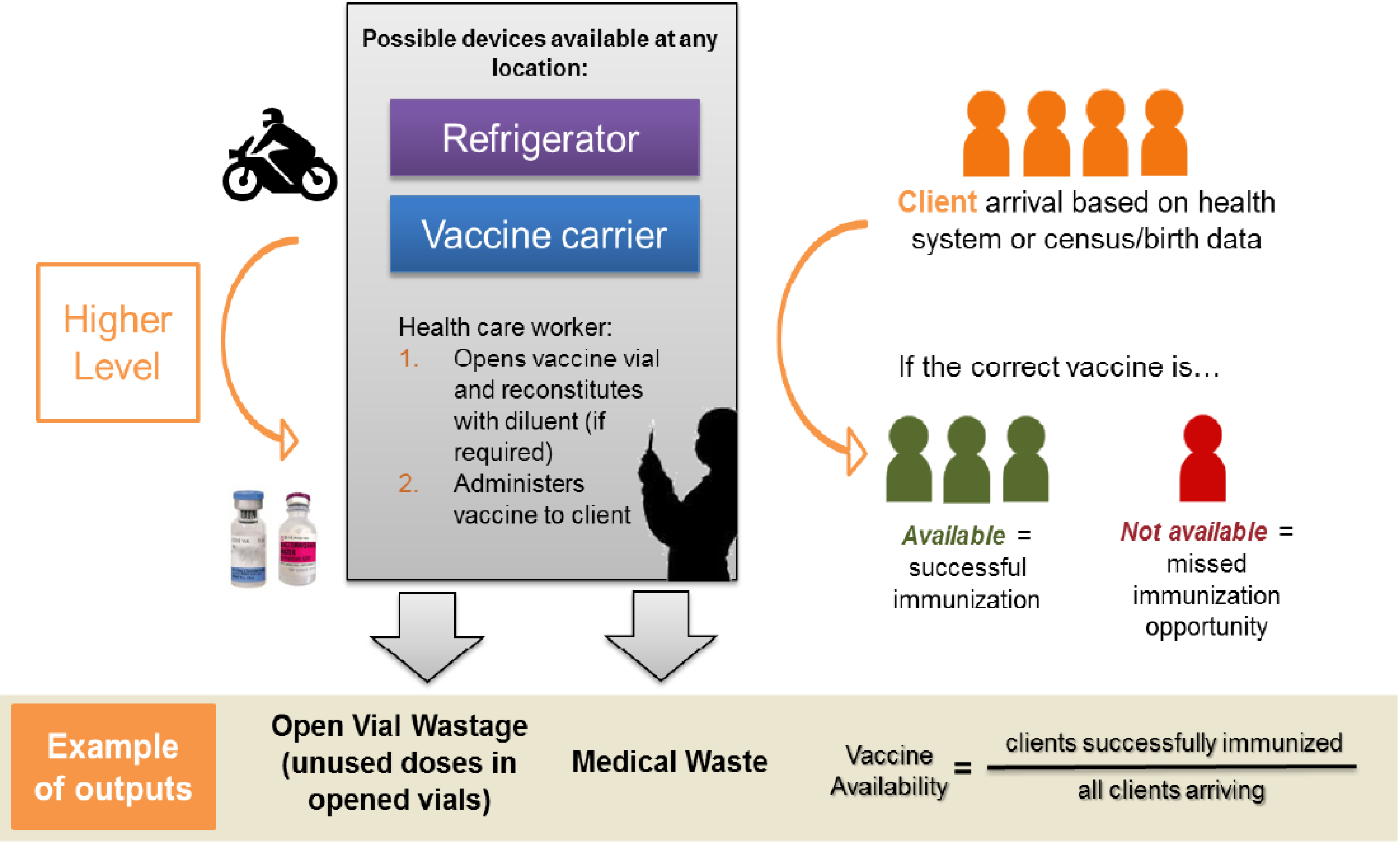
Creating a new supply chain model



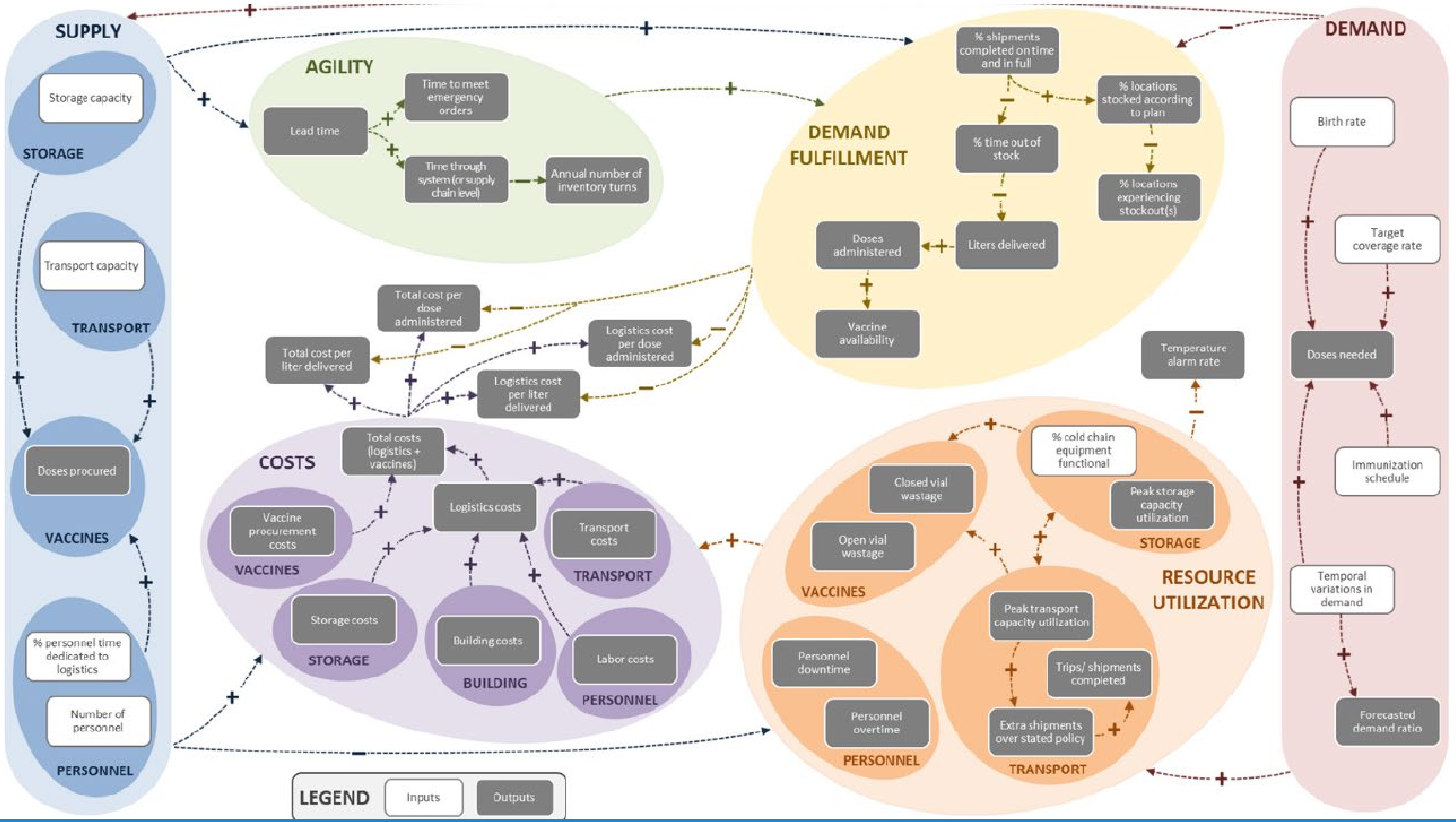
ating a new supply chain model



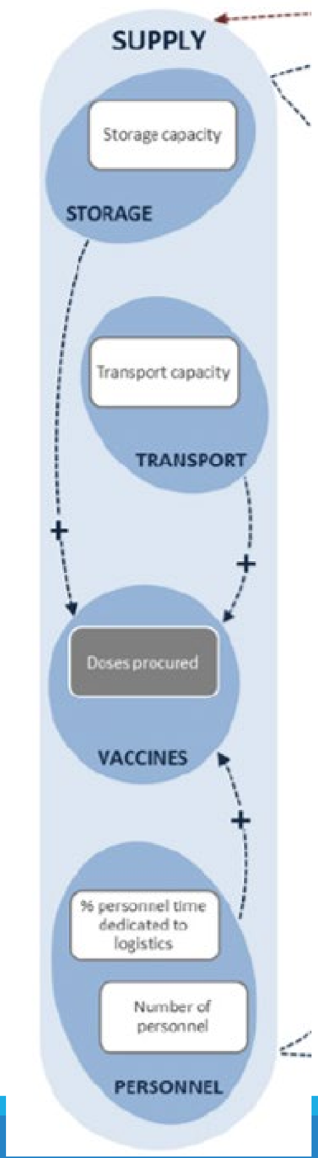
Creating a new supply chain model



Map of Different Vaccine Supply Chain Efficiency Measures



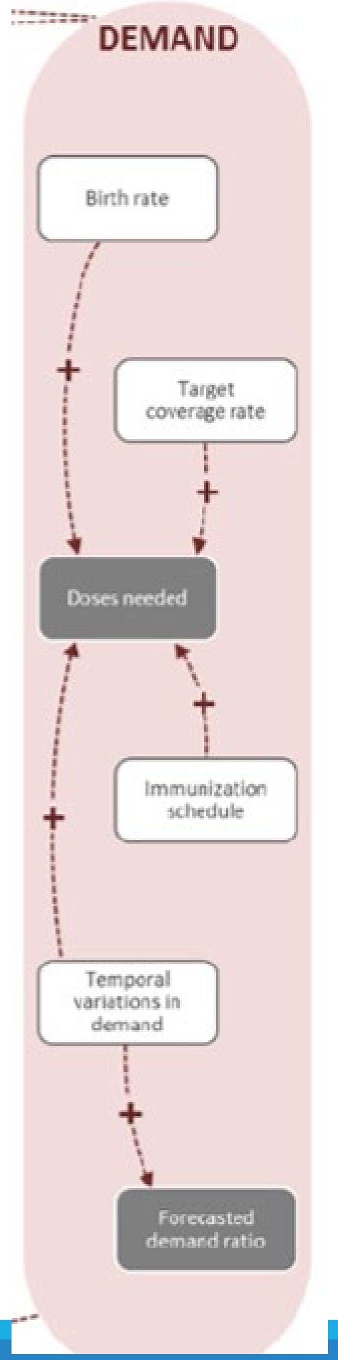
Supply Measures



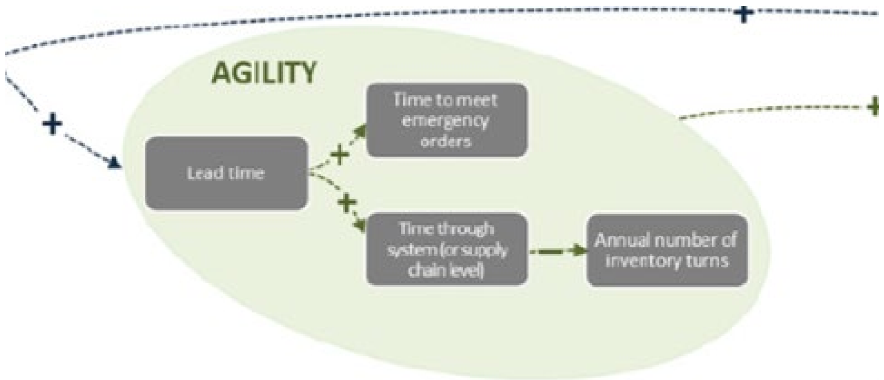
- **Storage capacity:** net storage space available for holding vaccines in their required storage conditions at a location or set of locations
- **Transport capacity:** net vehicle space available for holding vaccines in their required storage conditions on a route or set of routes
- **Doses procured:** vaccine doses purchased and brought into the a system in a given time period
- **Number of personnel:** staff members working in vaccine supply chain logistics at a location or set of locations in the supply chain
- **% of personnel time dedicated to logistics**: proportion of staff members' normal working hours spent on supply chain logistics

Demand Measures

- **Birth rate:** Live births per thousand persons in a population in a given year
- **Temporal variations in demand:** Periodic changes in the rate at which people arrive at immunizing locations seeking vaccines
- **Immunization schedule:** number and time of the full set of vaccine doses in a routine immunization program
- **Target coverage rate:** proportion of needed immunizations a system attempts to provide
- **Doses needed:** vaccine doses that need to be administered to a population in order to achieve a target coverage rate
- **Forecasted demand ratio:** ratio of actual consumption of one or more products in a given time period compared to the forecasted consumption



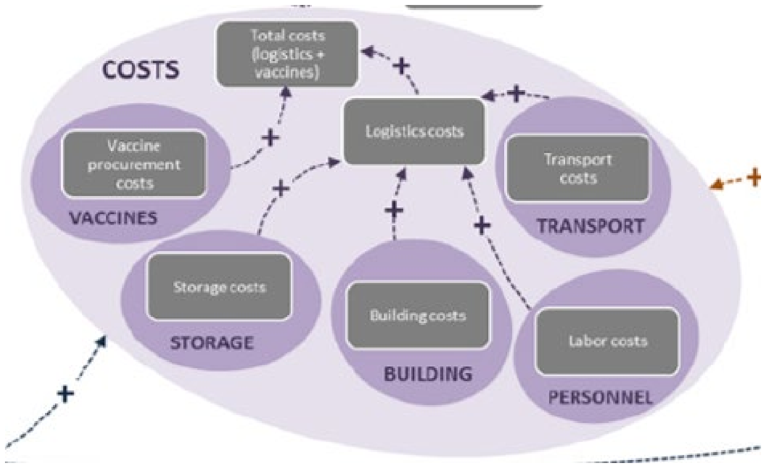
Agility Measures



- **Lead time**: average number of days from the time a shipment is ordered to the time it is received
- **Time to meet emergency orders**: average number of days from the time an emergency shipment is ordered to the time it is received
- **Time through system (or supply chain level):** average number of days products spend in storage or transport
- **Annual number of inventory turns**: annual vials consumed or wasted / average number of vials in inventory

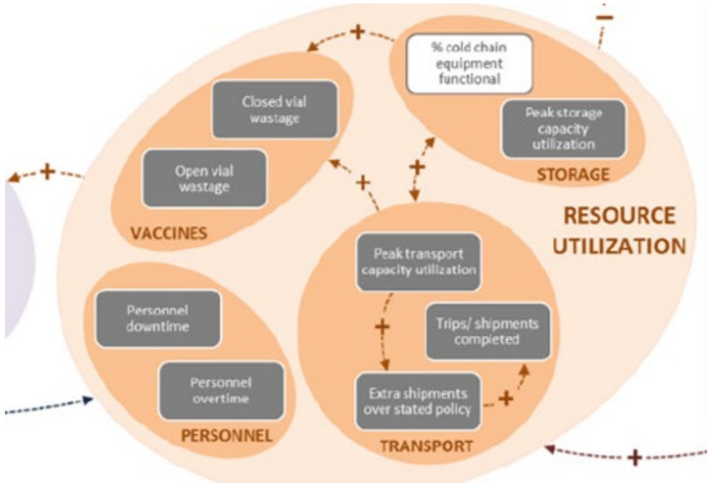
Cost Measures

- **Vaccine procurement costs**: costs of purchasing all vaccines that entered a system, or part of a system, in a given time period
- **Transport costs**: costs of per diems as well as vehicle fuel, amortization, and maintenance in a given time period



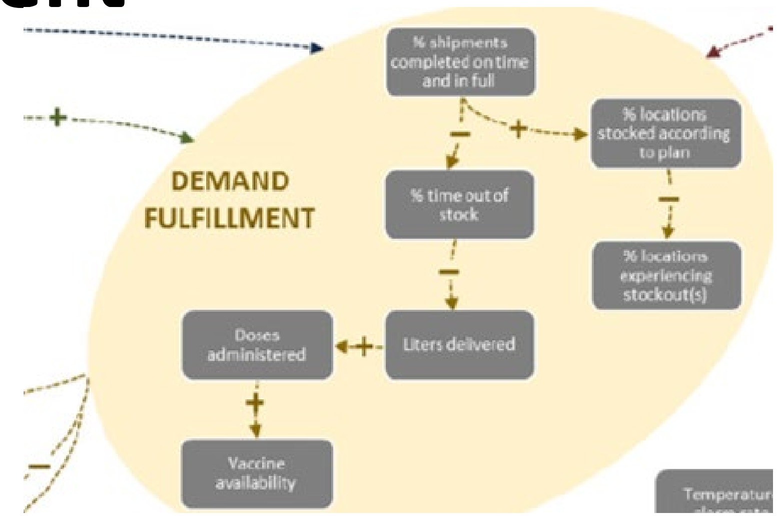
- **Storage costs**: costs of storage equipment, energy, amortization, and maintenance in a given time period
- **Building costs**: costs of building overhead and amortization in a given time period
- **Labor costs**: costs of personnel salaries in a given time period
- **Logistics costs**: operating costs of supply chain logistics (storage + transport + labor + building)
- **Total costs**: logistics costs + vaccine procurement costs

Resource Utilization Measures



- **% cold chain equipment functional:** proportion of cold chain equipment (CCE) storage devices operable for storing vaccines
- **Peak storage capacity utilization**: maximum percentage of available storage capacity occupied by products at any time
- **Peak transport capacity utilization:** maximum percentage of available transport capacity needed to complete any shipment
- **Trip/shipments completed:** number of trips taken for a route or set of routes in a given time period, as a percentage of trips set by policy
- **Extra trips over stated policy:** number of annual trips taken for a route or set of routes on an as-needed basis, above the stated policy
- **Personnel downtime**: percentage of normal working hours dedicated to supply chain logistics spent inactive
- **Personnel overtime**: hours spent by personnel working on vaccine supply chain logistics in addition to normal working hours
- **Closed vial wastage**: unused vials discarded due to expiry, heat exposure, or breakage during a given time period
- **Open vial wastage**: partially used vials expired as a percentage of all vials opened

Demand Fulfillment



- **% shipments completed on time and in full**: on-time shipments containing the full amount ordered as a % of all shipments
- **% locations stocked according to plan**: locations maintaining stock levels according to policy as a % of all locations
- **% locations experiencing stockouts**: locations experiencing at least one stockout of at least one product in a given time period as a % of all locations
- **% time out of stock**: number of days in a year when a location or set of locations had no inventory on hand for one or more products as a % of total days measured
- **Liters delivered**: liters of vaccine in packaging delivered to a location or set of locations in a given time period
- **Doses administered**: vaccine doses administered to patients in a given time period
- **Vaccine availability**: successful immunizations administered to patients as a % of immunizations needed

Measures Across Multiple Categories

- **Logistics cost per liter delivered:** logistics costs / liters delivered in a given time period
- **Logistics cost per dose administered**: logistics costs / doses administered in a given time period
- **Total cost per liter delivered**: total costs / liters delivered in a given time period
- **Total cost per dose administered**: total costs / doses administered in a given time period

Running the HERMES systems model and viewing results

HERMES Simulation Results

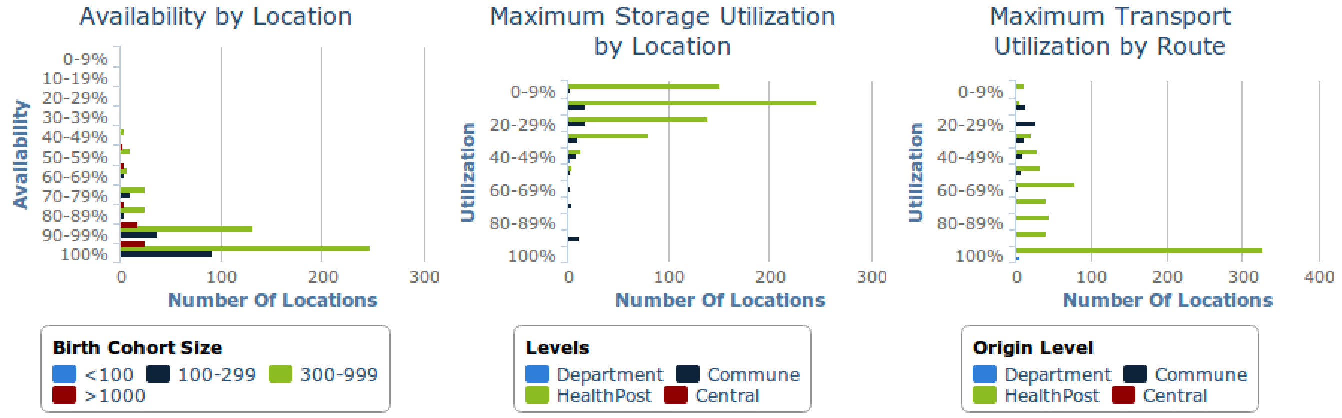
Welcome | Models | People | Vaccines | ColdStorage | Transport | Demand | Costs | Run Hermes | Results | Developer | Help

Welcome

Vaccine Results

Vaccine	Availability	Vials Used	Doses Per Vial	Doses Requested	Doses Administered	Open Vial Waste	Percent Stored 2 to 8 C	Percent Store Below 2C	Vials Spoiled
Measles Vaccine Generic 10 Dose	85.37%	51,646	10	322,743	275,512	46.65%	100.00%	0.00%	0
DTP HepB Hib Generic 2 Dose	94.79%	519,861	2	1,067,900	1,012,235	2.64%	100.00%	0.00%	0
Tetanus Toxoid Generic 10 Dose	95.50%	60,332	10	631,420	603,028	0.05%	100.00%	0.00%	0
Prevenar PCV13 1 Dose	94.86%	969,903	1	1,022,473	969,903	0.00%	100.00%	0.00%	1
BCG Generic	89.69%	32,032	20	362,254	324,908	49.28%	100.00%	0.00%	0
OPV Generic 20 Dose	95.42%	67,968	20	1,424,008	1,358,855	0.04%	16.35%	83.65%	0
Yellow Fever Generic 10	85.36%	51,704	10	322,741	275,479	46.72%	100.00%	0.00%	0

Show Google Earth Viz



The importance of measuring the entire system

In what situations would a metric appear reasonable, but the system itself is not functioning effectively or efficiently?

Example metric: **Vaccine availability (percentage of people presenting at immunization locations who are vaccinated)**

Vaccine availability may be high in systems…

Maintaining **high buffer stock levels**, which may help ensure an uninterrupted supply of vaccines but can also contribute to **high vaccine wastage rates** due to expiry of unopened vials

Using **large multi-dose vial sizes**, which can alleviate supply chain bottlenecks due to the small cold chain volume required per dose but can cause **high open vial wastage rates** as more unused doses must be discarded

Holding **overly frequent vaccination sessions**, which can help to minimize missed vaccination opportunities but can incur **high logistics costs** from operating immunizing locations or conducting outreach activities

Transporting vaccines in **vehicles that are larger than needed**, which may alleviate transport bottlenecks by providing ample capacity for each shipment but can result in **high transportation costs** from operating the large vehicles

Storing vaccines in **storage devices that are larger than needed**, which may alleviate storage bottlenecks by offering more than sufficient capacity for locations to store vaccines but can incur **high storage costs** to operate the large devices

The importance of measuring the entire system

Vaccine availability may also be high in systems…

Employing **more personnel than are needed**, which may minimize supply chain bottlenecks due to understaffing but can incur **high labor costs** from employee wages and benefits

Making **more frequent shipments** than prescribed by system policies, which may deliver more vaccines where storage or transport bottlenecks restrict shipment sizes but can lead to **high transport costs** from taking vehicles on extra trips

Storing vaccines in **overfilled storage devices** or in **equipment not designed for vaccine storage**, which can allow a system to store more vaccines where storage bottlenecks limit stock levels but can lead to **high vaccine wastage rates** due to the increased risk of exposing vaccines to conditions outside of their required storage temperatures

Setting **low coverage targets** that represent a fraction of each age cohort, which may allow a system to adequately achieve its goals while even substantial **parts of the population remain unvaccinated**

Offering **few vaccines in the immunization schedule**, which may allow a system to achieve high coverage but would leave the population **unprotected against certain preventable diseases** and may fail to take advantage of economies of scale potentially gained by adding vaccines to the existing program

Sampling only some locations that are not representative of the entire system or **reporting only one overall value for the entire system** may produce estimates of vaccine availability that miss the **lower performance in some areas** that were not sampled or represent a subset too small to produce significant changes in results for the overall system

Understanding Country Vaccine Supply Chains

- VACCINE ECONOMICS WORKSHOP-3
- MAKERERE UNIVERSITY SCHOOL OF PUBLIC HEALTH
- 28 – 30 MAY, 2018

Background

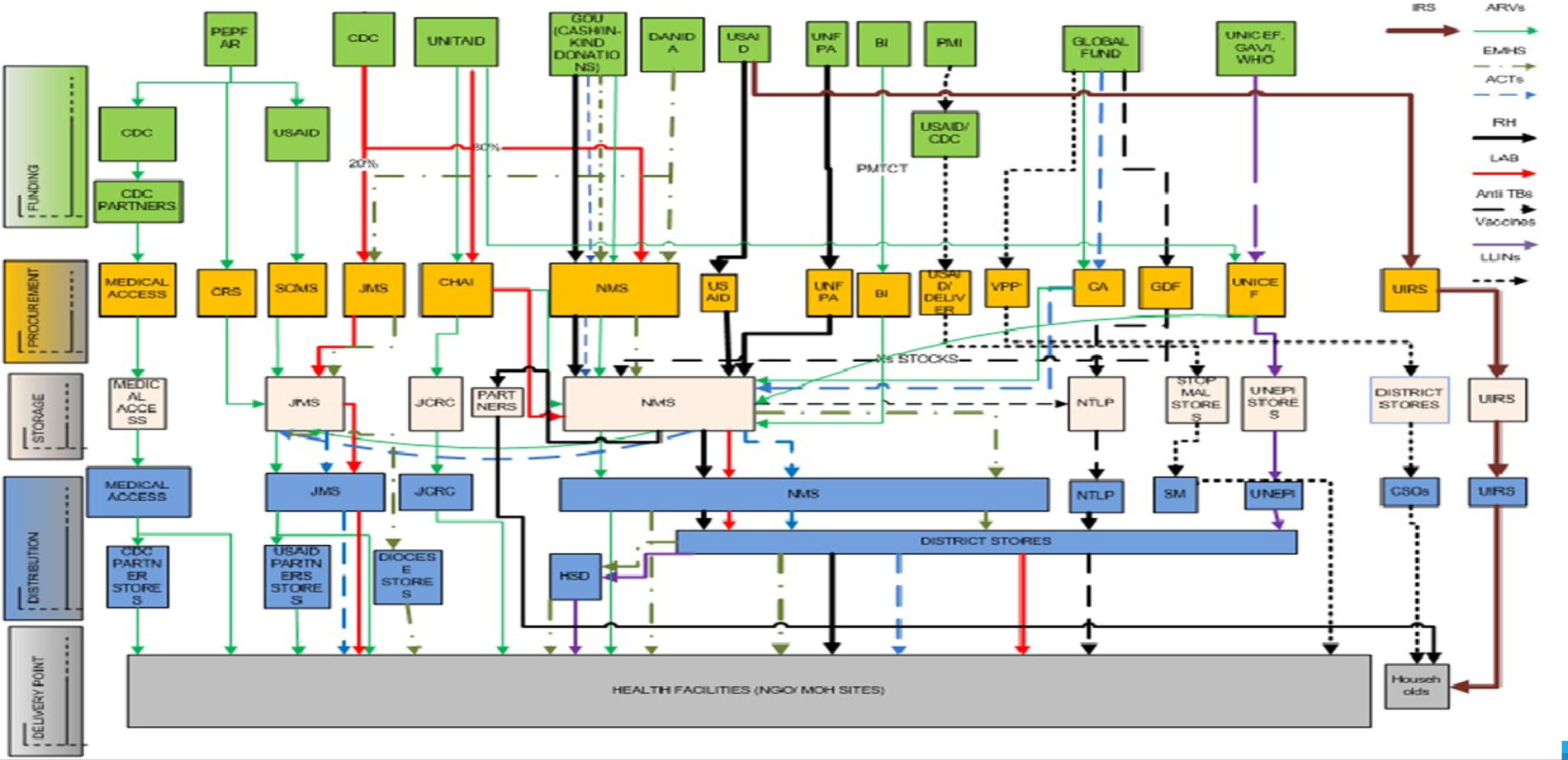
- **Functional supply chain systems as the backbone of routine immunization. However;**
  - Supply chain systems currently strained in keeping up with the demand for immunisation services
  - Lack of alignment of investments in the vaccines and cold chain systems to protect them

- **Immunization supply chain networks should be designed to maximize efficiency, effectiveness, agility and responsiveness to needs of the specific country immunization programme.**

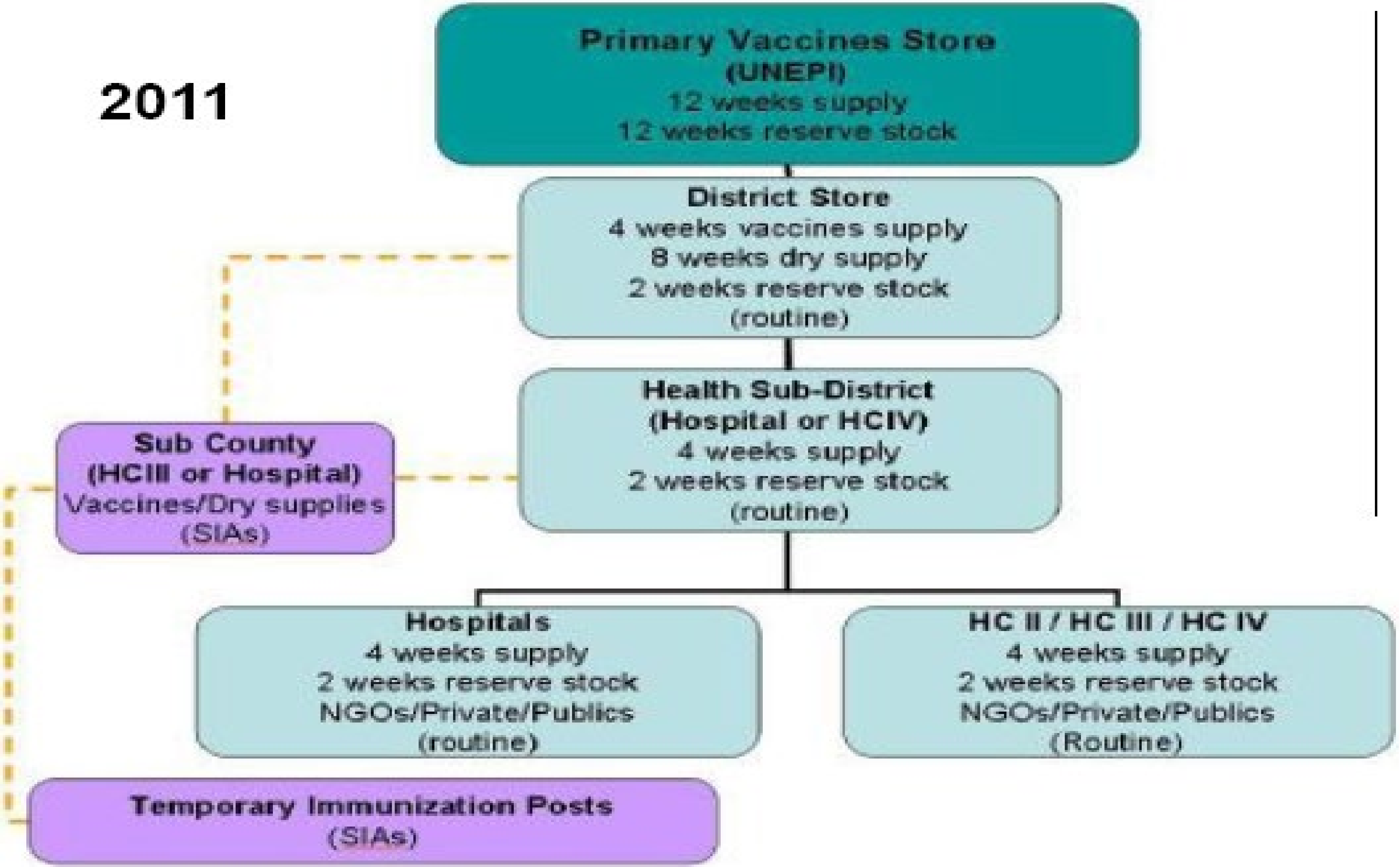
- **Supply chain models need to be developed to address specific questions within specific country contexts:**
  - Optimisation of supply chain operations (procurement, storage, ordering, distribution)-doing it right?
  - New Vaccine Introduction (NUVI)- Effect on entire EPI supply chain system
  - How do we allocate the available resources more effectively?—allocative efficiencies
  - Effect of conditions & circumstances on the performance of the supply chain

Uganda vaccine supply chain case study

Uganda's supply chain system [SURE,2011]--- Example of a complex system



Vaccine Supply Chain (pre- supply chain Integration)-Uganda



Performance on vaccine Supply Chain Indicators

- **Agility**

- Lead time

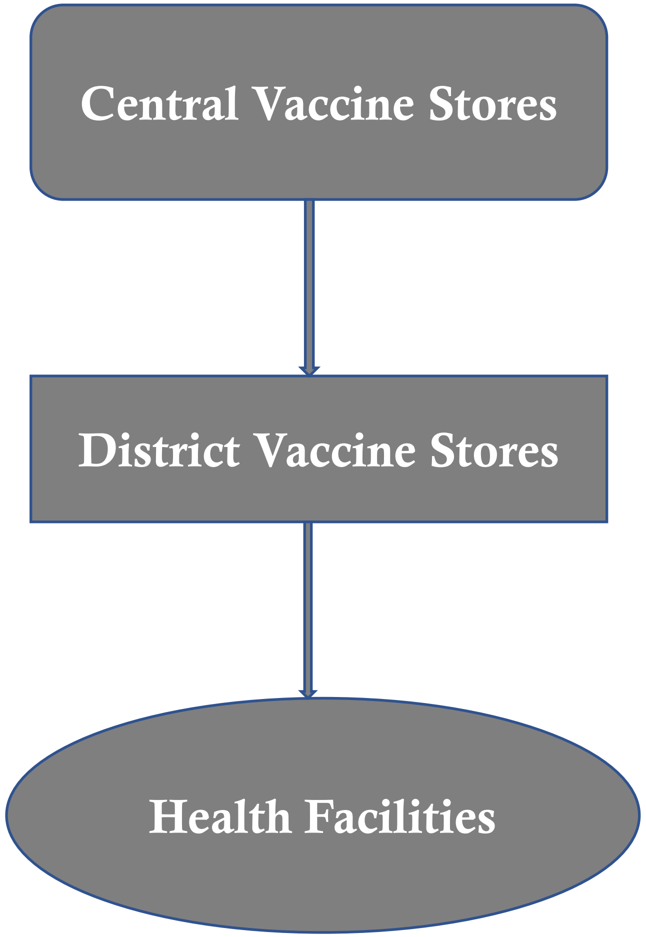
- **Cost**

-Cost per dose administered
-Logistic cost per dose administered
-Cost per litre delivered

- **Demand Fulfilment**

-Vaccine availability –days out of stock

Vaccine Supply Chain (After- supply chain Integration)-Uganda



Expected Benefits

- Lower cost-storage and distribution costs
- Lower vaccine lead time
- Sustainability of in country vaccine delivery systems

How do you demonstrate such benefits to policy makers?

How do you answer the-"What if "questions from the policy maker/implementers?

Other vaccine supply chain optimisation reforms?-CMYP

- Strengthening of transport and logistics as well as standard immunization practices at all levels. --HOW

New Vaccine Introduction (NUVI) Pipeline for Uganda

- **What is planned?-cMYP**
  - Introduction of new vaccines (Rotavirus, MenAfriVac),
  - Under-utilized vaccines (IPV, Yellow fever, Rubella containing vaccines)
  - Switch from tOPV to bOPV and from TT to Td

- **What could be the effects of these changes?--Discussion**
  - Consideration of the system wide effects of NUVI—e.g based on PCV experience

EVMA--Identifying Vaccine Supply Chain Challenges and Opportunities

- **EVM a tool for supply chain system diagnosis-However, we need to go beyond knowing the challenges to identify the corrective actions**

- **Effective Vaccine Management Indicator Areas (assessed at National, District, Facility-80% target on each**
  1. Vaccine arrival
  2. **Storage capacity**
  3. **Storage temperature**
  4. Buildings, Equipment and Transport
  5. Maintenance
  6. stock management
  7. Distribution
  8. Vaccine management;
  9. Information systems and supportive functions
  - *****Uganda (2011 & 2014)**

  - *"Of the 65 low and lower-middle income countries assessed on effective vaccine management, none has met the recommended WHO standard." WHO/UNICEF Joint Statement on Effective Vaccine Management*

Uganda's EVMA Assessment (2014)—Target 80%

Criteria mean score 2014 EVM Assessment by level

EVM Criteria	Vaccine supply chain levels		
	National	District	HF
E1: Vaccine arrival	80%		
E2: Temperature	61%	77%	72%
E3: Storage capacity	93%	75%	71%
E4: Buildings, equipment, transport	91%	73%	81%
E5: Maintenance	73%	57%	55%
E6: Stock management	82%	63%	50%
E7: Distribution	67%	57%	66%
E8: Vaccine management	87%	82%	68%
E9: IMS, supportive functions	77%	57%	37%

NB: Criteria E1 is not applicable at district and service delivery levels

EVMA quality improvement cycle –WHO/UNICEF

Other country vaccine supply chain case studies

- **Discussion**

1. **Examples of reforms (implemented/planned) to optimise supply chain operations --- making the vaccine supply chain more efficient**

- (procurement, storage, ordering, distribution)-doing it right?
  1. **Ethiopia**
  2. **Uganda**
  3. **Kenya**
  4. **Tanzania**
  5. **Rwanda**

- **2. Role of modelling in demonstrating effect of these proposed/implemented reforms**

Example: Changing the Vaccine Type

Contents lists available at SciVerse ScienceDirect

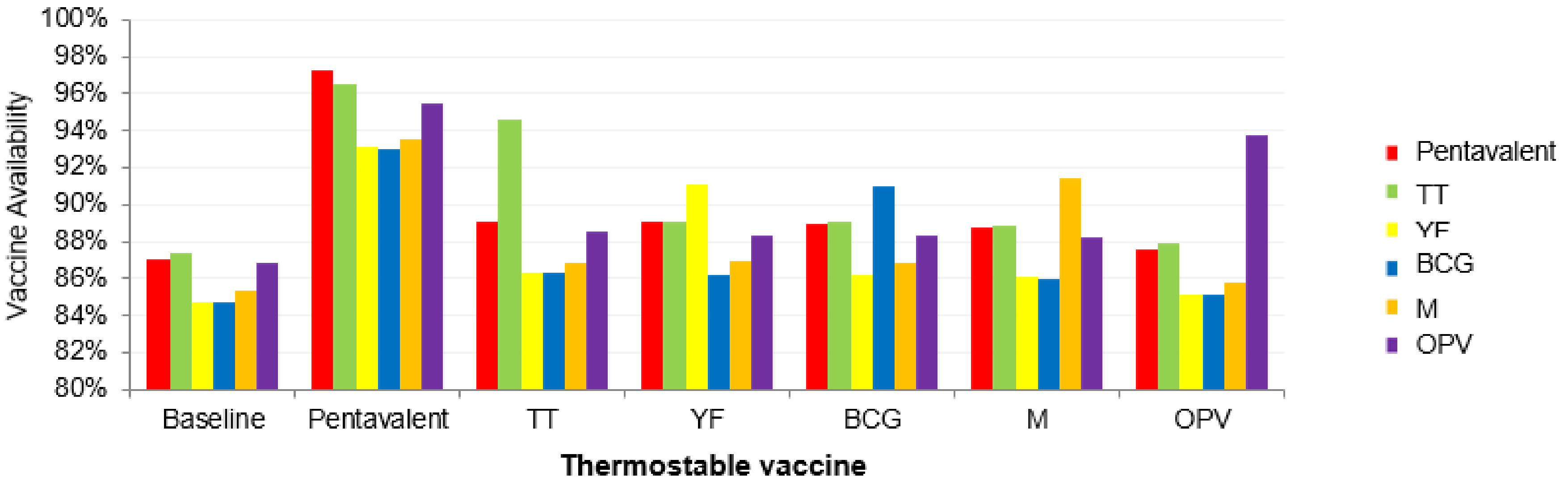
Vaccine

journal homepage: www.elsevier.com/locate/vaccine

ELSEVIER

The impact of making vaccines thermostable in Niger's vaccine supply chain

Bruce Y. Lee[a,*], Brigid E. Cakouros[a], Tina-Marie Assi[a], Diana L. Connor[a], Joel Welling[b], Souleymane Kone[c], Ali Djibo[d], Angela R. Wateska[a], Lionel Pierre[e], Shawn T. Brown[b,f]



Example: Changing the Vaccine Type

Context:

- Many health centers in Niger have unreliable power or lack cold chain infrastructure, and therefore face difficulties in maintaining vaccines within 2–8°C
- There is lack of reliable methods for keeping vaccines adequately cool or cold in many parts of the world → motivation to develop and introduce thermostable vaccines
- Concerns about the extent of benefits: if only some vaccines are made thermostable, they still have to maintain a cold chain for the non-thermostable vaccines thereby limiting the benefits

Main Questions to be answered:

How will Niger's existing cold chain infrastructure benefit from thermostable vaccines?

- Is there a significant difference between the benefits of having all vaccines thermostable or just a few individual vaccines thermostable?

Example: Changing the Vaccine Type

Methods:

- Constructed a detailed discrete-event simulation computational model of the Niger vaccine supply chain using HERMES software.
- The model incorporated 7 EPI vaccines (bCG, DTP, DTP-HepB, OPV, Measles, Tetanus toxoid, YF)
- The model includes the type, make, model, age, and the specific capacity of every single cold room, refrigerator, and freezer at each location in the Niger supply chain.
- Each simulation experiment generated the following measures of supply chain performance: Vaccine Availability, Transport Capacity Utilization, and Storage Capacity Utilization

Example: Changing the Vaccine Type

Results:

- Making any EPI vaccine thermostable relieved existing supply chain bottlenecks (especially at the lowest levels), increased vaccine availability of all EPI vaccines, and decreased cold storage and transport capacity utilization.
  - Biggest impact came from making the pentavalent vaccine thermostable, increasing its own vaccine availability from 87% to 97% and the vaccine availabilities of all other remaining non-thermostable EPI vaccines to over 93%.
  - However, making each of the other vaccines thermostable had considerably less effect on the remaining vaccines, failing to increase the vaccine availabilities of other vaccines to more than 89%.

Take-away:

HERMES model shows that even a single thermostable vaccine (or a subset of them) could significantly help alleviate supply chain bottlenecks that occur throughout the world

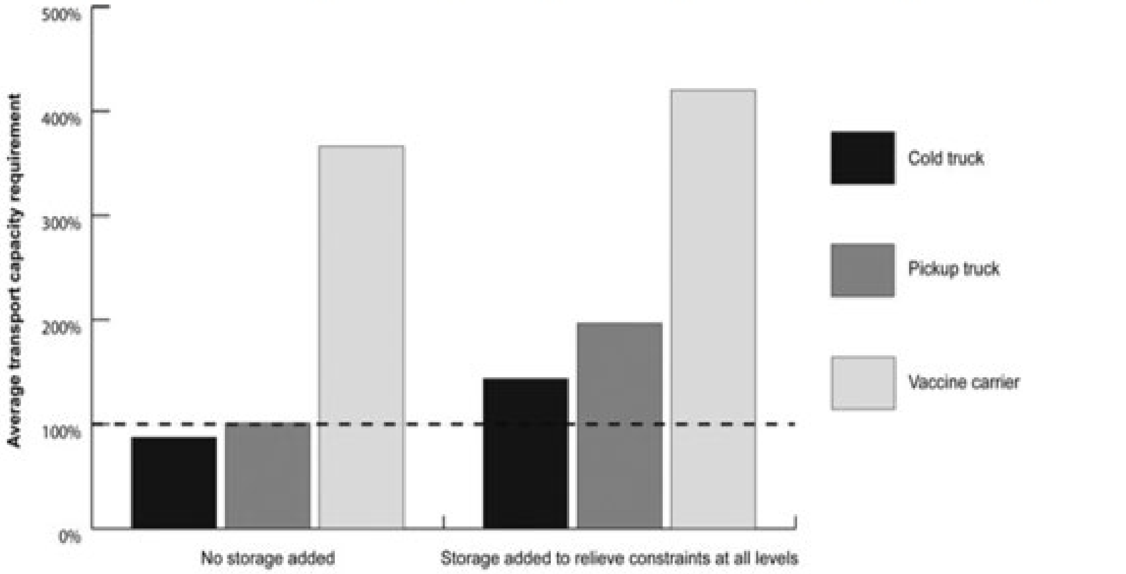
Modeling can help help funders, policy makers, scientists, and manufacturers prioritize which vaccines to make thermostable, delineating the potential differential benefits of each on the vaccine supply chain.

Example: Making Changes to Cold Chain Equipment

Only Adding Stationary Storage to Vaccine Supply Chains May Create and Worsen Transport Bottlenecks

Leila A. Haidari, MPH; Diana L. Connor, MPH; Angela R. Wateska, MPH; Shawn T. Brown, PhD; Leslie E. Mueller, MPH; Bryan A. Norman, PhD; Michelle M. Schmitz, BA; Proma Paul, MHS; Jayant Rajgopal, PhD; Joel S. Welling, PhD; Jim Leonard; Erin G. Claypool, PhD; Yu-Ting Weng, MS; Sheng-I Chen, PhD; Bruce Y. Lee, MD, MBA

FIGURE ● **Transport Capacity Requirement Before and After the Addition of Stationary Storage**[a]



[a]A transport capacity requirement of more than 100% indicates a transport bottleneck.

Example: Making Changes to Cold Chain Equipment

Context:

- Vaccine supply chains in many countries currently experience bottlenecks due to limited storage or transport capacity
  - expected to get worse with the introduction of 12 new vaccines by 2019 (perhaps now optimistic at best).
- International donors tend to donate stationary storage devices far more often than transport equipment.

Main Question to be answered:

What is the impact of adding stationary storage equipment on the capacity requirements of transport devices and vehicles?

Example: Making Changes to Cold Chain Equipment

Methods:

- Constructed a detailed discrete-event simulation computational model of the Niger vaccine supply chain using HERMES software.
- The model simulated the population demand and EPI vaccine schedule for 2015, as projected in the Niger CMYP
- The transport capacity requirement was measured for each of the 3 types of vehicles and transport devices used in the Niger vaccine cold chain (cold trucks, pickup trucks, and vaccine carriers) under the current system, without additional storage or transport equipment.
- Cold rooms and refrigerators were then added to relieve all stationary storage constraints and measured the transport capacity requirement under this altered system.
- A transport capacity requirement of more than 100% indicates a transport bottleneck

Example: Making Changes to Cold Chain Equipment

Results:

- Relieving storage constraints aggravated existing transport bottlenecks and created new bottlenecks for routes that did not experience constraints before storage was added.
- With the addition of stationary storage, the average transport capacity requirement increased from
  - 88% to 144% for cold trucks
  - 101% to 197% for pickup trucks
  - 366% to 420% for vaccine carriers.

Take-away:

Models such as this one can be used to evaluate supply the effect of different technologies on the supply chain and how a new technology introduction may affect other parts of the system

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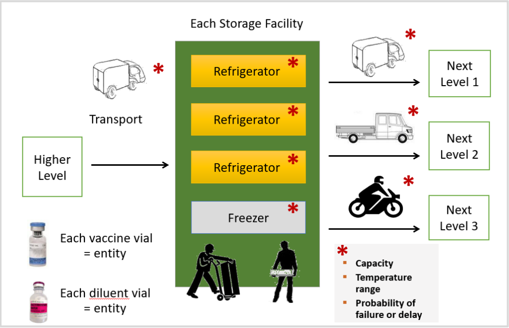
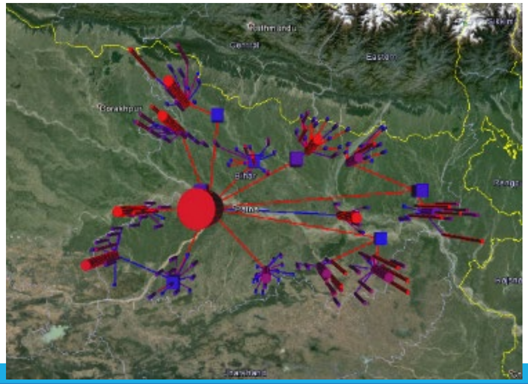




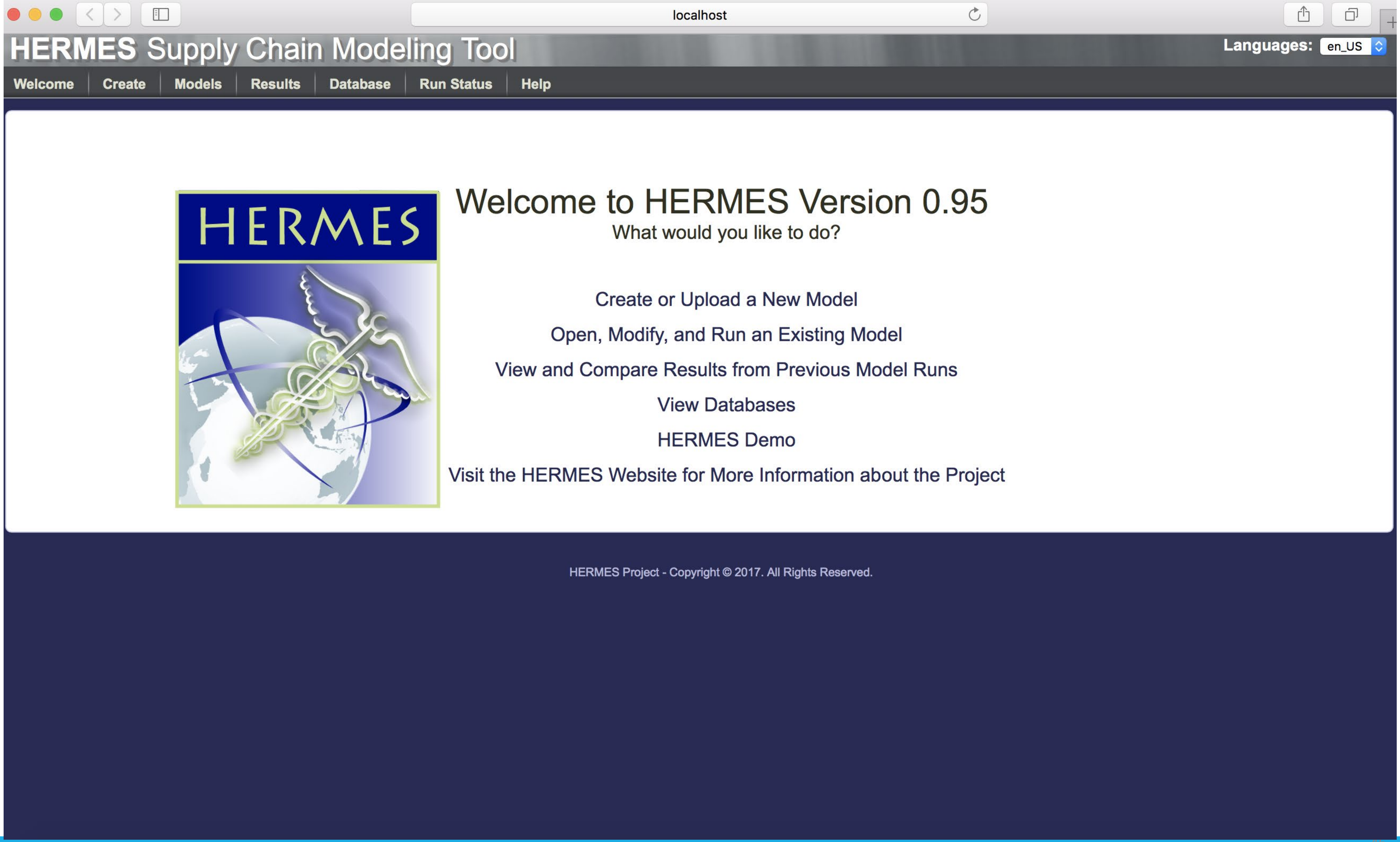
Download HERMES 1.0

Go to: http://hermes.psc.edu/

→ Click “Download” tab

→ Chose the appropriate download (Mac users vs Windows users)

→ Follow the prompts, then open the software


localhost
HERMES Supply Chain Modeling Tool
Languages: en_US
Welcome
Create
Models
Results
Database
Run Status
Help
HERMES
Welcome to HERMES Version 0.95
What would you like to do?
Create or Upload a New Model
Open, Modify, and Run an Existing Model
View and Compare Results from Previous Model Runs
View Databases
HERMES Demo
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