Using simple economic and transport models to provide quick estimates of equipment and storage requirements for national vaccination logistics strategy plans

The global vaccine response to the COVID-19 pandemic has illustrated the importance of logistics readiness when rolling out medication to an entire country's population. The efficiency of such an operation can result in significant numbers of lives being saved and widespread improvements in health outcomes; however, the COVID-19 pandemic has also shown, in some cases, how the lack of robust national vaccination plans leads to piecemeal, disorganised rollouts lacking in central planning, resulting in inefficient use of logistics resources, vehicle fleets and underused capacity at storage locations. Excessive journeys also contribute to unnecessary carbon emissions; if the global response to future pandemic events is to be robust and sustainable, it should be possible to analyse any country's population distribution and transport network and calculate the most efficient logistics flows in advance to satisfy any desirable mission target, without needing to pre-condition it through any information about current logistics flows and facility locations that may be sub-optimal for efficient national distribution plans.

In this research, based on Bangladesh but applicable to any country with similarly detailed data, we outline a process to show how a basic census-derived population distribution can be combined with the known road network and models of transport and inventory costs to provide a "ready reckoner" plan for how an efficient supply chain might be identified. This plan can include details of where equipment distribution nodes would need to be at points of accessibility and local demand, the expected inventory at these nodes, and an estimate to the size of vehicle fleet required to service such a network. In this way, a set of rules and conditions can allow the model to produce a solution that has been derived according to local needs and constraints, and provide a good basis for further, more detailed plans to be made. As the model chooses location significance based solely on demand patterns, its results can be compared with existing network performance to show any improvements in efficiency over the status quo. In addition, its use is not restricted to vaccine distribution, allowing its application in other fields such as cold-chain logistics.

The model calculates supply chains through a reflective, adversarial process. To begin with, the ports of entry are defined as the only possible nodes from which deliveries can be made, and the relevant deliveries and overall system costs calculated on this basis. The model then applies an iterative process whereby successive sets of winning orders can be scrutinised by any remote facility in the simulation, to ascertain if overall system costs could be reduced through a bulk movement of stock, with a set of orders being reoriented to receive fulfilment from the remote facility instead. This can be repeated for all candidate facilities in the model setup, and the best value bulk movement selected to be included in the base case for the next iteration. This process is repeated until no further overall cost savings can be identified, resulting in a list of distribution facilities and estimates for the inventory size required to serve catchment demands over the course of the simulation.

When applied to vaccine distribution, it is important to ensure that the most vulnerable, or highest priority, demand populations are served first. One of the key features of the system is its use of a continuous histogram model of demand priority to ensure flexibility of input. Any number of different priority classes can be described and compared in this manner, allowing the model to choose and prioritise stock movements between different priority profiles.

Results are presented based on the Bangladesh road network and simple models of transport and inventory costs, with preliminary conclusions drawn on the required equipment locations and sizes. Results from the model are compared where possible to known storage capacities at existing facility locations within Bangladesh, comparing overall system efficiency and costs.