A NEW DAY FOR HOME DELIVERY

Driverless delivery vehicles and specialized distribution centers could form the backbone of a new retail network

By Michael G. Kay

The recent rapid advances in the development of self-driving cars and aerial drones have made it seem likely that within a short time it will be feasible to have products delivered to the home without human intervention.

This brings an important question to the mind of industrial engineers. Should the existing logistics network for retail products in the United States just be augmented with an automated delivery option from the existing set of stores and other retail establishments, or are there unique aspects of this new mode of delivery that warrant the reconsideration and possible redesign of the retail network to better realize the full potential of these automated delivery vehicles?

Logistics networks for home delivery companies like UPS and FedEx are designed to economize on their one big, indivisible cost of operation: the wage paid to the driver of each truck. To use the driver's time best, a large-payload truck is used to make multiple deliveries along a carefully planned route. Of course, this makes it impossible to schedule deliveries for times that are convenient for a person at home, and often products are just left at the door.

More customized delivery

Driverless delivery vehicles make it cost-effective to provide for direct deliveries to the home at times that are most convenient to the customer, allowing the inclusion of things like hot meals and frozen foods. Having the vehicle make a delivery while a customer is at home makes it possible to address the one step in the delivery process that, at least for now, would be too costly to automate fully – the unloading of the vehicle at the home.

Without a human driver, the vehicle can have a small enough payload so that it is cost-effective to dedicate it to making deliveries to individual homes and to wait, if necessary, in the driveway to be unloaded manually.

To support this type of direct home delivery, a new type of logistics network is proposed that consists of a network of small distribution centers (DCs) located near the home. Goods would be delivered to the home in reusable standardized containers transported by driverless delivery vehicles.

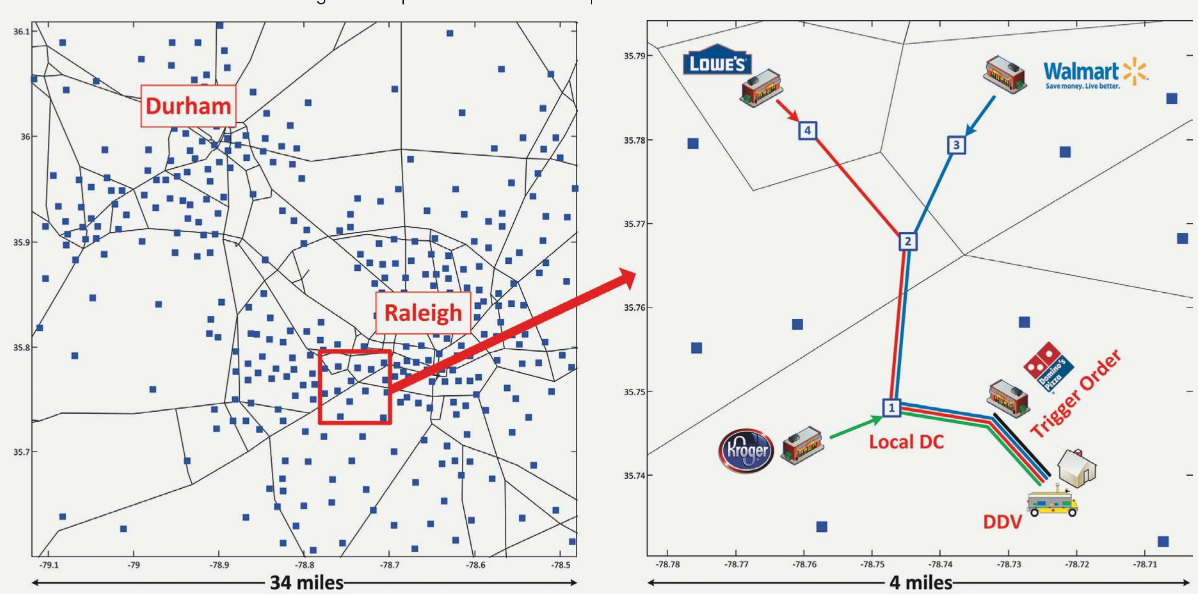
A single shipment delivered to a home can consist of either a direct delivery of a single order from a store or, more economically, several orders from stores at different locations that have been sent to a small DC located near the home and then delivered as one load.

In order to be located close to a home, the size of each DC has to be small, serving just several thousand people. In order to be cost-effective, the loading/unloading, sortation and storage capabilities of the DC should be automated fully, since each container delivered to a home might visit

FIGURE 1

The new delivery network

This home delivery logistics network example on the left, with distribution centers shown as blue squares, covers the Raleigh-Durham metro area in North Carolina. The right-hand panel shows an example of how four orders would be delivered to a home.



(a) DCs covering Raleigh-Durham metro area

(b) Delivery of four orders to a home

a dozen or more DCs while it's in transit. In order for it to be economical to locate a fully automated DC close to a home, the capacity of the storage system should be able to be specified in small fixed-cost increments so that the cost of the DC is proportional to its size.

Pop-up power

The storage system design proposed in this article meets these requirements by using as its primary material handling device arrays of small square modules, each with orthogonal pop-up powered wheels. The arrays are used within each DC and on board each delivery vehicle.

An example of the operation of a home delivery logistics network is illustrated in Figure 1. Three orders originating from stores located far from the home would be sent a DC close to each store and then transported through a sequence of DCs until reaching the DC close to the home.

If these orders do not need immediate delivery, they can accumulate at the local DC. When a new order needs immediate delivery (e.g., a takeout order from a restaurant), it serves to trigger the delivery of all of the accumulated orders to the home in one trip.

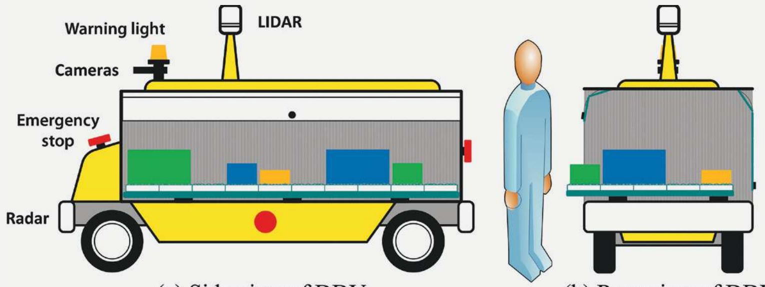
Since the final DC is located close to the home, the lead-time for delivery is short. And since the trigger order is presumably of no value until it is in the hands of the person, it doesn't matter that it has to be unloaded from a vehicle as opposed to waiting for him or her on the front porch, as is current practice for most parcel delivery in the United States. And, of course, an additional benefit of triggered delivery is how it eliminates the potential that packages could be stolen while an order is left unattended on a porch.

The driverless delivery vehicle (DDV) would be a cargo-only version of a self-driving car. A DDV would be a great first area of application for driverless technology since, as compared

FIGURE 2

Have no driver but will deliver

A driverless delivery vehicle (DDV) would have sensors and computers similar to a driverless car, along with additional warning lights and large emergency stop buttons on all sides.



(a) Side view of DDV (b) Rear view of DDV

Shopping 'little and often' will drive big changes

Warehousing and distribution channels worldwide will have to evolve toward agility and flexibility to match changing consumer expectations, according to *Port Strategy* magazine.

E-commerce, home deliveries and a growing trend toward shopping "little and often" are forcing a transition from economies of scale to economies of scope, Peter Ward, chief executive of the UK Warehousing Association, told the publication.

"That means sufficient bandwidth to be able to speed up, slow down and go both ways, handling deliveries and returns," Ward said. "It also means frequent replenishment of smaller, convenient stores."

These days, consumers want to order something online and have it in an hour, or at least by the next day.

"This requires something different to the fixed, linear model based on 'big is beautiful' and everything centralized," Ward said. "We are moving away from traditional out-of-town supermarkets to the convenient stores. So instead of having pallets in and out of one warehouse in the Midlands and lots of 'stack high and wide,' it is more of an immediate supply chain."

James Nicholls, a partner at architect and planner Stephen George, said future warehouse design will have to consider flexibility. Warehouses will need larger yards to handle more light goods vehicles and more doors to allow goods to move more quickly.

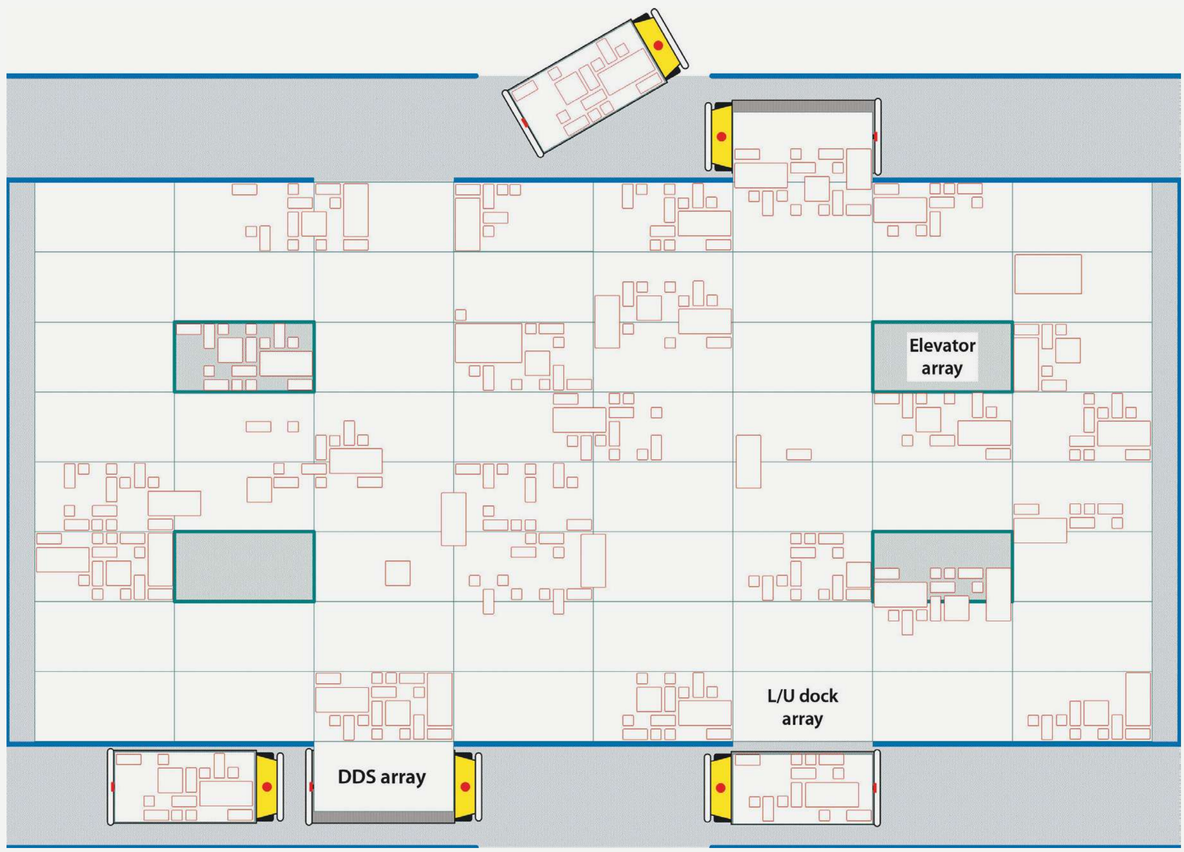
Ports need to figure out how to add value instead of being an essential node in the supply chain that adds cost, Ward said. Port managers should examine how they can help the flow to the supplier by reducing time, cost or both.

Drones and robotics also will pave the way to the future. Amazon's Kiva robots reduce warehouse operating costs by 20 percent, and Maersk Tankers reports that drones could save up to $9,000 per vessel per day by reducing the need to hire tenders for deliveries when a ship is not tied up in port.

FIGURE 3

View from the top

This overhead view shows a four-dock distribution center designed for an automated home delivery network. All loading, unloading, sortation and storage operations are performed on a large open surface composed of arrays of modular material handling devices.



to self-driving cars, driverless delivery vehicles only have to travel short distances at slow speeds to the home. They also would not have to operate in adverse weather conditions, such as snow, and in good conditions they could operate 24/7, with the vehicles used for DC-to-DC line haul transfers during overnight hours. Such operational efficiencies would reduce road congestion.

Figure 2 represents a possible driverless delivery vehicle design. It could be built on top of the chassis of a low-cost electric utility vehicle since it would not have to travel at a high speed (a maximum of 35 mph on roads and 5 mph on neighborhood streets) or for long distances (several miles from a DC to a home and 40 miles between charges).

It would be fitted with the same suite of sensors and computers as used on a self-driving car. However, designers should add a flashing warning light and large emergency stop buttons on all sides since a human passenger will not be on board the vehicle to stop it in an emergency.

And future designs could include LIDAR (light detection and ranging) systems. LIDAR is the most expensive sensor for driverless vehicles, and some designs, like Tesla, don't use it. However, its cost has decreased from $70,000 to $25,000 in the past three years. Perhaps it could be less than $1,000 in five to 10 years.

The driverless delivery vehicle's only payload would be an enclosed array of storage modules that would be accessible for loading and unloading from either side.

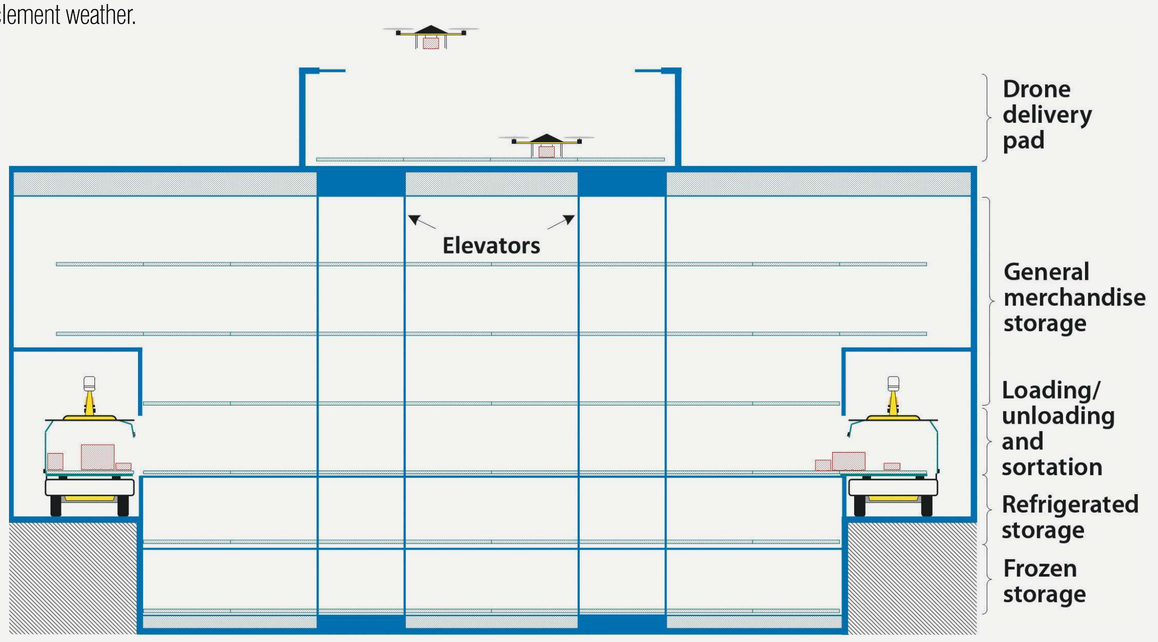
Figure 3 and Figure 4 show a possible design for distribution centers. By using arrays of modules, the design provides the flexibility needed to allow any size container to move to any location at any time by integrating sortation with storage. It enables high cube utilization during sortation and storage, together with full accessibility to different size containers.

High cube utilization reduces the amount of space required, while full accessibility provides the flexibility needed to reroute containers at any time, and it reduces the time and cost associated with retrieving items from storage. All loading/unloading, sortation and storage operations are performed on a large open surface composed of arrays of 25-by-25 centimeter pop-up wheel modules. Only individual arrays are visible, not the individual modules.

FIGURE 4

A look from the side

This side view shows the distribution center's seven levels. Drones could deliver goods to the top level, which could be closed during inclement weather.



In Figure 3, DDVs are at three of the loading and unloading docks. The DC has seven levels. The top level is for delivery drone loading/unloading, where a retractable roof can close in inclement weather. Three levels below the roof pad provide storage for general merchandise. The next (at grade) level is for loading driverless delivery vehicles, unloading and sortation. And the bottom two (below grade) levels are for goods requiring refrigerated and frozen storage, respectively.

Four elevators are used to move loads between levels. As compared to a design that uses traditional sortation and storage equipment (e.g., conveyors or an automatic storage and retrieval system), the proposed module-based design provides complete container accessibility at all times. The design differs from traditional designs by trading mechanical complexity for control complexity: Each module is a simple mechanism, but each container in the system must be continuously controlled (even when it is in storage, since it will be moving continuously to provide clear paths for other loads).

Loading/unloading at a DC dock is shown in Figure 5, where individual modules are visible. At each dock, loads of containers are automatically loaded and unloaded to and from a fixed array in the DC by positioning a moveable array on board a DDV.

ISEs have the tools to design this future

Due to the explosion in the number of companies interested in self-driving cars, most of the basic technology needed to implement the type of DDV envisioned can be assumed to be on track to be available in the near future. The research needed to help realize the proposed home delivery logistics network is focused on the following additional basic technologies, all of which are within the scope of things done in industrial engineering:

- **Storage system control:** At each level in a DC, the movement of containers across arrays of modules gives rise to a complex multiobject motion control problem that requires efficient algorithms to handle simultaneous rectilinear movement of multiple multisize objects (the containers) within an object-dense and limited-free-space environment (the module arrays).
- **Module design:** Develop prototype modules and containers to determine the performance vs. cost trade-off with respect to container transit time across each module. Transit time impacts the time required for movement within a DC, and the cost to build each module is the major cost associated with building each DC. Significant economies of scale are possible in module manufacture since 2.5 billion identical modules would be used in an estimated 100,000 DCs needed to cover the United States.
- **Network coordination:** Develop a mechanism to coordinate the operation of each container, vehicle and DC in the network where, at each DC, containers going to the same DC compete to be in the next transported load, loads going to different DCs compete to be selected by a DDV, and DDVs are compet-

ing with each other to select loads for transport. Unlike most logistics operations, there are significant diseconomies of scale associated with container size, with smaller containers able to be transported at a lower per-unit cost due to their increased ability to fit into a load as it is being formed.

- **Performance analysis:** Estimate delivery times and associated cost for a given logistics network. Initial estimates are that it would cost between $1.50 and $5 to have an entire DDV load of goods sent to a home, depending most significantly on the weekly demand for the service and the cost to build each module used in the DCs and on board each DDV. The transit times of the home delivery network can be modeled as an open network with batch arrivals and batch service at each node (DC) in the network.

A home delivery logistics network, as envisioned, would make it possible to eliminate all nonrecreational shopping for most people.

In addition to general merchandise, meals and groceries could be delivered to the home. This would be especially important for the disabled and the elderly and would allow them to live in a typical sprawling suburban neighborhood and still have their shopping needs met without the need to drive or own a car.

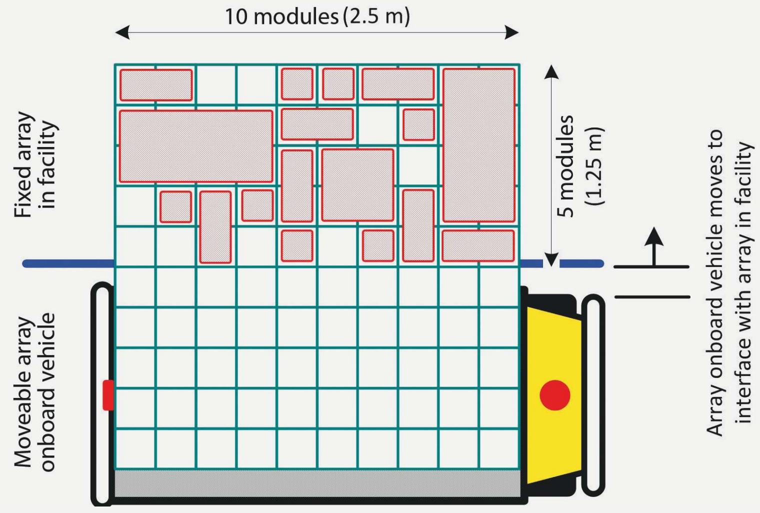
Since empty containers would be available after delivery, each vehicle would provide a low cost means of shipping items from the home; e.g., waste requiring special recycling or sending specimens obtained at home to a lab or goods manufactured by a home-based business.

The proposed delivery service is meant to be cost-effective even during the early stages of development for those like the elderly and disabled who would likely value the service even at a higher cost and longer delivery lead-time (initially, relatively few DCs would be available in the network).

FIGURE 5

Loading up, automatically

At each dock, containers are loaded and unloaded automatically to and from a fixed array in the DC by positioning a moveable array on board a DDV.



The only two major factors impacting overall long-term cost would be the cost of manufacturing the modules and the cost of providing driverless technology for a DDV. A DDV is likely to provide a good testbed to deploy driverless technology because it will operate at slower speeds than self-driving cars. Therefore, DDVs would benefit from nearly all early self-driving car developments.

Initially, the cost of this type of delivery service would only add to the cost of the goods purchased at the store (although it would eliminate the cost and time required for nonrecreational shopping).

Over time, this cost would decrease because stores would be able to eliminate many of their costs associated with stocking shelves and checkout, and they could implement a more efficient means of fulfilling orders, using more automated material handling equipment to receive goods and the same modular storage arrays used in the DCs to load orders directly onto driverless delivery vehicles for shipment to customers.

Existing retail stores would become, in effect, fulfillment warehouses, with possibly a front showroom area for customers to visit. And as the cost of a module decreases, many people might want to purchase a modular storage array for use inside their garage, especially since garage space would become available once people are able to call self-driving cars on demand for their transportation needs. ❖

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