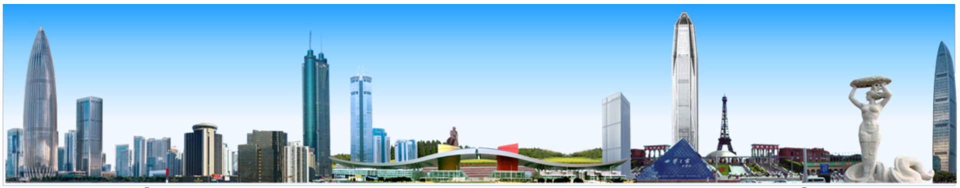

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Data-driven analytics-based capacity management for hyperconnected third-party logistics providers

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Abstract: *In this paper we provide justifications why and ways how to enable 3PLs to be poised for success in the Physical Internet (PI) while facing a highly competitive and uncertain world. We notably argue that 3PLs have to transform from relying on static, inflexible, and disconnected ways and technologies for managing their capacity, to leveraging dynamic, flexible, and interconnected ways and technologies. Indeed, in the PI context, 3PLs have to be keen to achieve hyperconnectivity and manage capacities in multi-tenant warehouses more efficiently by leveraging data and ultimately increasing revenues and profits. We specifically propose a three-layer decision-making framework that offers 3PL organizations one stepstone enabling this transformation: successfully translating available data into decision-making, increasing service capabilities and performance, revenues and profitability, as well as sustainability. In the framework, a descriptive layer allows visibility over past capacity and activity related to key resources (e.g. storage capacity), a predictive layer allows visibility in the future, and a prescriptive layer allows automatic and dynamic diagnosis and planning to fully exploit and develop capacity and to best serve clients and the overall market. The framework maps descriptive, predictive, and prescriptive analytics to outcome-oriented activities, and to their data-driven and/or model-based foundations. The framework currently focuses on capacity management for warehousing, distribution, and fulfillment facilities, and can be expanded to encompass all logistics offers, activities, and assets of a 3PL as part of a logistics web. The contribution is illustrated through the context of a major American 3PL.*

Keywords: *3PL, Capacity Management, Data-driven Decision-Making, Decision Automation, Decision Support Systems, Demand Forecasting, Hyperconnected Logistics, Physical Internet, Supply Chain Management, Warehouse Management*

1 Introduction

The traditional 3rd party logistics provider (3PL) has long-term contracts with its customers, negotiated when existing contract terms come to an end, and when new aspiring to sign new customers. This 3PL is also very asset intensive, reaping revenues from owning assets and offering them to their customers for a fixed and typically long period of time. This traditional 3PL is well adapted to the world of past decades. Indeed, in a world that is only slowly changing, this traditional 3PL can be successful through its double focus on long-term selling and planning from one side, and on steady operational excellence from the other side.

Today however, the world is ever more characterized by volatility, uncertainty, complexity and ambiguity (VUCA, Bennett, 2014). In the logistics environment, VUCA's volatility and uncertainty induce a highly competitive market with companies having products with short product life cycles and many promotions (Packowski, 2014), which then translates into high fluctuations in demand for logistic services and capacity. As depicted in Figure 1, these fluctuations result in situations where warehouses face a risk of overflowing, or capacity becomes available and remains unused, calling for improved capacity management.

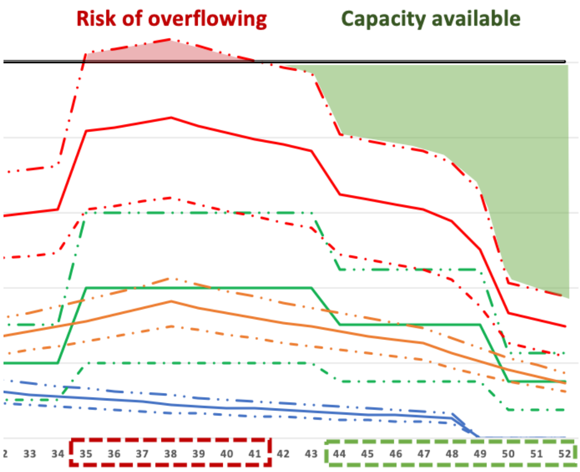

Figure 1: Impact of demand volatility on warehouse capacity

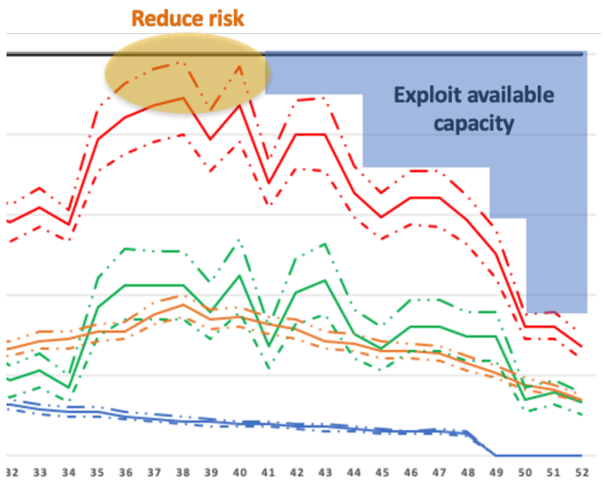

Figure 2: Successfully managed demand volatility

VUCA's complexity is notably induced by the increasing product portfolio of clients and the increased pressure for reliable timeliness, resulting in a higher number of individual SKUs (stock keeping units) to be managed by warehouses in a fast-pace, often omnichannel context. This creates a high pressure environment for competitiveness, efficiency and sustainability for all logistics companies, and thus for logistics service provider. To become an advanced player in this context, the company needs to be able to dynamically manage its assets, countering the VUCA world with vision, understanding, clarity and agility so that it can reduce and manage risks, exploit available capacity, and develop capacity options (e.g. Figure 2). It can do so by adopting the hyperconnected paradigm through the Physical Internet (Montreuil, 2011; Montreuil et al., 2013; Ballot et al., 2014; Montreuil, 2017), with more dynamic and open interconnection with clients on one side, and with other logistics web players on the other side. Client interconnectivity enables higher information and communication capabilities, and dynamic elaboration of win-win service and capacity offers. Logistics player interconnectivity enables to enhance the services and capacity options that can be leveraged to smartly fulfill client needs.

Becoming an advanced hyperconnected logistics service provider in the VUCA Physical Internet world requires a full transformation along many threads. Our contribution lies in one of these required threads: the ability to manage 3PL capacity in a smart, dynamic, hyperconnected way.

As a key enabler for this transformation, we hereafter propose a three-layer decision-making framework that includes a descriptive layer, a predictive layer and a prescriptive layer. We argue that implementing and leveraging this analytics-based framework to build 3PL capability in logistics capacity management is a necessary step towards thriving in a VUCA Physical Internet world.

We first briefly review in section two the literature that has been published on 3PLs, their decision-making and analytic frameworks. We then outline in section three key differences between a traditional 3PL and a hyperconnected 3PL. In the fourth section, we propose our data-driven capacity management decision-making framework to enable 3PLs to monitor, predict and plan their warehouse capacity. Note that the words "warehouse" and "facility" are used interchangeably throughout this paper, both naming a warehouse that the 3PL operates to serve its customers. Finally, in section five we provide conclusive remarks and avenues for further research.

2 Literature Review

Third-party logistics provider have an increasingly important role in today's supply chains, becoming the core orchestrator of many companies' supply chains. They therefore face a need to improve their efficiency and effectiveness (Zacharia, 2011). Despite these developments, to the best of our knowledge, there is no research focusing on capacity management for logistics service providers and their facilities.

Research concerning 3PLs is often (1) written from the point of view of other industry companies that are looking to use the services of 3PLs, (2) analyzing 3PL market development, or (3) analyzing the competitiveness of logistics providers. While these are observational studies, they fall short of proposing frameworks for 3PLs to work with. Hertz and Alfredsson (2003) analyze the development of companies that enter the field of 3PL business from being integrators, standard shipping firms or traditional brokers. Marchet et al. (2017) find that while 3PLs operate in a competitive market, only 25% of 3PLs are at the technical efficiency frontier and only 10% have innovative processes.

The notion of descriptive, predictive and prescriptive analytics has been discussed in the world of business analytics and in the context of supply chain analytics. Souza (2014) notably showcases that analytics is not new in supply chain management and that with the increasing amount of data available, opportunities for the application of analytics increase.

The research that is most related to our work is the framework developed by Hahn and Packowski (2015) for supply chain management. Their framework associates descriptive, predicative, and prescriptive analytic approach with types of use cases and methodological requirements from a business perspective, and with decision support systems concepts and formal types of IT systems from an information technology perspective.

Their four use case types are monitor-and-navigate, sense-and-respond, predict-and-act, and plan-and-optimize. The uses cases are associated by pairs to methodologies, respectively: monitoring and reporting, data modeling and mining, forecasting and simulation, strategic and operational planning. Descriptive analytics is mainly data-driven and relying on systems such as Enterprise Resource Planning (ERP) systems, expert systems, and business intelligence (BI) systems. Prescriptive analytics is mainly model driven, enabled by advanced planning systems (APS). Predictive analytics stands between them, borrowing from both model and data driven concepts, and relying on APS, BI, and expert systems.

Borrowing from Hahn and Packowski (2015), we adapt it to address the specific challenges of hyperconnected 3PLs and expand it to encompass the activities related to managing capacity in multi-tenant 3PL facilities.

3 Traditional 3PL vs Hyperconnected 3PL

In general, 3PLs may provide a variety of services to their customers, notably transportation, forwarding, warehousing, and value-adding services (VAS) such as relabeling/repackaging, assembly/installation, and blast freezing.

In this paper, we focus on 3PLs that own or lease, and operate, deep storage warehouses, distribution centers as well as fulfillment centers. The customers of these 3PLs are producers, distributors, and/or retailers (brick-and-mortar, e-commerce, and omnichannel). So, some of the customers are upstream in the supply chain while others are downstream. Traditionally, these 3PLs sign contracts with larger customers that tend to be long-term agreements that are renegotiated every three to five years. They often serve smaller customers on an as-needed basis, accommodating their small flow and storage of pallets and cases. Naturally, this leads to multi-tenant warehouse environments where multiple customers share one facility of the 3PL. The multi-tenant characteristic is the critical complexity factor justifying the emphasis on smart capacity management capabilities addressed in this paper.

Each customer has unique dynamic patterns relative to their inbound flow, storage needs, and outbound flow. The shock of these multiple customer-specific patterns can create significant disruptions, some positive, some negative, and some potentially both, yet all having to be addressed.

Relative to disruptions, consider for example a case where it becomes clear that a major customer tenant of a 3PL is to use significantly less storage space and throughput capacity than allowed in its contract, such as illustrated in Figure 2. Normally, its contract has it pay for the storage space, whether or not it uses that space, yet it is to be charged for operational inbound and outbound activities only if these actually occur. Negatively, this means that the 3PL is to have less revenues from that client, a fact attenuated somewhat as this client will require less resources to serve it, and thus induce less costs. Positively, this can be smartly turned into an opportunity if the 3PL recognizes fast enough the situation and is capable of offering to other customers the time-window-specific extra availability of space and throughput capacity, in a win-win mode for the customer tenant at the source of this opportunity.

Relative to risks needing to be managed, consider overflows as an example. Overflows happen when 3PLs, similarly as airlines with passengers, book more flow and storage than they are capable of dealing with concurrently, betting on the stochasticity to smooth requirements, or simply due to them not having planned their capacity commitments correctly. Overflows create havoc as excessive concurrent truck arrivals and excessive total goods inventory in a warehouse cause serious productivity disruptions with lack of available docks, too many trucks and trailers waiting in the yard and beyond, almost no available storage bays, overspill of stock in aisles, and huge congestion due to high flow intensity and disrupted aisles, potentially leading to an ultimate complete operational deadlock. Risks of overflowing need to be managed smartly. Indeed, 3PLs usually like tenants to use their allotted capacity at a high level inducing lucrative high inbound and outbound operations and revenues. Yet, when most tenants use near their maximal contractually allotted capacity, and some going overboard, there is significant risk of overpassing a threshold leading into overflow and deadlock. This risk and reward trade-off needs to be carefully managed.

A hyperconnected 3PL is to face the same challenges as traditional 3PLs, yet with higher intensity and dexterity. Let us consider first the intensity perspective. In the Physical Internet, the clients of logistics service providers aim to seamlessly deploy dynamically their products in a way enabling them to offer their customers fast, cheap, convenient, and reliable fulfillment services. They want to be able to shift products to locations best fitting the swiftly-changing market patterns, and to do so in an efficient and economical way. This leads them to request shorter and/or more flexible contracts, with less restrictive commitments blocking them from their aspirations toward best serving their customers. Also, the Physical Internet openly interconnects logistics networks, which induces each node of the overall logistics web to be prepared to deal with more customers, as long as they respect and use the standardized protocols, interfaces and modular encapsulation. This means potentially more contracts of shorter duration with more distinct clients. Overall, this heightens the intensity of the capacity management challenges, requiring 3PLs to act according to a higher clock speed, and with more agility, adaptability, and resilience.

Let us now consider the dexterity perspective. In the Physical Internet, logistics service providers are to be interconnected much more and better on multiple layers, including physical, digital, operational, transactional, legal, and personal layers, with clients and other logistic service providers. This interconnection is not to be achieved solely through long-term contracts, alliances, and consortiums, but rather through accepting to act according to standardized protocols, leveraging standardized interfaces notably embedded in digital platforms and marketplaces, and using standardized modular containers across industries and across territories. The hyperconnected 3PLs are notably to be exchanging operational and transactional data on a much faster and intense pace with their clients and other logistics service providers used by their clients and/or offering capacity options leverageable for dealing with dynamic surges in capacity requirements. Exchanging plans and forecasts with clients, focused on their intersection space, is to be customary, enabling both to best anticipate and respond to forthcoming certain and uncertain changes. The same goes first, amongst the facilities and business units of a single logistics provider, and second, between hyperconnected logistics service providers. Each provider becomes a source of capacity options for the others, and everyone is part of the multi-service-provider supply web of multiple clients, having to interact to ensure smooth, seamless, and efficient overall performance. Overall this heightens the required dexterity of logistics service providers in meeting capacity management challenges, equipped with interconnected smart tools, and trained to think, plan and act in the Physical Internet so to achieve the necessary efficiency, agility, adaptability, and resilience.

The combination of heightened intensity and dexterity puts significant pressure on raising the capabilities of 3PLs for managing their capacity in a much more proactive way, fed by data from interconnected sources within their own organization and with interacting clients and other logistics providers, through direct links or platforms. As a contribution to this quest, the framework introduced in this paper guides the development of decision support technologies and processes for hyperconnected 3PL capacity management.

4 Data-driven capacity management decision-making framework

The decision-making framework, depicted in Figure 3, links three components: the type of analytics approach, namely descriptive, predictive, and prescriptive; the key groups of outcome-oriented activities; and the data-driven and/or model-based foundations. Each analytics approach is linked to a set of outcome-oriented activities, and each of these is calibrated in terms of its relative reliance on data-driven vs model-based foundations.

The decision-making framework has three layers of analytics approaches: the descriptive layer, the predictive layer and the prescriptive layer. This is line with the works of Hahn and Packowxski (2015), and as described in the landmark work of Davenport and Harris (2017) in the update to their work from 2007 that introduced business analytics. Some analytics professionals also argue that a fourth layer should be explicitly identified, that is diagnostic analytics, referring to the analysis of why something happened (e.g. Banerjee, 2013). In the framework, even though we recognize the importance of diagnostic analysis, we have not made it a fourth layer, but rather incorporated analytical diagnosis in each of the analytical layers. To predict future activity successfully (predictive layer), one needs to be aware of the underlying factors that result in certain activities. At the descriptive layer, the reason for certain flow activities are a result of market movement. To understand the why of certain flows, market factors are therefore incorporated into the descriptive layer. For example, during the initial impact of the COVID-19 crisis in the USA, for the American 3PL storage usage changed. Some customers saw increased inventory, while others saw decreasing inventory not being able to keep up with the market. In the descriptive layer, it is not only sufficient to highlight the shifts of inventory, it is also important to help diagnose why these happening. Overall, in this example, the COVID crisis is a root cause, yet it must help to understand why some activities climbed while others went down, here notably linking with increasing demand on the market for essential products, and decreasing capacity in COVID affected supply chains. Seeking to raise alerts and to identify causes is at the core of the framework, at the three analytics layers.

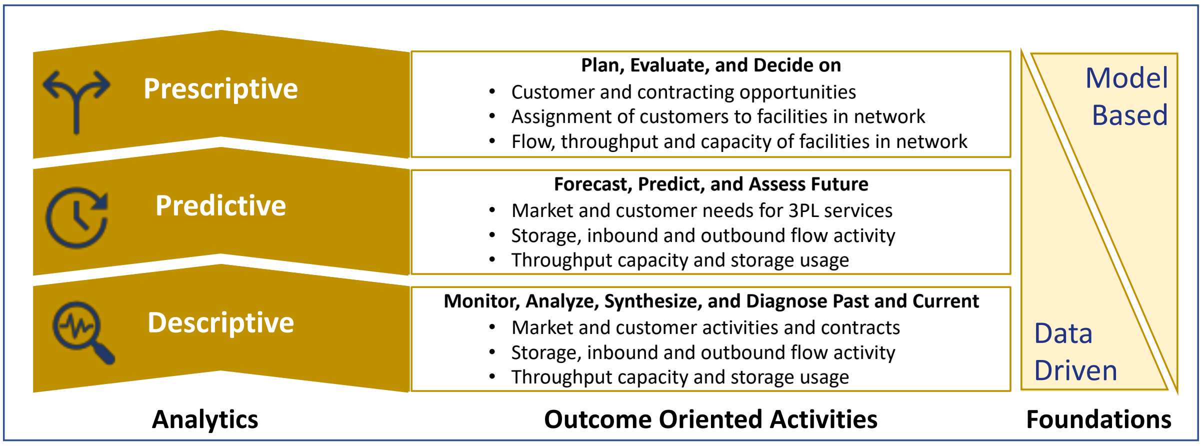

Figure 3: Data-driven model-based logistics provider capacity management framework

We hereafter describe the framework further by focusing on each of the three analytics layers and their outcome-oriented activities. Each layer concerns three aspects of the capacity management task: the market, the customer and its own network. We emphasize how the layers combine to allow an effective management of storage and throughput capacity in 3PLs' facilities.

4.1 Descriptive Layer

The descriptive layer allows monitoring of the current activity of the overall market, of the facility network and at the level of an individual warehouse. It offers near real-time insights and visibility across its network to decision-makers. It is in line with the well-recognized importance of visibility as a core attribute of 3PLs, along being a neutral arbitrator and collaborator (Zacharia, 2011).

On a facility level, the descriptive layer must let a decision-maker see the current storage and throughput capacity available, current throughput demand, storage demand but also customer service level. More importantly, it should allow to highlight the usage of this capacity per combinations of warehouses and customers. Questions such as "How much capacity does Customer X currently use in our facilities?" should be easily answered overall and per facility.

Relative to monitoring capability, the descriptive layer should also allow a 3PL decision-maker to look at the historical development of the activities in specific facilities. In addition to usage, the descriptive layer should offer visibility over flows in the network: storage, inbound and outbound flows have to be monitored, and tracing should be kept over time.

Lastly, a fully implemented descriptive layer also allows visibility into the general 3PL market, customer activities and current contracts. Since this last aspect depends on outside information, it is harder to implement in the early Physical Internet phases and thus, the initial focus of 3PLs is expected to be within the 3PL organization, and then gradually evolve to encompass this wide-angle out-of-the-box visibility.

Monitoring, analyzing, diagnosing, and synthesizing the current and historical activities provide the decision-maker facts, insights, intuition about the state of the activities and how they generally behave. Monitoring facts, states, and events is clearly data-driven. Analysis is fed by the monitored data, yet is often sustained by some high-level descriptive model to structure the approach. Diagnosis builds on monitoring and analysis, being strongly data-driven, yet often builds upon rule-based models and cause-and-effects models. Synthesis builds on monitoring, analysis and diagnosis, and is mostly still relying on human-centric skills combining reasoning, mental models, intuition, and discussions.

When attempting to move forward and decide on future actions, descriptive analytics sets the stage, yet it becomes critical to understand and project future capabilities and capacities, which is the focus of the predictive layer of the framework.

4.2 Predictive Layer

The predictive layer aims to offer reliable forecasts of forthcoming capacity and throughput demand and as a result capacity utilization, future service levels, and flows throughout the network. For prediction purposes, this layer builds upon hybrid timeseries forecasting methods (Zhang, 2003) based on traditional methods such as ARIMA and machine learning techniques (Ahmed, 2010) such as neural networks.

At the predictive layer, the power of the Physical Internet comes increasingly into play. Through hyperconnectivity with its customers, the 3PL may gain access to their current demand and/or supply logs and predictions. These predictions can include the customers' production plan and potentially privacy-protected point-of-sale (POS) data that it receives from its retailers, or the equivalent from e-commerce websites. This source offers richer data than the data generated internally by the 3PL, which represents solely its own history. In the predictive layer, the forecasts from the 3PL and the forecasts from the customer should then be ensembled into an overall forecast as depicted in Figure 4.

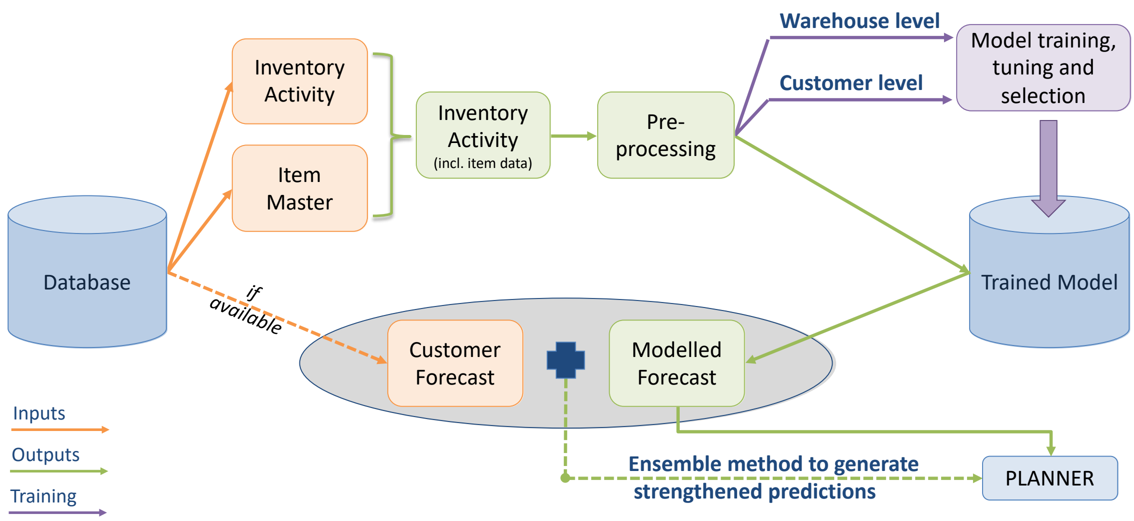

Figure 4: Possible information flow in predictive layer

Such ensembled forecasts, generated by combining several forecasts, have long been known to have the potential for better accuracy (e.g. Bates, 1969) and have become a core part of the fields of ensemble learning and statistical learning (Hastie, 2009). In our initial experiments with the American 3PL, ensembled forecasts have shown as expected to have a higher accuracy, resulting in lower forecast errors.

Strengthened by the hyperconnectivity and the customers' forecasts, the predictive layer then should project expected future warehouse activity while explicitly recognizing the uncertainty in its prediction. It is important to note that it is usually impossible to reach 100% accuracy in predictions and it is thus important for the decision-maker to understand the accuracy reliability of a forecast. To support this understanding, uncertainties should be clearly exposed by the descriptive layer through prediction intervals, such as X% lower bound, most probable, and X% upper bound. As X climbs to higher levels, such as 99.9%, the prediction interval gets wider. It usually also gets higher as the future horizon covering the prediction is farther away (e.g. for tomorrow, next Monday, Thanksgiving) and usually gets relatively smaller with higher aggregation (for a specific day vs a week or a month). Explicitly acknowledging uncertainty and prediction accuracy is fundamental to assess correctly the forthcoming future and to enable well-informed decision making.

4.3 Prescriptive Layer

The prescriptive layer aims to offer decision facilitation capability. It builds upon the descriptive layer and the predictive layer, and enables decisions based upon the output of these layers. It is the final layer in the framework and offers the 3PL support in decisions concerning the market, the network and individual facilities. Activities such as accepting, rejecting and seeking customers and new contracting opportunities that fall into the area of business development are supported through the information available in the descriptive layer. It also helps to assign customers to facilities within the 3PL's network and can suggest potential assignment adaptations. In addition to these strategic and tactical activities concerning the customers, the prescriptive layer can also suggest adaptations of the flow, throughput and capacity of facilities in the network (Figure 3).

The prescriptive layer should help the 3PL to plan for future growth and contraction. Future growth of a customer might expand beyond the capacity available at a facility. To preclude related service failure, the 3PL can act proactively with the support of the prescriptive layer. It could for example reassign this customer to a facility that allows for this growth or move another customer to a suitable facility. To onboard a new customer into the 3PL's network, the planning ability of the prescriptive layer should offer an analysis of suitable facilities. It will conduct a feasibility analysis based on storage capacity, throughput capacity and the availability of other necessary services such as the capability to handle a specific type of product.

The prescriptive layer should be able to support more complex capacity planning, encompassing multiple clients over multiple sites. Figure 5 provides a simple yet realistic example of such dynamic planning. On the left side are provided the storage capacity requirement predictions for clients using two facilities in the 3PL's network. In a logistic campus, buildings A and B each currently host three distinct customers. Building A is projected to overflow as capacity requirements from client C are to climb, while building B is projected to be gradually less utilized, mostly related to declining capacity requirements from client F. Smart planning through the prescriptive layer has led to a reshuffling plan with clients D and E shifted to building A, and client C shifted to building B, resulting in smoothing the capacity requirements over the two buildings and avoiding both overflow and underusage, as depicted on the right side of Figure 5.

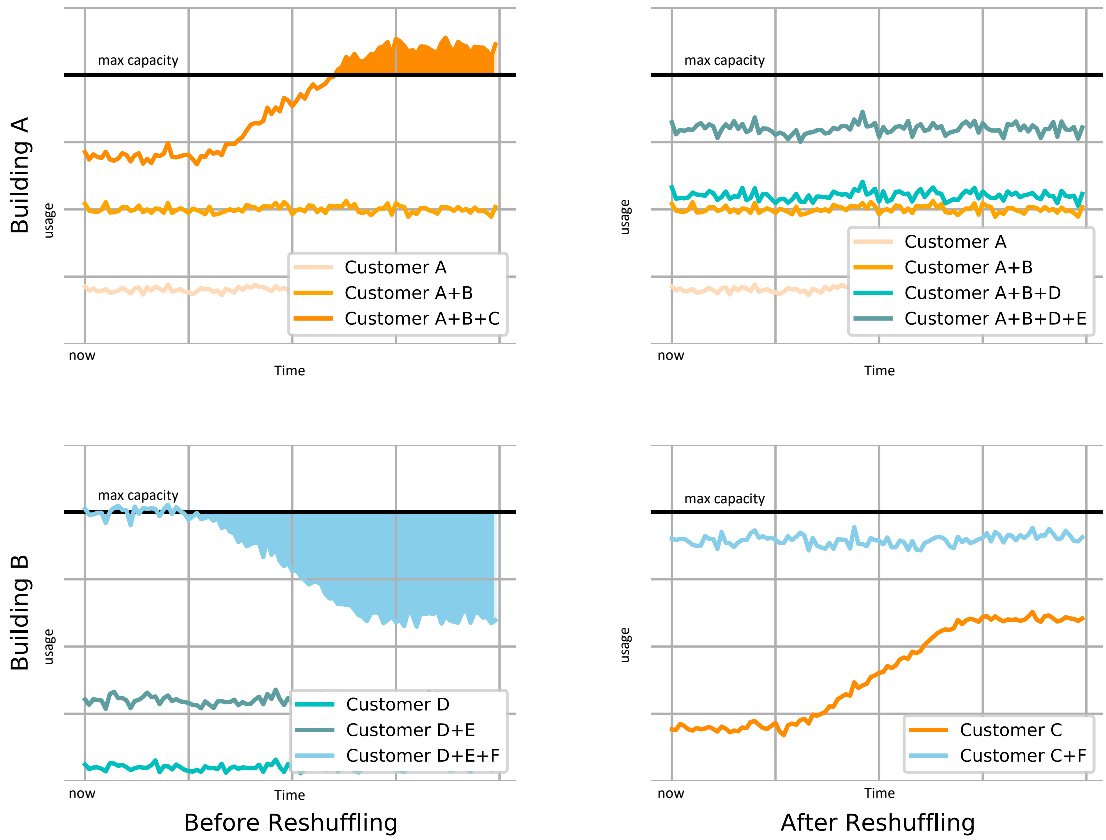

Figure 5: Example of reshuffling suggested in the prescriptive layer addressing storage capacity

The prescriptive layer can to a degree offer decision automation capability, in the line autonomous analytics as proposed by Davenport (2017). Some decisions can be taken by software agent, without direct human intervention beyond setting the agent's rules and methods, especially those requiring fast response time and taken repetitively over many instances. For most of the higher-impact, more strategic decisions, the prescriptive layer is rather to provide support to human decision-makers. For example software agents can make recommendations and assessing their impact according to multiple metrics, notably through simulation, optimization, and machine learning based methodologies, and then letting the human decision-maker at the 3PL reject, accept, or modify them.

5 Conclusion and Outlook

The three-layer decision-making framework we introduce in this paper for hyperconnected 3PL capacity management allows logistics service providers to counteract the volatility, uncertainty and complexity they are faced with. Through the descriptive layer, the hyperconnected service provider gains insights into the past and current states of the 3PL market, customer activities, contracts, and flow activity in their network. Based on forward looking predictions of these in the predictive layer, the prescriptive layer facilitates decision-making concerning customer and contracting opportunities as well as adapting capacity, assignments and flow within its network. This serves as one thread for a 3PL towards a transformation into a proactive hyperconnected logistics player.

In this work, to the best of our knowledge, we are first to introduce an analytics-based framework for logistics capacity management in the Physical Internet. At each layer of the framework, there is room for future research.

In the descriptive analytics layer, research is notably needed on which information should be shared by logistics service providers and clients in the Physical Internet; how to filter the wide scope and huge scale of information into high-value, focused, and actionable knowledge and insights; how to better leverage novel visual analytics, as well as augmented and virtual reality, technologies; what new key performance indicators should by developed to leverage the hyperconnected essence of the Physical Internet and thus to provide 3PLs with fresh and enlightening perspectives.

In the predictive analytics layer, much research is notably needed on interlacing the various correlated capacity and throughput predictions, to acknowledge alternative probabilistic future scenarios, and to support risk and resilience management in the context of hyperconnected logistic service providers.

Fed by the descriptive and predictive layers, the prescriptive analytics layer opens a wealth of research opportunities for better design and planning of solutions, for better selection between alternative options, for optimizing client, facility, and network wide decisions (e.g. expanding on the example from Figure 5).

From a deeper perspective, the framework allows to break away from rigid contracting modes having been instituted to ensure conservative and robust guidelines and decision framework when having to maneuver a complex organization with minimal timely information availability, minimal predictive capability, and minimal prescriptive decision-support capability. It indeed opens up more hyperconnectivity oriented research and innovation avenues such as considering multiple dynamic external capacity options, and considering smarter and more agile client contracts.

The framework also uncovers relationships between information available to, and decisions taken by, various organizational units within a logistics service provider. This is clearly the case between sales, marketing, and business development; information technology; facilities acquisition, planning and design; transportation and logistics operations. Much research is needed in synergizing these relationships, and guiding decision makers within each unit to take smart decisions with a more holistic perspective.

While the framework is currently being implemented at a major American 3PL player, the initial focus is on putting it into action within a single region, developing the methods, models, and technologies necessary to do so, leveraging could technologies. Next efforts are planned to address the whole North American landscape allowing overall visibility and decision-making facilitation on a continental level, and ultimately expanding at a multi-continent international level.

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