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Abstract — To close the gap between current distribution operations and today's customer expectations, firms need to think differently about how resources are acquired, managed and allocated to fulfill customer requests. Rather than optimize planned resource capacity acquired through ownership or long-term partnerships, this work focuses on a specific supply-side innovation – on-demand distribution platforms. On-demand distribution systems move, store, and fulfill goods by matching autonomous suppliers' resources (warehouse space, fulfillment capacity, truck space, delivery services) to requests on-demand. On-demand warehousing systems can provide resource elasticity by allowing capacity decisions to be made at a finer granularity (at the pallet-level) and commitment (monthly versus yearly), than construct or lease options. However, such systems are inherently more complex than traditional systems, as well as have varying costs and operational structures (e.g., higher variable costs, but little or no fixed costs). New decision-supporting models are needed to capture these trade-offs.

Keywords—platform; logistics; sharing economy; facility location.

I. Introduction

It is a disruptive time in distribution and logistics. Today's customers expect quick delivery of a wide assortment of products, in small units, to many dispersed locations at low costs. This is fundamentally different than yesterday's demand, which aggregated at fixed (store) locations. Specifically, the proliferation of e-commerce has fundamentally changed demand characteristics - changing order profile structures, handling units, lead time expectations, and the number of delivery locations. Existing distribution solutions, which built efficiencies through economies of scale for known, fixed, and aggregated demand points are often too rigid for today's customers. This has left a gap between what today's customers demand and what companies can deliver. Consequently, our hypothesis is that current distribution systems are optimized for yesterday's customers. Distribution systems designed for retail store orders are unable to meet today's customer requirements; fulfillment costs average 18 cents for every $1 of e-commerce revenues [1], leaving most retailers today unprofitable in their e-commerce businesses [2-4]. A recent survey found only 10% of global brick-and-mortar retailers are making a profit fulfilling e-commerce orders [5].

To close the gap between current distribution operations and customer expectations, we need to think differently about how resources are acquired, managed and allocated to fulfill customer requests. Rather than optimize planned resource capacity acquired through ownership or long-term partnerships, this work focuses on a specific supply-side innovation, on-demand logistics platforms. Such systems create spatial and temporal resource elasticity by accessing underutilized resources on-demand, where and when needed. We first explore in Section 2 on-demand distribution platforms in general, defining the system's components and fundamental characteristics. Then in Section 3, we compare and contrast on-demand distribution business models with traditional models, in terms of acquiring, managing, and using distribution resources. In Section 4, we expand on a specific application – on-demand warehousing models, defining three primary benefits: capacity granularity, commitment granularity, and access to scale. In Section 5 we briefly review related literature and identify open resource gaps. Then in Section 6, we explore how a company's strategy, costs, and operations can change when they consider on-demand warehousing models, in conjunction with the more traditional build or lease distribution alternatives. Section 7 concludes with directions for future research.

II. On-demand distribution Systems

On-demand business models, exemplified by prominent companies like Uber and Airbnb, operate marketplaces, in which a crowd of independent entities rent access to their resources. On-demand business models are part of the sharing economy and collaborative consumption movements [6]. Media coverage has been plentiful, including *Time Magazine* naming sharing as one of the "10 ideas that will change the world," [7]. Nonexistent just ten years ago, this disruptive new business model is now a $75 billion industry [8] with investments made by start-up and Fortune 500 companies, not-for-profits, and government entities [9].

A special type of on-demand systems, are on-demand distribution systems, which move, store, and fulfill goods by matching autonomous suppliers' resources (warehouse space, fulfillment capacity, truck space, delivery services) to requests on-demand. On-demand distribution platforms facilitate the interactions between supply owners and requests and include companies like Uber Freight, Flexe, Deliv, Instacart, Postmates, Cargomatic, GrubHub, and onRout. The nonprofit American Logistics Aid Network matches logistics capabilities with community and relief agency disaster needs. In these examples, the platform owns no resources, instead is a 3rd-party marketplace. Alternatively, a platform can supplement an organization's fixed capacity by accessing resources on-demand. Examples are Wal-Mart's Associate Delivery Program [10], which utilizes store associates to fulfill and make deliveries of online order requests on their way home; Amazon Flex, which supplements traditional courier services with crowd participants and their vehicles, and nonprofits supplementing regular staff and volunteers with on-demand volunteers to make deliveries.

An on-demand system consists of three primary components.

1. **A set of supply owners:** Supply owners are the primary owners of the resources and get to decide whether or not to allow access to their resources. Supply owners can be individuals (such as in the Uber model) or businesses (which is more common in on-demand distribution applications).
2. **A set of demand requests:** Demand requests are indicated needs for resources made by secondary entities (either individuals or businesses) who do not own the resources. In this work, when we refer to users of the system, we are referring to a demand request.
3. **A central mechanism:** A central mechanism, also known as a platform, is a third-party organization responsible for managing the interactions between the supply owners and the demand requests. The central mechanism owns no resources; instead operates a marketplace.

On-demand distribution systems use internet-based platforms to provide wide-reach visibility into untapped resource capacity and demand requests. The central mechanism designs and operates a process to match specific resource capacity with demand requests. Users of on-demand systems can access resources when and where they are needed. This creates a dynamic supply network able to respond to changing demand requirements and can increase utilization of otherwise, underutilized, or idle resource capacities. However, due to the following fundamental characteristics, on-demand systems operate differently than traditional ways of acquiring, managing, and using distribution resources:

1. **Marketplace.** On-demand systems operate a two-sided marketplace to match supply owners' resources with demand requests. This comes with central mechanism challenges of scalability and balance. On-demand systems are viable only if a "critical mass" of both supply owners and demand request users participate. Network effects, which denote the value of a solution increases in proportion to the number of users of a solution, are also at play. Further complicating on-demand design and operation is the need to grow to this critical mass in a balanced way (e.g., the number of supply owners and demand requests participating in the marketplace needs to grow together).
2. **Open Market or Open Crowd.** Supply resources originate from a crowd of independent entities, and membership to the crowd typically has a low barrier to entry. Matching in an open system typically uses a one-size fits all, pre-determined terms of agreement, which sacrifices specific requests and negotiation of terms. However, this standardization reduces decision lead times and enables demand participants to use and find many different suppliers, all tied together through a single platform and contract. Open systems create a fluid set of supply owners, and hence supply capabilities and characteristics. Such open systems have advantages in terms of reach and agility. However, this also creates challenges for demand-side users of the system, specifically around capacity.
3. **Capacity.** Supply owner participation is what constitutes capacity. Instead of setting capacity, capacity needs to be enticed from the fluid set of supply owners. Quality and assurance of service, as well as how best to entice supply owners to participate and make their resources available are important design considerations for central mechanisms. For demand requests this creates challenges in terms of decision making, given uncertainty in what resources and the quality of those resources will be available on the platform in the future.
4. **Resource Management and Allocation.** Critical to a central mechanism's success is its ability (1) to entice significant participation by both supply owners and demand requests and (2) to accommodate their preferences in resource management and allocation decisions to ensure repeat participation. Demand requests expect high-quality service (e.g., tasks completed to desired specifications within a given time). This is achieved when the central mechanism takes a systematic view of allocating supply owners' distributed resources and develops review mechanisms to promote high quality participation. Demand requests benefit from a large participation pool of supply owners and when the central mechanism retains some control to ensure service expectations are met. Because independent entities provide access to their supply resources, resources are not owned or employed by a central organization. Supply owners desire autonomy and discretion to decide when and how they want to provide access to their resources based on their individual preferences. If discretion is not provided, this limits supply owner participation. Preferences are not always aligned. Take for example a crowdshipping application, like Deliv or Cargomatic. The supply owners are drivers that prefer delivery tasks with origin and destinations on their current route or to a high populated area (where another demand request is likely). Demand requests want their item to be picked up quickly (preferring the closest driver). The central mechanism wants to maximize the number of successful matches and repeat participation by both supply owners and demand requests. This leads to interesting trade-offs and an important design consideration is how best to design matching of decentralized supply and decentralized demand. Centralized, top-down approaches typically limit participation. Decentralized approaches struggle to make matches quickly. A hierarchical approach capturing systematic

resource decisions and prioritizing quick time to match, with an ability of supply owners and demand requests to accept or deny matches that do or do not meet their preferences is recommended.

5. **Online-to-Offline.** Supply owner's resources and demand requests are matched online using a computer application, often on a mobile device, but the logistics service is performed offline (physical transport, order fulfillment, or storage and movement of goods). The online visibility created by the central mechanism is required before the offline service can occur.
6. **Unlocks Underutilized Capacity through Technology.** On-demand systems utilize technology platforms to provide visibility into underutilized capacity, as well as a large reach for demand requests. This results in potential asset utilization increases.

III. Compare and Contrast Traditional Busines Models with On-Demand Distribution Systems

In this section, we compare and contrast traditional business models (e.g., UPS, J.B. Hunt [10], Kenco, Americold) with on-demand distribution systems (e.g., Flexe, Instacart, GrubHub, Postmates, Uber Freight, Cargomatic, Flow Space). This comparison is made in terms of acquiring, managing, and using distribution resources.

A. Supply Resource Acquisition

Supply resource acquisition is about how supply resources are acquired. In a traditional business model, a single company acquires resources by either owning them or accessing them through long-term commitment contracts. Ownership or long-term contracts of assets results in relatively fixed capacity. To buffer against demand and inventory variability over time, companies can be (1) proactive, acquiring additional capacity to meet peak demands, knowing such capacity will sit idle during less-than-peak periods; or (2) reactive, acquiring capacity for a given design parameter (e.g., two times the mean, or the 95th percentile). Then, when demand needs exceed this capacity, reactively acquire capacity through overtime, outsourcing, or buffering with time (demand requests completed late). On the other hand, if a business acquires resources through an on-demand distribution system, capacity can be elastic, as platforms enable the firm to scale capacity up and down, dynamically adjusting capacity needs to meet demand. To facilitate this, the platform (central mechanism), which owns no assets, needs to entice supply owners to provide access to their resources in a balanced way with demand requests.

B. Supply Resource Management

Supply resource management considers incentives and controls needed to manage resources, as well as decision making to match specific resources to specific customer requests. In a traditional business model, supply resources are under the company's control; thus, resource capacities are typically known. This enables systematic supply resource management planning, holistically allocating specific resources to demand requests. In on-demand distribution systems, neither supply nor demand requests are under direct control of the platform. This requires incentives to attract both supply and demand. Current incentives to attract supply resources are flexibility and the ability to capitalize on otherwise idle or sunk costs. An additional challenge is the need to facilitate matching of decentralized entities (in which a strictly centralized optimization approach is no longer applicable), and thus systematic efficiency can be lost.

C. Supply Resource Use: The Supply Chain Network

A traditional business operates a fixed, static supply chain network. Typically, there is a few-to-many configuration, with known and finite participants, transfer points, and entry points. This has advantages to coordination and resource investment, but can lead to rigid, expensive supply chains, especially at the last mile when demand is dynamic. On-demand distribution systems can enable a dynamic supply chain network, in which a many-to-many configuration is possible. With open platforms, the number and locations of resources can be magnitudes greater than a company's owned resources. Coordination, authentication, and possibly security and quality become more complex. Yet, by tapping into resources on-demand, can potentially improve adaptability and resiliency.

IV. On-Demand Warehousing Models

In this section, we explore a specific on-demand distribution business model -- on-demand warehousing models. These systems operate marketplaces to connect companies who have extra warehouse space and fulfillment services to companies who need extra space or fulfillment services. With the advent of on-demand warehousing models, companies have three options for increasing their storage and distribution needs: (1) construct a dedicated distribution center, (2) lease for long-term use, or (3) share access to a facility on-demand for short-term use. Next, we identify three primary benefits of an on-demand warehousing model.

A. Benefits of On-Demand Warehousing Models

As illustrated in Figure 1, the three distribution options vary in terms of capacity granularity, commitment granularity, and access to scale.

Capacity granularity is defined as the minimum capacity that can be acquired by a given distribution alternative. Capacity granularity is measured for construction in full building units (e.g., number of warehouses), in square feet for lease, and in pallet positions in the on-demand option. Capacity granularity influences a company's flexibility and scalability.

Commitment granularity is defined as the minimum commitment (in time units) a firm must maintain their decision. The commitment granularity of new *construction* is related to the payback period for needed return on investment, which is typically at least 5 years. For *leasing*, because of long decision lead times, negotiation periods, contracting and minimum leasing periods, a common commitment granularity is 1 to 3 years. With *On-Demand* commitment granularity is typically monthly. The on-demand pricing structure are per pallet and do not include fixed charges (which removes the high costs of changing decisions common in other warehousing options). They have short predefined leasing periods (e.g., one month

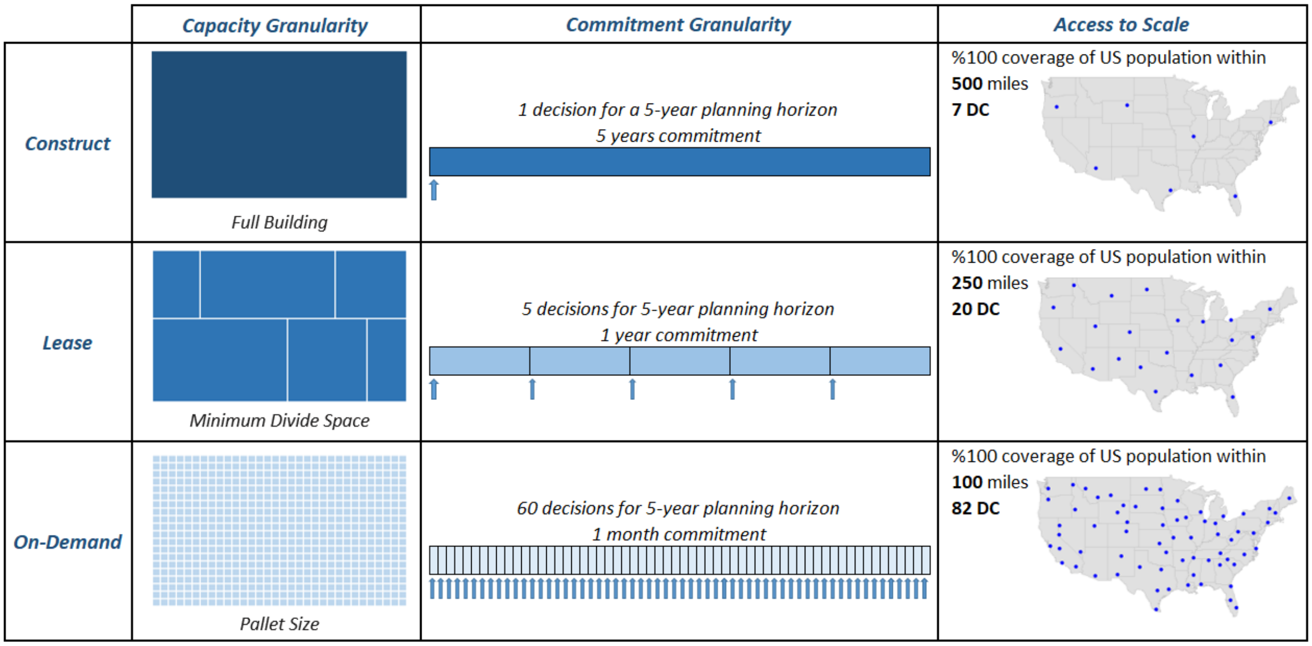

Fig. 1: *Comparison of construct, lease, and on-demand options in terms of capacity granularity, commitment granularity, and access to scale.*

minimum). Platforms standardize contracting, which reduces the setup time required for negotiation and agreement to terms. Because of decreasing commitment granularity, on-demand alternatives provide flexibility due to increased number of decision-making opportunities.

Access to Scale is defined as the percent of demand reachable within a given distance from distribution resources. The name of the game in distribution today is speed or reducing customer response times. Moreover, what drives response times is the distance from resources to demand points. When companies own their distribution resources, this allows them to operate only a handful of facilities, making for long last leg deliveries to fulfill customer requests. Quick deliveries with only a few distribution locations require expedited shipment methods, which are more expensive transportation modes. Access to scale can be increased without fixed building costs by collaborating and accessing distribution resources through an on-demand system rather than through ownership.

These three benefits are interconnected; if a company decides to build a facility, this is a strategic decision, in which initial large fixed costs drive long commitment granularity, but if used at full capacity, results in lower variable costs. Whereas in on-demand platform systems, distribution resources can be acquired at the pallet level and for short one-month commitment periods. This can lead to improved flexibility and agility, as well as access to scale, but also can make for more complex operations and systems. Variable costs are higher in on-demand systems than construct or lease options; thus, trade-offs exist, and likely a combination of options is best for most companies.

V. Related Literature and Open Research Gaps

Two basic questions motivate this work. When and how much value is there for users to adopt on-demand distribution systems? How should companies update their distribution capacity decisions based on the availability of on-demand alternatives? While answers to these questions are related to existing work in facility location, supplier selection, and on-demand systems, existing work is not able to capture the characteristics and benefits needed to answer these questions.

A. Facility Location Models

A vast literature of facility location models exist [12-20]; however, needed are dynamic capacitated facility location-allocation models able to capture the unique characteristics of facility location-allocation problems when a firm has the option to utilize build, lease, and on-demand systems simultaneously.

- *Modeling different commitment granularities of distribution alternatives in a multi-period planning problem.* While research exists considering strategic and tactical decisions based on the warehouse type (private-public) [21-24], these either fail to reflect the needed flexibility in decision making or do not capture the varying costs and resource management policies of three warehouse types. For example, existing studies do not allow closing of private warehouses once opened [24,31], or only allow capacity adjustments and location changes to be made at specific predefined strategic decision periods [23,24]. Others do not take into account commitment constraints that vary by warehouse type [25].
- *Modeling less restrictive capacity adjustment options.* While existing literature separately captures the features needed, no models exist to simultaneously capture: the need for multiple types of facilities in one location [26, 27],

capacity adjustment through opening and closing facilities [28-33], capacity expansion a possibility during the planning period (for leasing options) [34], modular capacities (for on-demand options) [26]. Other articles capture restrictions on when opening/closing facilities can occur [35], expansion is possible, but contraction is not possible, and only incremental, increasing demand is considered [36-38].

B. *Supplier Selection Models*

A wide range of supplier selection research exists [39-43]. Different from traditional outsourcing or supplier-customer relationships, on-demand distribution systems facilitate sharing of underutilized distribution assets or services. Such sharing by companies, whose core business focus is not outsourcing, creates new dynamics not captured in existing supplier selection models. A lack of quantitative models exists to aid in understanding who, when and how to utilize on-demand strategies. Supplier selection models may be adapted for use when a firm is using an on-demand system for storage capacity in inventory overflow situations, in which the outsourcing decision is independent of demand locations. However, supplier selection literature ignores the location aspect of options and the trade-off regarding distribution facility costs with transportation costs.

C. *On-Demand Models*

On-demand, also known as resource sharing platforms, have garnered an emerging body of research. This includes many descriptive studies [44-46], and an emerging body of prescriptive models [47, 48]. Dynamic ride-sharing matches drivers with riders to share one-time trips [49-57]. Crowdsourced delivery taps into independent entities to make deliveries (typically last-mile deliveries to consumers) [58-60]. On-demand distribution systems are aligned with the Physical Internet movement [61, 62]. While platform systems in general, and logistics platforms in particular, are an emerging business and research area, still needed are innovative models and solution approaches specific for the design of on-demand distribution platforms and for decision supporting models for users of on-demand distribution systems.

VI. DATA AND ESTIMATION OF CAPACITY GRANULARITY, COMMITMENT GRANUALARITY, AND COST CALCULATIONS

In this section, we provide data and ways to calculate capacity granularity, commitment granularity, and cost structures for three distribution options (construct, lease, and on-demand). We use the index a to denote the set of alternatives, which consists of the distribution option and its capacity (e.g., lease a 70,000 pallet location facility); *j* to denote the set of distribution candidate locations; and *p* to denote the set of time periods. To capture varying operational characteristics, specifically capacity and commitment granularities varying by distribution alternative, we define K_{jp}^{a} to denote the pallet capacity of distribution center at location j for alternative a in time period p, and N_a to denote commitment granularity in number of periods for alternative a. Capacity granularity is defined in terms of demanded units, which in this work we assume is pallet units. However, most of the facility cost references are in cost per square foot (sf). Thus, the following formula converts between facility size (in sf) and pallet spaces. This requires an input $\propto$, which is an estimate for the percent of the facility used for pallet storage.

$$DC\ size\ (in\ sf) = \frac{K_{jp}^{a}\ *\ pallet\ size\ (in\ sf)}{\#\ of\ vertical\ levels * \propto}$$

Table 1 provides common alternatives, capacities and commitment granularities. For conversion from pallet units to square feet, 13.30 SF/pallet (40”x48” inch standard GMA pallet) is used. Furthermore, we assume four levels of storage and $\propto$ =70% efficiency of the total warehouse space is for pallet storage. For example, 10,000 pallet spaces require $\frac{10{,}000\ x\ 13.30}{4\ x\ 0.70} = 47500\ \text{ft}^2$.

TABLE 1: DISTRIBUTION ALTERNATIVES, CAPACITY GRANULARITIES AND COMMITMENT GRANULARITIES

A	Type	Capacities (K_{jp}^{a}) & equivalent ft²	Commitments ($\boldsymbol{N_a}$)
1	Construct (Small size)	30,000 pallets 142,500 ft²	60 months
2	Construct (Med size)	70,000 pallets 330.000 ft²	60 months
3	Construct (Large size)	160,000 pallets 760.000 ft²	60 months
4	Long-term lease (Capacity 1)	5,000 pallets 23,750 ft²	12 months
5	Long-term lease (Capacity 2)	10,000 pallets 47,500 ft²	12 months
6	Long-term lease (Capacity 3)	20,000 pallets 95,000 ft²	12 months
7	Long-term lease (Capacity 4)	30,000 pallets 142,500 ft²	12 months
8	Long-term lease (Capacity 5)	70,000 pallets 330,000 ft²	12 months
9	Long-term lease (Capacity 6)	160,000 pallets 760,000 ft²	12 months
10	On-demand	Uncapacitated	1 month

A. *Cost Structure and Data Estimation*

A fundamental trade-off in determining a distribution network is the need to balance facility costs with transportation costs. Thus, in this section we articulate the different cost structures when construct, lease, and on-demand distribution alternatives are available to a firm to create their distribution network. First, we break the facility cost components into:

- F_{jp}^{a} Cost of initial set-up/contract/building of an a type distribution center at location j in time period p.
- R_{jp}^{a} Fixed cost of keeping open an a type distribution center at location j in time period p
- H_{jp}^{a} Cost of holding one unit in an a type distribution center at location j in time period p

- G_{jp}^{a} Cost of handling one unit in an a type distribution center at location j in time period p

For the majority of distribution center cost estimations, [63] is used for construction and lease alternatives, and [64] for on-demand alternatives. The average value for each state is used to define the related locations' setup (F_{jp}^{a}), holding (H_{jp}^{a}) and handling (Y_{jp}^{a}) costs. The initial set-up costs are defined as (a) 15% of the total cost of constructing a new DC for construction options, and (b) one month rent for the leasing options. For the construction option, we selected 15% because privately owned DCs can be converted into capital in the real estate market. Thus, the start-up costs in the model are defined at a much lower level of the total initial investment. To estimate fixed operational costs (R_{jp}^{a}) of the construction and the lease option, [65, 66] are used. Table 2 summarizes facility cost component references and calculations.

TABLE 2: CALCULATION AND COST REFERENCES OF FACILITY COST FACTORS FOR DISTRIBUTION ALTERNATIVES

Type	**Cost of initial set-up** (F_{jp}^{a})	**Fixed cost of keeping open** (R_{jp}^{a})	**Cost of holding one unit** (H_{jp}^{a})	**Cost of handling one unit** (G_{jp}^{a})
Construct	Capacity x Average SF investment cost [62]	Fixed operational costs depending on the size [64,65]	None	None
Lease	Capacity x Average SF leasing cost [62]	Capacity x Average SF leasing cost [61] and fixed operational costs depending on the size [64, 65]	None	None
On-demand	None	None	Average Cost [63]	Average Cost [63]

Table 3 provides the pallet storage cost per pallet per month, calculated using two separate equations. For the construct and lease options, these monthly per pallet costs are calculated as:

$$Pallet\ Storage\ Cost = \frac{\frac{F_{jp}^{a}}{N_a} + R_{jp}^{a}}{K_{jp}^{a} * \beta}$$

Where, β denotes the utilization of pallet spaces.

For the on-demand option, monthly holding costs are given in pallet units. This holding cost is combined with an additional fixed handling cost per pallet, charged regardless of the storage duration.

$$Pallet\ Storage\ Cost = H_{jp}^{a} + \frac{G_{jp}^{a}}{Storage\ Duration}$$

In Table 3, a bound for the on-demand pallet storage cost is given. The upper bound is derived using the minimum storage duration (1 month); the lower bound is derived using the maximum storage duration (the planning horizon, 60 months).

TABLE 3: PALLET STORAGE COSTS OF ONE PALLET PER MONTH FOR DISTRIBUTION ALTERNATIVES AT 100% AND 80% UTILIZATION

A	Type	Capacity (K_{jp}^{a}) (in pallets)	Pallet storage cost per pallet per month with β =100% utilization	Pallet storage cost per pallet per month with β =80% utilization
1	Construct	30,000	\$2.02	\$2.53
2	Construct	70,000	\$1.89	\$2.36
3	Construct	160,000	\$1.73	\$2.16
4	Lease	5,000	\$2.27	\$2.84
5	Lease	10,000	\$2.27	\$2.84
6	Lease	20,000	\$2.25	\$2.81
7	Lease	30,000	\$2.23	\$2.79
8	Lease	70,000	\$2.15	\$2.69
9	Lease	160,000	\$1.97	\$2.46
10	On-demand	Uncapacitated	\$7.96 - \$15.63	\$7.96 - \$15.63

Table 3 illustrates that construction options have the advantage of economies of scale (i.e., the per pallet storage costs are lowest for the construct options). However, for construct and lease, these per pallet costs are a function of pallet utilization and costs increase as utilization goes down.

Freight costs are calculated in \$ per pallet per mile. Data from [67] is used to estimate 53' dry freight costs per mile. To convert data, given in truckload costs per mile, the price per pallet is calculated as a function of the truck load size (assumed to be 30 pallets [68]). From supply locations to DCs (inbound freight costs) the trucks are assumed on average 75% utilized; and from supply plants and DCs to demand locations (outbound freight costs), the trucks are assumed 60% utilized [69]. The US average cost per mile is used for inbound freight costs; for outbound from DCs to demand points, the regional average costs are used. This results in average cost per pallet per mile to be between \$0.082 and \$0.102.

VII. FUTURE RESEARCH AND PRELIMIINARY RESULTS

Future research is needed to quantify under which circumstances which warehousing alternatives are most beneficial. Such a model can be used by decision makers who would like to design or reorganize their distribution systems given the advent of on-demand distribution options. This requires developing optimization models to simultaneously determine which distribution option (construct, lease, on-demand) from what supplier and for what quantity should be used to fulfill distributed demand requests over multiple periods. These location-allocation decisions need to be made simultaneously considering detailed start-up, operational, transportation, handling, and fixed costs. The comparison between construction, leasing and on-demand options should be studied capturing varying capacity and granularity commitments for varying demand requests over a multi-period planning horizon. Varying supply availability for the on-demand option should also be explored.

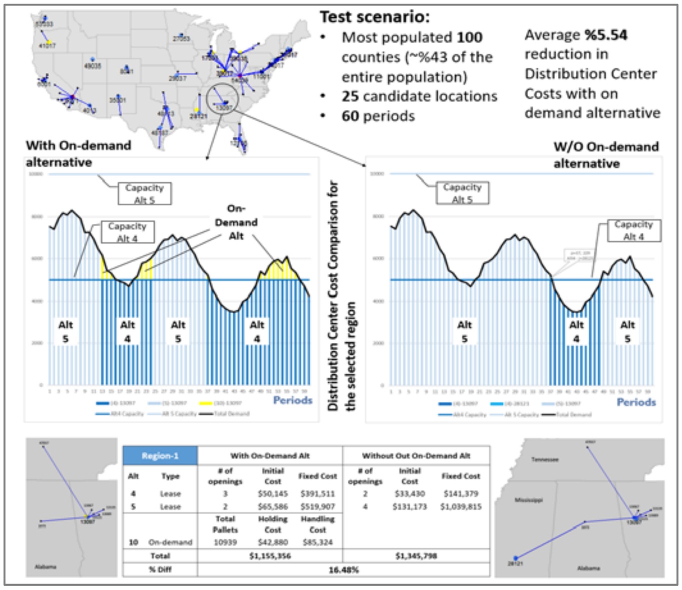

Fig. 2: *Preliminary Results Comparing Distribution Network Solutions with and without an On-Demand Alternative.*

Preliminary results obtained through a novel mixed integer linear programming (MILP) approach are shown in Figure 2. These results present solutions with and without the on-demand option, using the same demand patterns and demand locations, as well as input costs. The middle graphs present how the total demand of the selected locations is fulfilled over the entire planning horizon. The first graph shows the selection of Alternative 4 (see Table 3) and the fulfillment of demand over the capacity with on-demand options (Yellow). However, without the on-demand option, a larger DC is selected in the second graph even though it is not fully utilized during the entire commitment period. This underutilized capacity creates a cost increase in the distribution system and with these dataset a 5.54% cost difference is observed. Heuristic solution methods for large-scale problems are especially important to analyze the access to scale property of on-demand systems. Further Computational experiments are needed to identify significant factors impacting performance and to codify policy recommendations.

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