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EVALUATING COST-TO-SERVE FOR A RETAIL SUPPLY CHAIN

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ABSTRACT

Driven by decreasing inventory storage space in stores and a corresponding need to increase delivery frequency, a major retailer is considering adding cross dock nodes, between distribution centers and stores, to its supply chain network. Currently, distribution centers serve stores directly. The retailer would like to understand if introducing an additional node allows for cost-effectively increasing delivery frequency. In the proposed scenario, the additional node would receive products from both the distribution center and upstream suppliers to serve the stores. Implemented as a discrete-event simulation, this cost-to-serve model compares the scenarios by applying costs to simulated logistics events and resource levels. Results suggest introducing new nodes is cost neutral, even considering the reduced transportation costs.

1 INTRODUCTION

McKinsey & Company coined the term "the Wal-Mart effect" to describe the significant impact that Wal-Mart had on the US economy in the late 1990s by driving efficiency in its supply chain and elsewhere in support of its low margin, high volume business model (Lewis 2002). Wal-Mart's drive for efficiency induced similar efficiency among both suppliers and competitors. The US economy is now experiencing what might be called "the amazon effect," with online retailers led by amazon.com forcing traditional retailers (including Wal-Mart) to boost efficiency in both online and in-store channels.

Among the focus areas for these traditional retailers in competing with online alternatives is to maximize the selling potential of store space. The retailer described in this case study not only devoted floor space to high revenue and traffic generating activities, but also increased the its store merchandising footprint at the expense of back room storage. The retailer anticipates that with less storage space, more frequent deliveries will be required to maintain acceptable levels of on shelf availability. The retailer would like to understand the cost implications of several alternative ways of accomplishing more frequent store deliveries.

Currently, suppliers deliver products to the retailer's Distribution Center (DC), which in turn delivers products to stores via multi-stop truckloads as illustrated in Figure 1a. As an alternative, the retailer may serve stores from a cross dock inserted between the DC and stores (see Figure 1b). In the latter case, suppliers deliver the majority of products to the retailer's DC, but select, high volume products are delivered by suppliers directly to the cross dock. The cross dock, which is located considerably closer to stores than is the DC, may or may not include storage space for the high volume products received directly from suppliers. A cross dock with storage space is referred to as a hybrid cross dock, while a cross dock without storage space is referred to as a pure cross dock. In either case, the cross dock merges products received from the DC with products received directly from suppliers and builds multi-stop store delivery routes.

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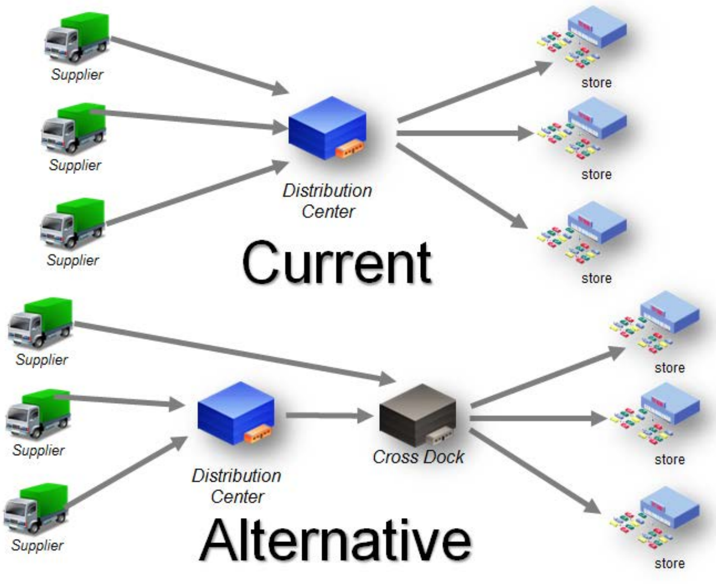


Figure 1: Current and alternative store delivery configuration.

At the same time, the retailer is considering a change to its process for loading and unloading trailers. The current process, known as floor loading, involves manually stacking cases and cartons from the floor of the trailer up. As an alternative to floor loading, the retailer is experimenting with a new approach, referred to here as semi-automated loading. This new approach, which is not detailed here, decreases the time to unload trailers at the expense of trailer utilization. Devices used for the new approach take up space in the trailer, thereby reducing the amount of space available for products.

Scenarios of interest to the retailer vary in terms of store delivery frequency, inclusion of a cross dock or not, type of cross dock, and type of trailer loading. The approach described in this paper for evaluating and comparing these scenarios involves a novel combination of Discrete Event Simulation (DES) and Cost-To-Serve (CTS) modeling. The next section explains the unique contribution of this modeling approach as compared to others described in the literature. Section 3 describes the retailer's supply chain network in more detail, Section 4 covers model implementation, and Section 5 explains how the model was verified and validated and describes and compares scenario results.

2 LITERATURE REVIEW

This paper concerns the application of simulation to evaluate whether or not a cross dock can enable more frequent, cost effective deliveries to retail stores. Not surprisingly, simulation has often been employed to analyze the supply chain in general and various aspects of cross docks in particular. For example, Chang (2001) argued for the value of simulation to address various supply chain problems, outlined a process for conducting a supply chain simulation study, and described data requirements. Cooper (2013) described application of simulation to the supply chain of a medical device manufacturer, which must reduce inventory related costs to enter new geographic markets where expected margins are relatively tight. In the remainder of this section, we describe related applications of simulation and optimization and compare and contrast the corresponding approaches with the approach described in this case study.

Supply chains can vary significantly from industry to industry and depending on organizational role (supplier, manufacturer, retailer, etc.). Several authors created general frameworks for modeling supply chains. Umeda and Jain (2004) documented requirements for a supply chain simulation system including four views-- Organization, Control, Activity and Communication. Umeda and Lee (2004) took those requirements one step further, providing a design specification for a generic supply chain simulation system. The specification included attributes for supply chain entities and interface data requirements. Thierry (2010) explored various simulation approaches for modeling supply chains, including continuous, discrete event and multi-agent simulation.

Modeling a complex supply chain using simulation can be time consuming. A number of authors shortened model development time with configurable supply chain simulation elements. Swaminathan (1998) created software components representing supply chain agents that can be assembled into a model quickly. Agents included structural components for the production and transport of goods and control elements to orchestrate decisions. Thierry (2010) suggested several approaches—abstraction, aggregation and replacing events with formulas or variables—to reduce simulation size.

Simulation has been used to model cross docks in a variety of ways. Rohrer (1995) simulated the hardware and software that closely coordinates cross dock receiving and shipping operations, treating material handling equipment in a detailed manner. Arnaout (2010) simulated flows from warehouses to delivery locations through cross docks, with varying sizes of orders and trucks. Orders for the same delivery location were combined at the cross dock. Galbreth (2008) used simulation to compare direct truckload shipments from suppliers to customer locations with flows through a cross dock, with truckload inbound from suppliers and less than truckload outbound to customer locations.

The simulation model described in this paper differs from simulation models referenced in the literature cited above in a number of respects. For one, the simulation model was for either a hybrid or a pure flow through cross dock rather than only for a pure flow through cross dock. For another, the simulation was combined with a routing optimization procedure to generate cost-effective multi-stop routes from the cross dock to stores. Moreover, the simulation included not only the cross dock, but also an upstream DC and unload operations at stores. Finally, the simulation model was married to a Cost-To-Serve model. Output from the simulation including resource levels and event counts and durations, were fed into a detailed cost model to evaluate scenarios.

Optimization is an alternative approach to supply chain design. IBM Corporation (2014) describes one of many available network design tools that provide the capability to optimize supply chain structure and product flow. Such tools allow scenarios to be defined, evaluated and compared. The chief reasons for adopting Discrete Event Simulation combined with Cost-To-Serve modeling rather than network design optimization include the following:

1. Network design optimization models store deliveries as individual flows as opposed to the multi-stop routes used within Discrete Event Simulation, which serve multiple stores and thereby achieve synergistic cost savings.
2. Network design optimization calculates variable costs at supply chain nodes such as DCs or cross docks as a function of volume and not based on the activity and resource levels as is the case within the simulation model.
3. Network design optimization provides only a coarse-grained way to model capacity constraints at supply chain nodes whereas Discrete Event Simulation provides the capability to model resource constraints at a detailed level.

3 SUPPLY CHAIN NETWORK

As mentioned earlier, the retailer described in this case study would like to would like to investigate alternative ways of accomplishing more frequent store deliveries. The retailer hypothesized that increasing delivery frequency under the current network configuration, with stores served directly from a DC, would be more costly than the alternative network configuration, with stores served from a cross dock inserted between the DC and stores. The following two subsections describe the functioning of the DC, cross dock and stores along with transportation between these nodes for the current and alternative network configurations, respectively.

3.1 Current Network Configuration

To understand the current network configuration and corresponding operations, first consider stores. Store personnel periodically review inventory levels and place orders to replenish levels of products for which on hand inventory is below specified reorder points. (In the case study, store sales and product inventory levels were not tracked. Consequently, store order quantities were based on historical volume.) Store orders are processed by the DC, which ultimately builds truckloads for delivery to stores. Depending on the scenario, each store receives deliveries on one or more prescribed days of the week. When a delivery truck arrives at a store, store personnel assist the driver to unload products and to store those products in the store's backroom. Unloading product at the store requires considerably less time when semi-automated as opposed to floor loading of trailers is employed.

The DC processes store orders by first picking requested products. Products ordered in small quantities are picked by the piece, while products ordered in larger quantities are picked by the case. Piece picking is more resource intensive and hence more costly than case picking. Products are picked from a forward pick area, which is itself periodically replenished from products stored in the DC. Different products picked for the same store are merged in the DC's shipping area and subsequently loaded to a trailer parked at an outbound dock door. Typically, orders for multiple stores to be serviced together are loaded to the same trailer to minimize overall cost based on geography, order sizes and timing.

The DC is located far enough away from stores, over 350 miles on average, that trailers leaving the DC must be relayed or handed off from one driver to another before arriving at stores. While relays prevent individual truck drivers from exceeding government mandated daily hours of service limits, relays also contribute additional cost to store delivery. One driver hauls the trailer from the DC to the relay location and then returns to the DC. A second driver hauls the trailer from the relay location to each store and then returns the empty trailer to the relay location.

The DC periodically places orders with suppliers for products when on hand inventory falls below specified reorder points. Suppliers fill these orders and the included products are transported to the DC via truck. (Supplier order fulfillment processes including transportation are not modeled in the case study since corresponding costs for the retailer do not vary in any of the scenarios of interest.) Inbound trucks are parked at dock doors in the DC's receiving area and unloaded. Products received from suppliers are moved from the receiving area to the DC's storage area in an automated fashion.

3.2 Alternative Network Configuration

To understand the alternative network configuration and its operation, first consider key differences between the alternative and current network configurations. The biggest such difference is the existence of a cross dock between the DC and stores in the alternative configuration. A second difference is that, for the alternative configuration, select high volume products are transported directly from suppliers to the cross dock, whereas all products from suppliers are currently processed through the DC. A third difference is that, for the alternative configuration, the DC can fill trailers for any mix of stores, since store-specific trailer loads are built at the cross dock.

The hybrid cross dock receives inbound trailers from two sources—the DC and suppliers of select high volume products. Products from the DC are labeled by store and are moved directly from the receiving area of the cross dock to the merge area of shipping. Products received directly from suppliers are moved to the cross dock's storage area.

The cross dock builds trailer loads for delivery to multiple stores to minimize overall cost based on geography, order sizes and timing. The cross dock assembles the products required to fulfill each individual store's order by merging products received from the DC with products picked from the cross dock's storage area.

Products are transported from the DC to the cross dock via round trip truckload routes. A single driver transports a trailer from the DC to the cross dock and returns to the DC with an empty trailer. Products are transported from the cross dock to stores via round trip, multi-stop truckload routes. A single driver transports a trailer from the cross dock to one or more stores, assists each store's personnel in unloading the trailer, and then returns the empty trailer to the cross dock. Products are transported from the suppliers to the DC or cross dock. (Transportation of products from suppliers is not considered in the case study since corresponding costs for the retailer do not vary in any of the scenarios of interest.)

4 IMPLEMENTATION

The discrete-event simulation, incorporating all data, scenarios, and routes, is implemented in the Python general purpose programming language using the SimPy discrete-event simulation framework. See Cooper (2013) for a SimPy overview. Events are executed, based on the scenarios, parameters, and data, and then written to a file. The cost calculator can then use this event output file to calculate the scenario costs.

4.1 Simulation

Scenarios are defined in the simulation as a set configuration parameter settings. Example parameters are maximum allowed trailer weight, time required for one worker to piece pick one item, distance from the distribution center to relays, and time required to unhook a trailer. Different scenarios have different parameter settings. For example, the time required to unload a trailer in a semi-automated loading scenario is lower than the time required to unload a trailer in a floor loading scenario.

The simulation also requires input data. Input data from the retailer has to be the same across all scenarios that are to be compared. Input data falls into the following five categories:

1. Product details and characteristics
2. Store locations
3. Store demand
4. Truck routes for store delivery from the DC or from the cross dock
5. Delivery schedule from suppliers to the DC

Products data contains product names, descriptions, and physical characteristics such as weight, and size. Store locations data includes a name and description for each store, the distance from each store to every other store, and the distance from each store to the DC. Store demand data characterizes the demand for each product at each store. A demand profile provides a store's orders for a single week based on history. Users may create demand profiles for each store for each week being simulated, users may create a single, averaged demand profile for each store, or users may create a single demand profile applicable to every store.

A route optimizer, which is a unique feature of the approach described in this case study, generates the truck routes input to the simulation. To ensure the routes are comparable across scenarios, they are generated using a common set of data and parameters. The data set consists of store and network node locations, as well as policy information such as maximum weight, maximum volume, and maximum drive time restrictions. The parameters for the generator may be different from scenario to scenario. For example, in semi-automated loading scenarios, the time to unload trailers at stores is much lower than in floor loading scenarios, so a different set of routes are generated.

The supplier order process, based on the supplier delivery schedule data, runs once per day to schedule the arrival of products to the DC, to the cross dock, or both. As scheduled, the receiving processes start. The truck arrives and undergoes processing for some amount of time. Processing represents time spent on scales, checking paperwork at a security gate, and any other activity that occurs before the trailer is brought to an unloading dock. At the dock, the trailer is unloaded and the products placed into the storage. The times required to take products off the trailer and bring the products to storage is logged.

Products that have been placed into storage are considered available inventory. Even while shipments are arriving and trailers are being unloaded, store orders are being placed and fulfilled. Each day, the DC performs order fulfillment for the routes requiring delivery as determined by the route optimizer. Store orders along the required routes are sorted by route so that order fulfillment can begin. Order fulfillment picks all orders for all stores in a route together and moves the products to the loading dock to be sorted and loaded onto a trailer. The picking process represents a person picking products at a flow rack in either cases or pieces. The process simulates picking from the flow rack as well as replenishment of the flow rack. Picking occurs at both the DC and, in the alternative network, at the cross dock.

The simulation logs each activity and any associated contextual information. An example event log is shown in Table 1.

Table 1: The event log contains timing and contextual information for each simulated activity.

ACTIVITY	START	END	ORDER	ROUTE	STORE
PICK	1440.00	1440.15	12	154	12739
CASE MOVE	1440.15	1440.31	None	None	None
PICK	1440.00	1440.43	71	977	7110
CASE MOVE	1440.43	1440.59	None	None	None
PICK	1440.00	1440.64	31	344	3177
CASE MOVE	1440.64	1441.00	None	None	None
PICK	1440.00	1440.68	71	977	7110
PALLET MOVE	1440.68	1440.69	None	None	None

The example log in Table 1 shows a section of a log file in which the simulation involving the picking and moving of products within the DC. The columns include a start and end time followed by applicable contextual information. The start and end times represent simulation clock time in minutes. The order, route and store fields contain identifiers that can be joined to corresponding detail data. In the case of the pick activity, an order and a route can be associated with the products as they are picked and recorded. Move activities, however, are not associated with an order or with a route. All activities, not just those shown in the example, are logged.

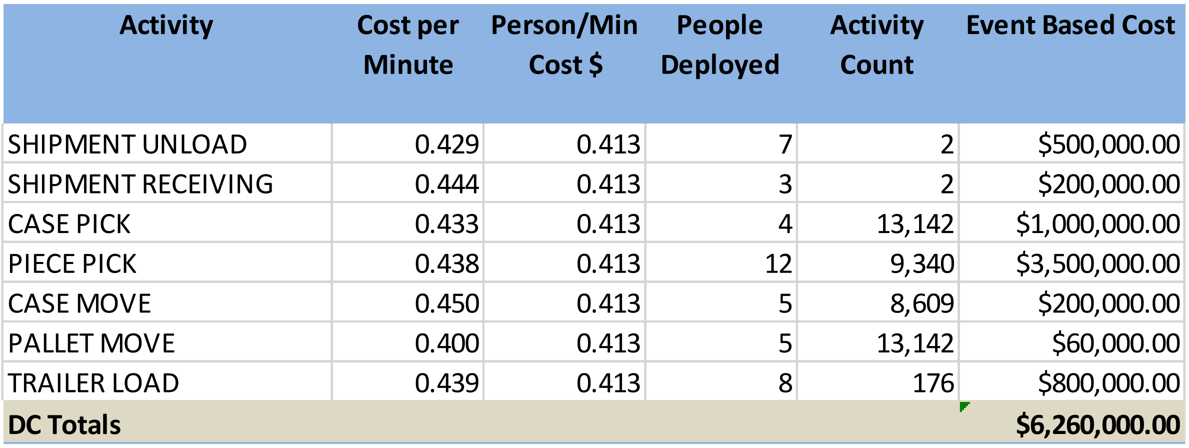
After picking is complete, the products, which are already assigned to a store and route, are moved to the loading dock. When all the products required to fill the route's orders have been collected at the loading dock, then those products are loaded onto a trailer. Trailers depart immediately when loading is finished. Trailers departing from the DC in the current network travel to the relay points and then to the stores of the route. Trailers departing from the DC in the alternate scenario go to the cross dock, and then to the stores of the route. Trucks returning from store deliveries, relay points, and the cross dock are also simulated.

4.2 Cost Calculations

The cost calculator its primary input from the event output file. The cost calculator receives 1) the type of activity that occurred, 2) start time, end time, and duration of the activity, 3) quantity and types of resources involved in executing the activity, and 4) contextual information to link events to specific stores or routes. The cost calculator also takes as input labor costs by geography of each activity and overhead time and costs of each activity. The cost of an individual activity is calculated by multiplying the duration of the activity by the associated resource costs and adding the overhead costs. The costs of every activity can then be aggregated into a total scenario cost. Activities, such as picking, performed in multiple locations will likely have different costs at each location.

Table 2 shows costs calculations applied to sample activities at the DC for a stylized example. Cost per minute is a multiplier for the duration of the activity; cost per minute is based on the overhead costs of the facility and throughput speed of the process. Person per minute cost is intended only to account for the time effort of the person to perform the activity. People deployed is the maximum number of people that could be allocated to an activity. In this scenario, the maximum number is rarely utilized. Activity count is the total number of times the activity occurred. The event-based cost is the total cost of each activity across the simulation run.

Table 2: Example cost calculations.



Activity	Cost per Minute	Person/Min Cost $	People Deployed	Activity Count	Event Based Cost
SHIPMENT UNLOAD	0.429	0.413	7	2	$500,000.00
SHIPMENT RECEIVING	0.444	0.413	3	2	$200,000.00
CASE PICK	0.433	0.413	4	13,142	$1,000,000.00
PIECE PICK	0.438	0.413	12	9,340	$3,500,000.00
CASE MOVE	0.450	0.413	5	8,609	$200,000.00
PALLET MOVE	0.400	0.413	5	13,142	$60,000.00
TRAILER LOAD	0.439	0.413	8	176	$800,000.00
DC Totals					**$6,260,000.00**

5 VERIFICATION, VALIDATION, ANALYSIS, AND RESULTS

The simulation model and cost model were verified using standard techniques including code review and unit testing. Both inputs and outputs of the two models for the existing scenario were validated through comparison with existing reports and metrics together with expert review. For example, the optimized store delivery truck routes for the current network configuration were compared with current routes based on such factors as average number of stops and total miles. Inputs for alternative scenarios were validated in a similar manner, while outputs for those scenarios were validated by analysis of directionality and consistency from scenario to scenario and expert review. The focus of validation was on all costs, DC and cross dock activity levels, and store delivery route efficiency.

Table 3 includes a list of scenarios. Scenarios differ in three dimensions—network, frequency of delivery and type of trailer loading.

Table 3: List of scenarios.

Scenario	Supply Chain Network	Store Delivery Frequency	Trailer Loading Type
1	Existing (DC only)	Once weekly	Floor
2		Twice weekly	Floor
3			Semi-automated
4	Proposed (hybrid cross dock)		Floor
5			Semi-automated
6	Proposed (pure cross dock)		Semi-automated

Indicative cost results for these scenarios are shown in Figure 2. Scenario 1, which serves as a baseline for comparison, represents the current operation, with stores receiving deliveries once weekly directly from the DC and floor loading of trailers. While Scenario 1 has lowest total cost among all scenarios, Scenario 1 does not provide for the desired twice weekly store delivery. Scenarios 2 and 3, which leverage the DC and no cross dock to serve stores, do include twice weekly store delivery. As expected, both of these scenarios are more expensive than Scenario 1 due to increased transportation costs to accomplish twice weekly store deliveries. Scenarios 2 and 3 leverage floor and semi-automated trailer loading, respectively. Scenario 3 is more expensive than is Scenario 2 due to increased trailer loading costs at the DC and increased transportation costs resulting from lower trailer utilization.

Scenarios 4 and 5 provide twice weekly store delivery with stores served from the hybrid cross dock. The two scenarios differ in terms of how trucks are loaded; in Scenario 4, trucks are floor loaded while in Scenario 5, trucks are loaded in a semi-automated fashion. As was the case for Scenarios 2 and 3, semi-automation is more expensive than floor loading due to increased trailer loading and transportation costs. The cost for Scenario 5 is higher than that for Scenario 4. The cost for Scenario 4, wherein stores are served through the hybrid cross dock, is quite similar to that of Scenario 2, wherein stores are served directly from the DC.

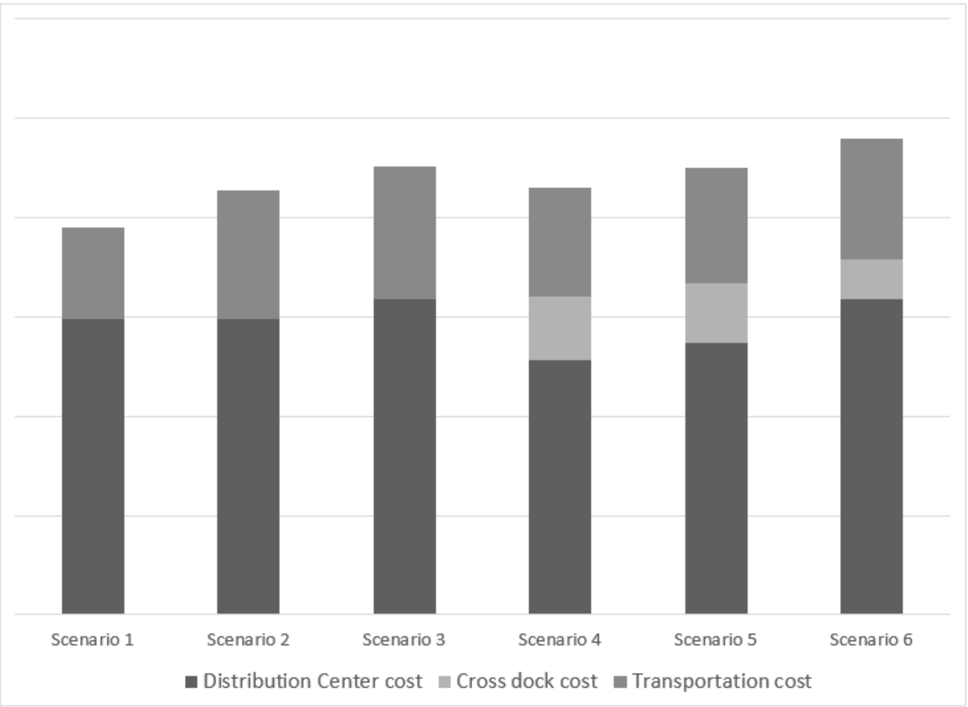


Figure 2: Cost comparison for scenarios of interest.

The most expensive scenario is Scenario 6, wherein stores are served through the pure cross dock. Operating the pure cross dock, which involves no storage and picking of products, is less expensive than operating the hybrid cross dock, which does include these activities. In Scenarios 4 and 5, the new cross dock costs are offset by a decrease in DC cost, but that is not the case for Scenario 6.

In summary, scenario comparison reveals the following key results:

1. Transportation cost to serve stores twice weekly directly from the DC is higher than the corresponding once weekly cost.
2. Overall cost to serve stores twice weekly through the hybrid cross dock with floor loading is roughly equal to the corresponding cost to serve stores directly from the DC.
3. Combined loading and transportation costs are higher with semi-automated loading of trailers than with floor loading.

These results suggest that the retailer can achieve its desired twice weekly store delivery, either leveraging a hybrid cross dock or not. As expected, increased delivery frequency will be accompanied by increasing total costs, but not appreciably so. Moreover, with increased delivery frequency will come additional, inventory-related benefits (e.g. reduced safety stock and decreased stock out duration) which were not considered in the case study but that can at least partially offset increase in other costs.

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