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The importance of vaccine supply chains to everyone in the vaccine world

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Abstract

While the focus of many in the vaccine world has been on developing new vaccines and measuring their effects on humans, failure to understand and properly address vaccine supply chain issues can greatly reduce the impact of any vaccine. Therefore, everyone involved in vaccine decision-making may want to take into account supply chains when making key decisions. In fact, considering supply chain issues long before a vaccine reaches the market can help design vaccines and vaccine programs that better match the system. We detail how vaccine supply chains may affect the work and decision making of ten examples of different members of the vaccine community: preclinical vaccinologists, vaccine clinical trialists, vaccine package designers, health care workers, epidemiologists and disease surveillance experts, policy makers, storage equipment manufacturers, other technology developers, information system specialists, and funders. We offer ten recommendations to help decision makers better understand and address supply chains.

Keywords

Immunization; Supply chains; Logistics

1. Introduction

While the focus of many in the vaccine world has been on developing new vaccines and measuring their effects on humans, even the most effective vaccine on the market cannot have any impact on human health without reaching the human body. A vaccine supply chain is the complex system of steps, processes, equipment, vehicles, and locations involved in getting vaccines (many of which are highly perishable or temperature sensitive) from their origin to their destination. Failure to understand and properly address this system can greatly reduce the impact of any vaccine. Therefore everyone involved in vaccine decision-making

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(not just those specializing in supply chains), ranging from scientists to funders to policy makers to public health officials to other decision makers, may want to take into account supply chains when making key decisions. In fact, considering supply chain issues long before a vaccine reaches the market can help design vaccines and vaccine programs that better match the system.

Other industries have examples of companies that used extra attention to supply chains to achieve considerable competitive advantages. One example is Amazon whose core business is helping a large and diverse array of manufacturers deliver goods to customers rapidly and effectively. Many of these companies employ or consult supply chain experts regularly to ensure that their supply chains run effectively and efficiently. Additionally, product design often occurs with supply chains in mind. The packaging, size, shape, and composition of the product facilitate its storage and delivery. Examples include IKEA developing furniture that can be shipped in its component parts more readily and food manufacturers adding preservatives and developing dried and compact versions of food.

By contrast, evidence suggests that vaccine supply chains have not received the same degree of attention. Studies have shown that many vaccine supply chains around the world have substantial constraints and bottlenecks and are not delivering vaccines to many people who need them [1]. Supply chains issues have hindered efforts to control, eliminate, or eradicate diseases such as polio and measles [2]. While supply chains in many low and middle income countries may have the most substantial problems, many vaccine supply chains in high income countries face challenges as well. For example, the 2009 H1N1 influenza pandemic exposed many existing limitations of the vaccine supply chains in the United States. During the pandemic, some locations faced vaccine shortages while others had surplus [3]. Additionally, studies have shown disparities in access to immunization services in the United States, affecting in particular lower income and minority populations [4].

A question is whether people in the vaccine world (beyond those who deal directly with vaccine supply chains) realize how much their work is affected by and affects vaccine supply chains. Many different scientific and clinical disciplines face problems with specialists remaining in silos with less than ideal communication among them [5]. Education, training, funding, and organization structures such as university departments can encourage rather than discourage such silos [6]. What follows are ten examples of different members of the vaccine community and how vaccine supply chains may affect their work and decision making.

2. Examples of vaccine stakeholders

2.1. Preclinical vaccinologists

The biological characteristics of a vaccine can greatly impact vaccine supply chains and their operations. For example, the number of doses required to achieve immune protection and the duration of protection can affect how often a person requires vaccination. Increasing the number of doses needed per person can increase the volume of vaccines that a supply chain needs to handle, leading to or exacerbating bottlenecks that impede the flow of all vaccines [7]. As another example, replacing even one routine vaccine with a thermostable presentation (i.e. a vaccine that can be stored and transported outside of the cold chain at ambient temperatures) can not only improve the availability of the thermostable vaccine but can also relieve bottlenecks and thereby raise the availability of other, non-thermostable vaccines [8].

2.2. Vaccine clinical trialists

Many decisions made by those involved in the clinical development and testing of vaccines are interconnected with vaccine supply chains. For example, as HERMES modeling work in Thailand demonstrated, a vaccine's selected target population can substantially affect the delivery of not only the vaccine but other vaccines as well [9]. Choosing universal vaccination rather than a more focused higher risk target population for the seasonal influenza vaccine such as children, pregnant women, health care workers, and older adults would result in bottlenecks from the additional volume of vaccines during the flu vaccination season that then would impede the flow of other vaccines. As clinical trialists make decisions such as identifying target populations for a new vaccine, they should consider the system-wide effects that various targets may have and the potential need for supply chain strengthening in order to accommodate such targets.

2.3. Vaccine package designers

The size and shape of a vaccine package can greatly affect supply chain operations as evidenced in 2006 when the initial packaging for rotavirus vaccines was too large for supply chains in Latin America to handle [10,11]. Both Merck's RotaTeq and GlaxoSmithKline's Rotarix filled substantially greater cold chain volumes than other routine vaccines, creating and exacerbating bottlenecks that ultimately disrupted the flow of all vaccines [12]. This led Merck and GlaxoSmithKline to re-design the packages to be smaller. Subsequent modeling has compared the relative impact on supply chain logistics and the availability of all vaccines when introducing rotavirus vaccine in various packaging sizes, showing dramatic, system-wide reductions in stockouts when changing the size of a single vaccine [7,13].

2.4. Healthcare workers

Healthcare workers have to adapt their practice based on the availability of products such as vaccines. Supply chain issues can lead to stockouts that cause healthcare workers to turn people away without vaccinations [14]. To prevent this, healthcare workers in some systems resort to ad hoc solutions. For example, healthcare workers at facilities that normally receive regular shipments of vaccines may instead travel from their posts to pick up vaccines when shipments do not arrive in time [15]. When vaccine refrigerators are not functional, healthcare workers may resort to storing vaccines in cold boxes with ice packs, which carries a greater risk of freezing the vaccines [16]. In both cases, health facilities may be forced to close while healthcare workers are away retrieving vaccines or ice packs, resulting in additional missed vaccination opportunities.

2.5. Epidemiologists and disease surveillance experts

The dynamics of infectious disease can depend heavily on vaccine coverage in a population. Many measures of coverage are indirect and may not account for the vaccine supply chain.

For example, if coverage estimates sample locations that have better functioning supply chains than others, will these be representative? Studies have shown supply chain constraints to vary widely within individual countries, resulting in substantial heterogeneity in vaccine availability [17,18]. When supply chains are not functioning effectively, allocating vaccines towards a population does not necessarily mean that the population will receive them.

2.6. Policy makers

Supply chain issues are integral to most decisions that policy makers have to consider. For example, while policy makers were working to introduce inactivated polio vaccine (IPV) procured through the United Nations Children's Fund (UNICEF) in low and middle income countries around the world, challenges in the planning and execution of IPV introduction impacted the supply chain from manufacturers to countries as well as in-country supply chains to the sites where vaccine are administered. UNICEF reported shortages of IPV in 2015 that continued through 2016 due to technical issues that manufacturers encountered when scaling up bulk production; additionally, a lack of firm guidance on the doses required and dosage timing when responding to an outbreak posed obstacles for estimating in-country demand [19]. These challenges have ultimately led to delays in introducing IPV in some countries. This experience highlights the importance of supply chain considerations when planning the implementation or scale-up of new vaccine introductions.

2.7. Storage equipment manufacturers

When developers and manufacturers are designing equipment to store vaccines at locations throughout the supply chain and during transport, there may be a tendency to focus on the individual user rather than the entire supply chain. But storage equipment sits within a larger ecosystem and characteristics such as power requirements, internal capacity, and price can have reverberating effects throughout the supply chain. Vaccine supply chain performance and efficiency depend on the ability of the system to meet storage device needs (such as maintenance technicians and spare parts) in the field. For example, the value of a passive vaccine storage device, i.e. ones that do not require a power source, depends on how well the ice supply chain can be coordinated, how mobile the device is, and how empty devices are swapped with refilled devices [20]. Gas- and kerosene-powered off-grid devices require an uninterrupted supply of fuel, which has led to vaccine stockouts and prompted the development of solar-powered vaccine storage devices [21]. However, first-generation solar-powered device batteries required frequent and costly replacement that posed challenges in many settings and led to the development of battery-free solar direct-drive devices [22].

2.8. Other technology developers

The vaccine world includes many who develop technology that help the production and administration of vaccines. This includes those developing new methods of manufacturing vaccines (e.g. cell culture) as well as new ways for healthcare workers to use them. Prefilled auto-disable syringes are an example of a relatively new technology that can have substantial implications for supply chain logistics. This technology offers benefits in improved safety and reduced medical waste, but these syringes require greater cold chain volumes than the traditional vials and ampoules they replace [23]. Their impact on supply chain bottlenecks must therefore be considered in order for these benefits to actually reach the places where they are needed. Microneedle technology such as the Bioneedle can produce freeze-dried thermostable vaccines that do not require cold chain and eliminate sharps waste [24,25]; modeling has shown that thermostable vaccines can prevent significant disease burden and medical costs [26].

2.9. Information system specialists

When developing information systems to process data to inform decision making, people may focus on providing particular capabilities to specific users but must consider the entire supply chain system to fully assess the potential impact of these systems. One example is computerized demand forecasting information systems for anticipating future vaccine demand to inform ordering and help ensure an adequate supply of vaccines [27]. However, modeling has shown that implementing a computerized demand forecasting system may not improve vaccine availability if supply chain bottlenecks are not also addressed; adjusting vaccine orders at individual locations to more accurately match future demand may have limited or no impact on actual vaccination rates when supply chain issues prevent timely fulfillment of orders [28]. Forecasting systems may help guide investments in supply chain infrastructure to relieve current and future bottlenecks, thus allowing demand forecasts to provide their maximum benefits to immunization programs.

2.10. Funders

Supply chains can make or break technology and programs, thereby playing a major role in the return-on-investment and success of funded initiatives [29]. However, many initiatives do not incorporate supply chains considerations. For example, prior to 2011, new vaccine introductions into different countries did not always include comprehensive evaluations of the relevant supply chains and approaches that could facilitate these introductions (such as supply chain re-design) [15,30,31].

3. Potential next steps

These are just a few examples of those in the vaccine world affected by vaccine supply chains. While attention towards vaccine supply chains has increased in recent years (e.g. the formation of a taskforce with representatives from the World Health Organization (WHO), UNICEF, Gavi, and the Bill and Melinda Gates Foundation [32], as well as the Global Fund's decision to increase investments in supply chain strengthening [33] and a forthcoming special issue in *Vaccine* on supply chains), much of vaccine decision making may still not involve vaccine supply chain considerations. Table 1 summarizes recommendations to help decision makers understand and address vaccine supply chain issues. One method of communicating vaccine supply chain needs to everyone is to develop Target Product Profiles (TPPs), a menu of desirable characteristics, features, and attributes for a product such as a vaccine, used to guide product development, more with supply chains in mind [34–37]. Computational models of vaccine supply chains can help develop such TPPs by serving as ‘‘virtual laboratories” to test the effects of changing vaccine and related product (e.g. refrigerators, monitoring devices, and administration technologies) characteristics [38]. One example is HERMES simulation modeling of unmanned aerial vehicles (UAVs) to guide their development and implementation for transporting vaccines [39].

4. Conclusions

Since the impact of vaccine supply chains extends well beyond those who directly work with them, it is important for scientists and decision makers throughout the vaccine world to understand the supply chain implications of their work.

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Table 1

Ten recommendations to help decision makers better understand and address vaccine supply chains.

Recommendations	Examples of possible actions
1. Raise awareness of supply chain issues	• More vaccine supply studies in the scientific literature • More stories on supply chains in the general media (e.g. news stories and documentaries) • Policy briefs and reports on supply chain issues for decision makers • Social media efforts focused on supply chain issues • More supply chain ''evangelists", thought leaders, and spokespeople
2. Educate and train various decision makers on supply chain principles and practices	• Incorporating supply chain courses into curricula for public health, medicine, and public policy degree programs • Up-to-date textbooks and other educational materials on supply chains for those not in the supply chain field • Intensive short courses for professionals at all career levels • Incorporating systems methods such as computational simulation modeling into courses and course material • Alternative learning methods and approaches such as workshops, online courses, etc.
3. Incorporate supply chain experts and considerations into all vaccine decision making	• Including supply chain experts at all stages of vaccine development and decision making (e.g. inclusion on committees and regulatory bodies) • Including impact on supply chains as a key outcome measure when evaluating different vaccine technologies, policies, and strategies • Utilizing computational modeling to understand the impact of the supply chain on decisions and vice versa
4. Improve communication between vaccine decision makers and vaccine supply chain experts	• Integrating supply chain experts into different committees, conferences, meetings, etc. • Establishing online data sharing sites and communications portals where decision makers and supply chain experts can collaborate • Harmonizing language between the supply chain world and other vaccinerelated disciplines
5. Develop computational simulation models of global and country-level supply chains to serve as virtual laboratories to help evaluate supply chains and test different policies, interventions, and technologies	• Providing resources for computational modeling efforts at every stage of vaccine development and decision making • Integrating computational modeling in different types and stages of vaccine decision making • Making computational modeling tools available to decision makers
6. Establish as a condition of major vaccine-related decisions (e.g. funding, new policy change, new vaccine introduction, etc.) the mapping and modeling of the relevant supply chain and the impact and value of the new policy, intervention, technology, or funds	• Writing such as requirement into requests for proposals, applications, or other decision-making documents • Next steps should be contingent on the mapping/modeling results, which in turn can guide future decision-making • Establishing mechanisms for periodic updating of such maps and models
7. Utilize supply chain models and other analyses to generate target product profiles (TPPs) to guide the design and development of new technology	• Establishing TPPs for all desired and new technologies • Supply chains impact and impact of the supply chain should be part of these TPPs • TPPs serve as blueprints for new technology development
8. Develop a database of vaccine decisions and how supply chain considerations and changes affected these decisions	• Database can include each occasion a major vaccine and supply chain related change is made • Database can help decision makers understand what succeeded and what did not and the relative challenges, obstacles, and benefits • Living database can evolve as more and more case studies are entered
9. Develop and disseminate a playbook on how a country's supply chain can be approached and improved when making vaccine decisions	• Step-by-step guide on how to evaluate and improve a vaccine supply chain (e.g. map and model the supply chain, identify bottlenecks, constraints, and data gaps, collect needed data, test different changes, policies, and interventions first in the models and then in pilot studies, implement changes, establish monitoring and learning system) • Testing and revising playbook in a set of exemplar countries to serve as a blueprint for other places • Conducting workshops, courses, etc. to train decision makers on use of the playbook
10. Begin implementing these changes systematically in countries, documenting and disseminating their effects, impact, and value	• Using observational studies, modeling, and other approaches to estimate the impact of changes (e.g. efficiency and disease effects) and identify challenges and potential improvements of the process • Publishing reports and scientific literature containing details of each re-design process (including stakeholder engagement, implementation, and impact evaluation) and lessons learned to guide decision makers in future re-design efforts