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Split Volume Cost Model

A layered pricing structure for logistics outsourcing

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A chi mi ha plasmato:

La dedico a Silvio, perché l'ho scritta pensando a lui.
La dedico a mamma, perché ha saputo attendere.
La dedico a Tonino, perché c'è tanto di lui.
La dedico a papà, perché gli voglio bene.

Summary

ABSTRACT

The main goal of the following thesis is to present the so-called Split Volume Cost Model (SVCM), engineered for logistics outsourcing purposes and fair for both the client and contractor.

The first chapter is for context, so gives a broad presentation of logistics outsourcing: it describes the drivers that may convince a firm to pursue that direction but also the challenges and potential threats. It does it by breaking down and detailing the workflow that the companies involved go through, starting from the selection phase, up to full operations.

The second chapter is the core of the thesis. The first two paragraphs are a long introduction that poses the foundation to understand the SVCM, explaining key concepts, dynamics and considerations. The last paragraph instead, details the model.

The appendix contains numerical examples and technical analyses, furtherly extending the theory. Of particular relevance is Appendix 4, where a real-life application of the SVCM is presented and commented in deep.

INTRODUCTION

The following work provides in-depth insights about logistics outsourcing and is the combined result of academic research on the matter, business studies and the author 5+ years of work experience in the field. Although having work experience does not necessarily means having access to high quality information sources, it surely helps developing at least a critical think on the subject and the mere act of doing something, especially the first few times, leads to errors that morphs into lessons that lead to a more qualified professional.

Moreover, being around experienced people affects the overall growth of an individual more than one can immediately realize. Then, there are the challenges of an everyday job which forces you to come up with solutions: sometimes is straightforward, other times one need to start over, rethink, be patient and iterate. However, theory is also important and not everything can be learnt just by doing, so academic researches and business studies will also be part of the dissertation to support and enhance the overall informative content.

1. LOGISTICS OUTSOURCING

1.1. Overview

"Do what you do best and outsource the rest" was the motto of Peter Drucker during his consultant activities in the 20th century. Outsourcing has become a standard practice at the time being (2024) and that is so because companies are focusing on pursuing the excellence within the boundaries of their core activities. The modern supply chain relies on a network of strategic partnerships between "shippers" and "3PL providers" or "3PLs". The naming is the one proposed by the "2024 28th Annual Third-Party Logistics study", where "shippers" are defined as purchasers of logistics services and "3PLs" as logistics services providers[1]. According to the study, in 2024 most shippers (95%) declared to be involved in a successful partnership with their respective 3PL. Warehousing stands as the most frequent outsourced activity, followed by transportation, brokerage and freight forwarding. From a financial standpoint, in 2024 the overall logistics expenditure revealed by the companies involved in the study averaged around **13% of sales revenues** and, although shippers report an upward demand in outsourcing services, they also stated that only 37% of the total spend is directed towards 3PLs. As *Figure 1.1.1* shows, the aforementioned expenditure used to be as high as 56% in 2020, so the overall decrease could be explained as a loss of bargaining power from 3PLs themselves.

[1] 2024 28th Annual Third-Party Logistics Study: The State of Logistics Outsourcing, C. John Langley Jr., Ph.D., and NTT DATA, 2024

1.2. Outsourcing Process

Although the relevance and the effects may greatly vary from firm to firm, choosing the right contractor to outsource logistics could be a though challenge even for experienced professionals given the amount of planning to be done ahead and the different activities to go though as this complex project progresses.

A first major headache derives from the early transaction costs, which could be seen as the price to be paid to make something start happening: relocate the logistics and having it managed by a third party may require burying the cost of a tender. However, in some cases, the company may not have the capability to draw tender outlines, draft documentation, evaluate different proposals and run interviews, so other transaction costs show up to choose the right consultant that will help choosing the right logistics.

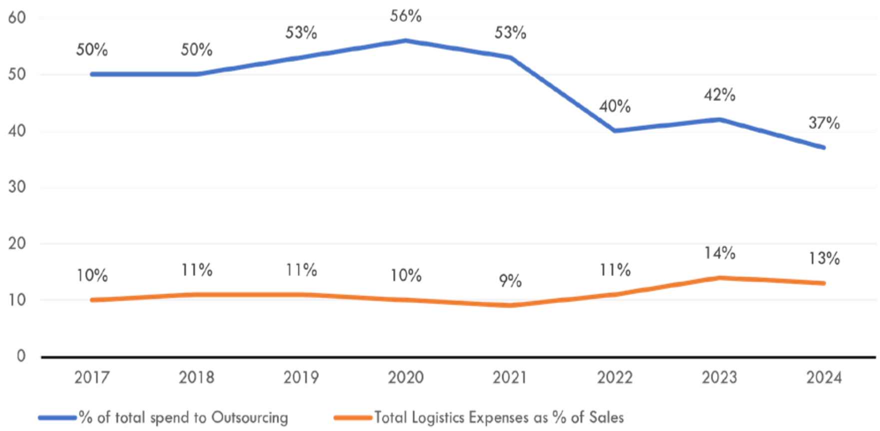


Figure 1.1.1: Evolution of logistics financials from 2017 to 2024.

Well-structured logistics tender usually contains:

- *A brief presentation of the issuer company*
- *Current supply chain shape*
- *A description of the desired outcome*
- *A list of mandatory services the 3PL must provide*
- *A list of optional services (or "nice to have")*
- *Tender timeline with deadlines*
- *An overview about the products to be handled*
- *The countries to be served*
- *Seasonality (if any)*
- *The desired service levels*
- *Business peculiarities (if any)*
- *Contacts*
- *Expected inventory to be relocated*
- *Expected inbound and outbound volumes*
- *Expected inverse logistics figures*

The information is given through a strictly confidential collection of files, usually in the form of data spreadsheets, textual documentation and visual representations (graphs, schemes, flowcharts etc.). An NDA signing precedes files forwarding and everyone involved must keep the confidentiality. Given that the figures of a tender are non-binding and that there is also the inherit uncertainty of the future, clients usually tend to slightly inflate numbers for the appeal but also to receive a more favorable quotation from all the 3PLs participating the selection. A tender is a multi-step process: *Figure 1.2.1* provides an example of a real-life timeline progression of a logistics outsourcing tender.

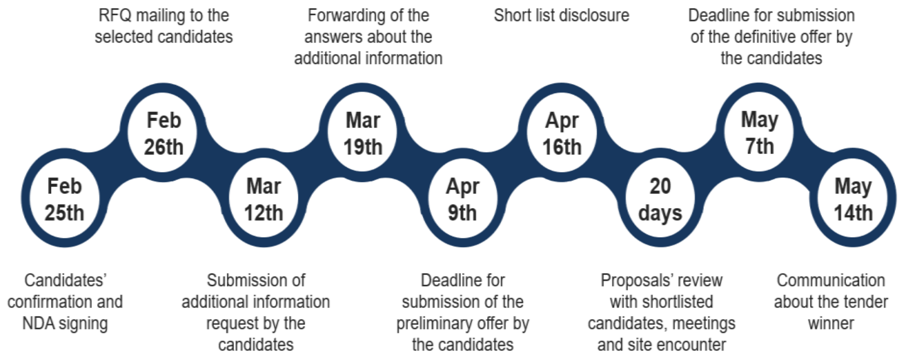


Figure 1.2.1: Logistics outsourcing tender deadlines and major steps.

Although each 3PL participating may have its own peculiarities and may want to show off somehow, it is necessary to prepare a standard template they need to fill-in so that the different proposals are easily comparable, and a first cut is done faster. Inviting 10+ different companies and go through each original proposal would lead to time waste and misunderstanding. The first cut is usually based on received documents only; companies cannot reach the issuer in any form except just once for the "additional information request" step, to be done in written form. Sharing the answers among all participants is ideal. After reviewing all the preliminary offers and choosing the best ones reaching the second phase, there should be a manageable number of candidates – usually around 3 – so that running interviews and site encounters are feasible within reasonable time. During this phase there are discussions and adjustments to be done between the clients and each 3PL, so having experienced professionals helping to decide is key: numbers surely matter - although the cheapest option is not always ideal - and having someone which knows what to look at during the site-encounters and what to ask to technical and operations staff, also matters. Overall, the final choice is based on many different factors and although the selection process itself is not easy, draw up the contract is also troubled: it takes the conjunct cooperation of technical and legal staff from both firms, going back and forth modifying sometimes for several weeks. Having a strong legal support - could be internal or outsourced - is something which should never be underestimated because a contract is the formal document of - sometimes - months of negotiation and the first to be browsed in case of troubles. Especially for those instances where the full logistics is being outsourced, the contract may be lengthy and it could take just one little sub-article to make the difference on a given aspect, so well trained legals are key. There is always the possibility to bring a lawsuit, however a signed contract still stands, toughening and stiffing the starting position right away. The main features of a logistics outsourcing contract are:

- *Scope*: It clearly outlines the outsourced services and defines their boundaries, distinguishing between mandatory and optional services. The latter can be activated or requested with written notice upon the occurrence of certain circumstances and typically require advance agreement.

- *Duration*: It specifies the starting and ending of the contract. More articulated contracts may present intermediate dates defining different phases where services are added overtime.

- *Economics:* It details the amount due for each service, including variable costs based on volumes, any fixed cost, and the payment scheme. Sometimes an extended tariff scheme is also agreed and includes quotation for general services that may come handy in a second time and/or covers the holes deriving from the imperfect nature of the contract.

- *Insurance and liabilities:* It clears each party responsibility and insurance requirements. Usually, the 3PL ensures the infrastructure from general casualties such as earthquake, fire, flood etc. (also called "All risk" insurance) and is up to the client to stipulate a specific insurance policy covering the inventory stored at the facility of 3PL against fire and theft.

- *Confidentiality, data protection and regulatory compliance:* It ensures that each party is compliant with the regulatory requirements about data protection, labor, safety standards.

- *Termination:* It details the procedures for each party to terminate the contract in advance and the effects related to it. Moreover, it also describes the circumstances which cause the contract to be terminated by law with immediate effect: it is usually because of severe violations from one party.

- *Performance metrics*: Each main service is broken down into sub-services and regulated by a set of SLAs (Service Level Agreement) and KPI (Key Performance Indicator). It could be a list or a table establishing the amount of output the 3PL is expected to process in a certain time window and, should it fail to comply to the set standards, the related penalties but also the potential bonuses in case of over-performance. The metrics are usually in terms of units/day or orders/day or total errors and in the modern landscape of relationships between client and 3PL, they are made accessible in real time though automated dashboards. Maintaining accurate displayed data could be difficult sometimes and metrics data availability could be the cause of continuous troubles and litigations. To limit the phenomenon, it is advisable to set up planned reviews and discuss about numbers and actions to undertake. Penalties are usually accounted and compensated on yearly basis, however in the end it is all a matter of what was negotiated and business specificities, there are no fixed rules. Table 1.2.1 depicts a basic example of performance metrics formalization for general warehousing outsourcing purposes; other metrics may regard customer service, ad hoc work orders, customization, rotating inventory etc. It is an overly simplified version whose main goal is to show a possible layout to be implemented according to the services. Other frameworks serving the same purpose are available in the academic literature and online papers.

Table 1.2.1: Basic performance metrics table for warehousing activities

ACTIVITY			Basis of calculation	SLA / KPI				
				YEARLY EXPECTED QUANTITY	SLA	TARGET	GOAL	PENALITIES
INBOUND	All the activities between truck offload and put away	Units arriving from producers or suppliers STANDARD SERVICE*	Units	40.000	0,5% yearly expected quantity	Day t+3	95%	50% tariff
		Units arriving from producers or suppliers EXPRESS SERVICE	Units	8.000	0,5% yearly expected quantity	Day t+1	95%	50% tariff
		Customer returns	Units	500	1% yearly expected quantity	Day t+2	95%	50% tariff
OUTBOUND	All the activities between picking and truck load	B2B order fulfillment	Units	25.000	0,5% yearly expected quantity	Day t+2	95%	50% tariff
		B2C order fulfillment	Orders	2.500	0,5% yearly expected quantity	Order received until 1 PM to be fulfilled on the same day	95%	Penalty: 50% tariff Bonus: 10% tariff
		Order Accuracy**	Total errors	--	--	< 75/year	--	100% tariff

* Expected Quantity = 40.000 units per year; Daily average = 40.000 / 250 = 160 units/day
SLA = 40.000*0,005=200 units/target time; KPI = 200*0,95 = 190 units/target time
The KPI establish the quantity the 3PL must process within the target time to prevent penalties. In this case, at the end of day t+3, if the 3PL inbounded only 180 units given 190 units incoming from supplier, the 3PL would incur in (190-180) = 10 units at 50% of tariff

** Order accuracy is given by the ratio between the number of orders processed correctly (i.e. orders in which what was shipped corresponds to the request, the recipient is correct, etc.) and the number of orders shipped in total. Reaching 100% order accuracy is not realistic. The best-in-class are between 96% and 98%, while for metrics lower than 95% it is necessary to intervene on the process. In the example is proposed 97%, therefore 2,500*0.97 = 2425 orders is the correctness baseline. 2,500 - 2425 = 75 tolerance orders; in other words, from the 76th incorrect order onwards, the penalty is applied against the 3PL.

A tender could take 1+ year just to come up with a signed contract, the effort to be made is not neglectable for everyone involved and operations have to start yet because not a single unit has been handled so far and more work is due before it could be done.

The next step is IT systems integrations, so that the data can be imported into the 3PL system, including product catalogue, orders import, pre-shipping notifications, reverse logistics modules, stock and shipping updates etc. During this phase the internal (or external) IT staff from each company must undergo meetings so that their respective systems can communicate. There are different technologies allowing information exchange. In 2024, APIs (Application Programming Interfaces) are one of the most used means. APIs act as a bridge between systems and there are several tasks they can perform apart from data exchange, such as triggering processes or actions. A more technical dissertation on the matter would be out of the scope; the takeaway is that IT integration is one of the steps of the process and must be performed right after contract signing because every transaction must be registered in a database to be readily available at need.

The next step to be managed is phase-out from the former warehouse (could be from another 3PL or from the shipper itself if first time outsourcing). During this phase a crucial decision must be taken, that is choosing who has to perform the unit count between the outgoing and ingoing logistics. Counting all the units and, ideally, – so not mandatory but highly recommended for stock efficiency purposes – undertake consolidation as well, which means trying to collect the same product code (SKU), in mono-SKU cartons (also called Master Cases/Cartons), and according to quantities, mono-SKU pallets (also called Master Pallets). More information and rigorous definitions about master cases and pallets are available on Chapter 2. Consolidation could be severely time consuming in some cases, especially if the outgoing logistics did not follow any slotting algorithm imposed by the WMS and used to perform the put away based on the warehouse operator free will which – not always – decides to place a pallet in a certain location without a particular reason other than it is a free one. Which warehouse takes the burden to perform inventory count and consolidation is up to management, circumstances and contract. There are instances where the client is leaving due to poor performances of the 3PL; in that case, it is recommended to consult a specialized external company to perform the unit count before the move-out, so that the position with the outgoing logistics is objectively closed to potential disputes. There are cases where the outgoing logistics is in a hurry and just unloads racks and loads trucks, performing no count, no consolidation and just communicating quantities according to the WMS. In those instances, is all up to the ingoing logistics. The ideal scenario is the one where the outgoing logistics counts each unit, consolidates and prepares an accurate and useful packing list. A packing list is a document reporting a detailed recap of the content of each carton and specifies which pallet each carton is on. Identify each unit of product is demanded to the product code (SKU) along with its barcode, whereas cartons and pallets identifiers are usually incremental alphanumeric strings printed on a sticky label. Table 1.2.2 and Table 1.2.3 provide an example of a well-structured packing list, which is very useful to the ingoing logistics during phase-in operations:

Table 1.2.2: Sku-Carton matching packing list

Carton_ID	Sku	Barcode	Description	Sku_Quantity
CC0000001	SKUA	8001234568753	RED SHORTS	18
CC0000002	SKUB	8009464828473	GREEN JACKET	4
CC0000003	SKUC	8007472829984	BLU SHOES	7
CC0000004	SKUD	8007472094032	WHITE SHIRT	9
CC0000005	SKUE	8007472384752	PURPLE SCARF	34

Table 1.2.3: Carton-Pallet matching packing list

Pallet_ID	From Carton_ID	To Carton_ID	Carton_Count
PP0000001	CC0000001	CC0000003	3
PP0000002	CC0000004	CC0000005	2

Carton and pallet identifiers (e.g. CC0000001 on Table 1.2.2 and PP0000001 on Table 1.2.3) in some cases are not only a simple text string but they can include a printed barcode which could really save time to the ingoing logistics if their WMS can import the contained data. Barcoded carton/pallet identifiers are called "Shipping Units" (SU); the idea behind them is that the packing list information is saved on a database and by scanning the SU, the ingoing logistics can inbound a carton or even a full pallet without opening each carton and scan every unit. This method requires an IT effort and for warehouse relocation between two different contractors is usually not the case. SU are mainly used between warehouses that exchange goods often because in that case, the IT effort is more than justified thanks to the achievable process efficiency. Once each unit is successfully transferred to the new 3PL facility and correctly inbounded both physically and informatically, the first orders can be fulfilled, and the warehousing outsourcing enters its start-up phase. During it, slowdowns must be expected due to the lack of experience with products, IT bugs which can lead to severe troubles, new routines to be set on, new procedures to be codified, new people to cooperate with and a new equilibrium to be reached. Even once in full operations, challenges and risks remain: "loss of control, loss of customer feedback (it may vary according to the outsourcing degree), dependency, poor service performance, poor coordination efforts, poor information sharing, risk of losing expertise, risk of exchanging confidential data etc.[2]"

The concept of **dependency** should not be underestimated. There is a quote from an unknown writer which says that an individual is not paid according to how hard they work but according to how hard they are to be replaced. Logistics providers are similar somehow: in 2024 difficulty in replacement is given by IT advancement more than the ability to process goods. That is because any 3PL knows how to inbound products, stock items and fulfill orders, but not so many can integrate IT systems and provide support, come up with scalable solutions and keep developing IT tools for data analysis, insightful dashboards, process information etc. A modern logistics provider is required to be top notch with traditional operations and retains customers through an environment of information technology tools, creating the aforementioned dependency. As a matter of fact, once the shipper commits hours of system integration with the 3PL, its employees get accustomed to the interfaces and shared data and new routines set in, it will likely be established strong inertia toward changes overtime. According to the 2024 28th Annual

[2] Latifa Fadile, Zitouni Beidouri, Mohamed el Oumami (2018). Logistics Outsourcing: A Review of Basic Concepts. University of Casablanca, Morocco

Third-Party Logistics Study[3], the percentage of companies satisfied with the IT capabilities of 3PLs is not the highest, around 49% (-4% compared to 2023). The study confirms also that technology advancement is a competitive differentiator for 3PLs and that the main areas to be invested-in are predictive analytics and warehouse automation, aiming to operational cost reduction and improved process efficiency. However, there is not a unique archetype to follow in order to achieve better profitability and process enhancements; everything has to be contextualized, and a solution may work great for a company and be a complete failure for another. To give an instance, warehouse automation is great but requires compliance with tight specifications: for example, only pallets with certain measurements can be inbounded, and for a growing 3PL aiming to serve in parallel different shippers with several suppliers, the rigidity given by the automation prevents the company to acquire potential customers. On the other hand, a 3PL renewing a long-term contract, single serving a well-established shipper in a mature market, definitely benefits the pros of automation. Balancing automation with the ability to customize services may be key to long-term success in outsourcing.

[3] 2024 28th Annual Third-Party Logistics Study: The State of Logistics Outsourcing, C. John Langley Jr., Ph.D., and NTT DATA, 2024

2. PACKAGING LAYERS

2.1 Impact on Operations

Presenting the Split Volume Cost Model for logistics outsourcing requires the introduction of key terminology and concepts. An over simplified version of a basic routine in a warehouse could be broken down and described by the following macro activities:

- *Inbound:* Activity that starts in the unloading bay and ends when the handling unit completed the put away, meaning that it was laid on a rack, on the floor, on a shelf or wherever it needed to be. Several different in-between tasks may occur according to circumstances.
- *Storage:* Activity that starts once the put away has been completed and ends with picking, which means that the handling unit is about to leave the facility for various reasons such as relocation, order fulfilment, disposal, other.
- *Outbound:* Activity that starts with picking and ends when the handling unit is entrusted to the shipper for delivery or given directly to the customer in case of agreed ex-works incoterms. Several different in-between tasks may occur according to circumstances.

Another relevant information is that modern warehousing revolves around mastering packaging layers inside the database and also physically. Figure 2.1.1 depicts a four-layer structure.

From left to right, the first layer is represented by the smallest sellable unit and is named “**Base Product**”, ”**each**”, or “BP”. Every BP is uniquely identified through an ID (called often “SKU”) and a barcode (EAN, UPC..) within the product catalogue table in the database.

Figure 2.1.1: A four-layer packaging structure for warehousing applications

The second layer is called “**Inner pack**” or “IP”. Among all the layers, IP is the less common but still useful in some contexts, spanning from little use to a significant use like in food industry (e.g. candy bags). Inner packs could be boxes or plastic wraps or cable ties or basically anything which contains or ties more than one unit of the same BP. Each IP is uniquely identified through an ID and a barcode. The word “inner” suggests it needs to rest on the inside of a carton and helps introducing the next layer: the MC.

A “**Master case**” or “**Master carton**” or “MC” is either a collection of homogeneous inner packs or a collection of homogeneous base products. It has to be a proper cardboard box and is usually identified through a unique ID and barcode. The best-in-class producers adopt a specific barcode to identify this type of layer, called “ITF-14”. Figure 2.1.2 depicts an ITF-14. The numeric sequence is not random: it is a combination of an indicator (one-digit prefix) denoting the packaging level + the GS1 Company Prefix (7-10 digit code uniquely identifying the company) + Item Reference + Check Digit. More information on this matter is available online at the GS1 website for free.

9 87 65432 10921 3

Figure 2.1.2: ITF-14 appearance and structure

A “**Master Pallet**” is a collection of homogeneous master cases lying on a wooden or plastic platform, in a single or multi-level pile and identified through a unique ID and barcode. There are instances where the base product itself has an exterior primary packaging sturdy and big enough that nullifies the intermediate master case, so that the master pallet is a collection of “BPs”.

It is important to stress around the fact that each layer must necessarily contain multiple units of the same exact base product. On everyday operations, especially for a third-party logistics, it is common dealing with deviations from the homogeneous ideal scenario, however it is important to have it presented because it plays a key role within the Split Volume Cost Model, affecting greatly the operations and - in turn - costs, as it will be seen.

The heterogeneous cartons and pallets are called respectively “**Mixed Case**” or “**Mixed Carton**” and “**Mixed Pallet**”. It may look straightforward - N units of a single base product compose a master case while N units of M base products compose a mixed case - but there is more depth to it. A level of complexity is given by product variants, of which Figure 2.1.3. provides a great example of how they can - but should not - be handled.

Figure 2.1.3: Common root approach

Initial disclaimer: The approach is not wrong in absolute terms but is definitely sub-optimal because of the implications it has on a database level, which are going to be furtherly detailed later. For the sake of identification, we will refer to it as the “*common root*” approach. Starting from the physicality, although the t-shirt comes in two different colors and sizes, it was used the same SKU (i.e. TShirt123) to identify all of them, relying on the other attributes of the tag to make a distinction. It works as long as there is an additional tag on each t-shirt showing a different barcode (ideally an EAN code to be also covered on online marketplaces where often EAN is mandatory) granting at least a unique attribute for product identification. The better way is showed by Figure 2.1.4 where – along with unique barcodes – there is uniqueness of the SKUs as well; having them as a combination of attributes (i.e. common root + color + size) helps warehouse operators. It will be referred to as the "Distinct root" approach.

Figure 2.1.4: Distinct root approach. Optimal handling of product variants

From a database standpoint, Table 2.1.1 and Table 2.1.2 provide an over simplified version of what a product catalogue table would look like following one approach or the other. The common root approach (Table 2.1.2) makes very easy to identify all the products of a certain color or of a certain size, however it is the only upside, and it is easily outperformed by a distinct root approach where the columns "size" and "color" are added. The biggest downside is having to deal with a composite key, which makes tedious developing queries around. Moreover, the common root brings a high degree of rigidity: what if, for N products, the attributes color and size does not matter at all? There would be $2 \cdot N$ NULL data entry, which is wasteful. What if for other products, other kind of attributes are needed? The choice is among ignoring additional attributes, improperly use the existing ones or ask the IT to add more columns, causing discontent (no developer is ever happy about table modification) and more NULL data entry. Especially for a company whose core business revolves around logistics outsourcing, where different costumers may have all sort of products, the distinct root approach is the solution. Moreover, the distinct approach makes easy and feasible the implementation and management of packaging layers, as it will be seen shortly.

Table 2.1.1: Distinct root

sku	**ean**
TShirt123-White-S	8009150502116
TShirt123-White-L	8009150502114
TShirt123-Blue-S	8009150502138
TShirt123-Blue-L	8009150502145

Table 2.1.2: Common root

common_root	**size**	**color**	**ean**
TShirt123	White	S	8009150502116
TShirt123	White	L	8009150502114
TShirt123	Blue	S	8009150502138
TShirt123	Blue	L	8009150502145

Turning back to the physical aspect, there are no doubts that, should 30 white t-shirts size S and 30 white t-shirts size L be stored within the same box, that box must be regarded as a mixed carton and not as a master carton because they are two different base products identified by distinct SKUs and distinct barcodes; they are logistically as different as a backpack and a pair of shoes.

Proper layers distinction and code separation matters - especially during outbound - because it impacts operations. Flexibility and adaptability are key features for a 3PL that strives to serve many customers having a wide range of necessities, because the logistics process itself undergoes variations based on the objective. Regarding variations, the following examples describe and analyze four scenarios of companies in need of logistics services:

- *Scenario 1*: Company A is a t-shirt producer approaching online sales through a B2C marketplace for the first time.

- *Scenario 2:* Company B is a t-shirt distributor launching physical stores that need to be restocked at certain intervals.

- *Scenario 3:* Company C externalized production in a foreign country overseas and needs a hub that can receive directly from the manufacturer and then ship to spoke warehouses.

- *Scenario 4:* Company D exploits a particularly favorable condition on the market and places orders significantly larger than what its current warehouse can store.

Assume that all of them opted for outsourcing to the same 3PL which – incidentally – runs its facility using packaging layers. It is true that warehousing, in its simplest form, is just a matter of inbound – storage – outbound, however the third-party logistics is likely to manage each customer following different approaches.

SCENARIO 1

Company A needs more than just plain warehousing services given the presence of online orders fulfillment. In technical terms it needs "e-fulfillment services". For the purpose of this discussion, is detailed the impact of packaging layers on the three basic operations only: *inbound, storage, outbound*. Although the process begins from the inbound, it is best to start from the outbound because is output that drives the best input strategy.

- *Outbound:* Although different B2C marketplaces presents different average units per order and outliers in the form of large orders are a possibility, it does not greatly affect the outbound process to the point where different strategies needs to be put in place. Assume that the average online order for Company A is 1,3 units, which is roughly the aggregate Amazon statistics. 1,3 units/order implies that picking in this case means dealing most likely with **base products**, the smallest existing commercial layer.

- *Inbound:* Granular picking (i.e. base product picking) strongly encourages sorting during inbound. Should any mixed case enter the facility, it would automatically be broken down, each SKU would be counted and separated from the others and subsequently put away in different storage units, or at least physically separated somehow. That is so because it increases dramatically picking efficiency. Imagine a scenario where the aforementioned mixed carton containing 30 white t-shirts size S and 30 white t-shirts size L was left unsorted and put away on a shelf during peak season, when orders are high and everyone is in a rush: the picker reads the next picking location on the portable terminal and from item description learns that a white t-shirt size L must be picked; they get there, grab the t-shirt, scan it and receive an error warning of incorrect barcode. From the t-shirt tag the operator learns that it is of the wrong size, so proceeds to dig the carton to find the L, having wasted time because the carton was previously unsorted. This scenario, if re-iterated over the course of the same day – let alone weeks or months – can lead to frustration and less output. Sorting and code separation during inbound in B2C contexts is key, especially if variants or similar products have to be managed. One may wonder whether this approach leads to storage space underutilization. In absolute terms is true, but there is a way to bypass it: having multiple items within the same location is correct as long as they significantly differ one to another; ideally, store together items of different product categories or even of different producers, but that depends a lot on the different order waving methodologies implemented for each warehouse, no general rules on the matter is available.

Master cases and master pallets were left out the discussion so far. The exact process they undergo during inbound is dictated by the outsourcing contract, which establishes whether each box must be opened, and every unit counted before put-away. When dealing with mixed cases, unit count is always implied because while the warehouse operator checks each tag for code separation, they count them contextually. Assume that between Company A and the 3PL is agreed to count 100% of units to inbound, so the contract is likely to be very strict in terms of missing units after inventory. Should the 3PL always comply to the clause? By doing it the 3PL reduces the risks to be short on units – so, yes – however during rush times, where resources are insufficient and an increase in capacity is not an option for whatever reason, there are some emergency procedures that can be put in place. The third-party logistics during the first few months dealing with Company A, must give its best effort to perform a 100% unit count and record data about the accuracy of producer(s) as the ratio between what was actually counted by the warehouse operators and the declared units to be inbounded (retrieved from transport documentation and/or IT data interchange). Should Company A license its brand to an environment of different manufactures, the 3PL should also keep separate statistics at producer level. Once historical data are set it, during peak times if counting 100% of units is not feasible, the 3PL can make at least an informed decision about which load is best to take risks on. A numerical example about inbound risk management is left in Appendix 1.

- *Storage:* Storage is the intermediate phase between inbound and outbound. Its duration is influenced by many factors, such as inventory turnovers rates, demand variability, orders fulfilment capacity, temporal constraints and due dates with customers etc. At this stage, every mixed carton was already broken down during inbound and each SKU it used to contain was counted and stored as base product. Every master carton and master pallet was opened for units counting, light quality checks and then re-taped and stored in a suitable location. What storing base products, master cases and master pallet exactly means from the IT systems perspective but also conceptually, is detailed in the next paragraph, right after the end of Scenario 4 description.

SCENARIO 2

In Scenario 2 the 3PL deals with Company B, a t-shirt distributor launching physical stores. While some retailers do have their primary warehouse located directly behind the store - in rural areas with low population density, lower cost per square meter, higher space availability etc. - in most cases physical stores have limited available storage space in the back, in an effort to maximize the sales floor surface to drive more revenues, instead of storage space which is a cost to manage. It would be unlikely for a store which needs to focus on the selling experience, to have bulk stock management in its core activities and also the equipment, the structure and everything needed to run successfully a warehouse. Thus, stores in most cases need to be replenished from an external bulk warehouse, adding the complexity of transportation on profitability. From the retailer perspective, having third-party logistics managing the bulk and/or transportation, helps also with cost tracking because they receive the invoices on agreed date for those services. From the 3PL perspective, the provisions stated earlier for storage stand still; the greatest impact regards mainly inbound and outbound.

- *Outbound:* A major role in the replenishment of retailers with limited storage is played by mixed cases. They are particularly effective when managing products that come in different size variants because instead of shipping full master cases for each size, it comes handy shipping cartons containing the right size mix according to historical data. It is not due to logistics deciding the mix; the 3PL usually receives a precise request directly from the retailer about what has to be shipped. Picking consists in retrieving base products, exactly as in B2C contexts and then pack them in mixed cases containing products that shares the same common root. In-between solutions are always a possibility according to the context: there could be cases where the logistics ships full master cases of sizes with high turnover rate and mixed cases for low turnover rate sizes.

- *Inbound:* There could be instances where it was agreed with the producer that for certain products, multi-size mixed cases are the manner in which items are shipped from the manufactory plant because is the optimal configuration for store replenishment. Should a 3PL manage this scenario, there would be no point in performing code separation during inbound - which is the contrary to what was prescribed in Scenario 1 - and the mixed case would be stored as-is after quality inspection and units' count. However, should it be the case, it is imperative that the store orders mostly quantities multiple of the ones in each mixed carton, otherwise the upstream optimization would have been done for nothing.

SCENARIO 3 – SCENARIO 4

Scenarios 3 and 4 are grouped together because they share most implications from the 3PL perspective, with just some adjustments to prove different points. In both instances the management of base product is not required, the minimum handling unit is master case. Moreover, scenario 4 is an extreme occurrence that in real-life applications is handled most of the times by transport companies instead of logistics because they can offer the service for a cheaper price give the lower degree of technicality and higher flexibility, especially for short periods.

In Scenario 3 the 3PL needs to manage a challenging *inbound* phase because dealing with loads from overseas is demanding. The bureaucratic side requires the knowledge of many technicalities while the physical side entails additional handling. The goods are most likely received in a container to unload and there could be many different custom and nonstandard solutions adopted by the manufacturer for increasing the occupied volume, forcing the logistics operator to palletize everything during the unloading operation, elongating significantly the task duration (e.g. Figure 2.1.5). In fairness, how the goods are received is part of the agreement with the manufacturer, but the 3PL is not always informed and/or has the chance to negotiate a handy unload.

Figure 2.1.5: Load in a container shipped from China lacking pallets support

Outbound is easier than in Scenario 1 and 2 because be the hub warehouse replenishing other spoke warehouses usually means that only master cases or pallet are shipped towards them which, in turn, implies that they are the only packaging layers in *storage.*

In Scenario 4, Company D overstocked on purpose to exploit an unpredictable yet favorable condition on the market. Assume they ordered 100 pallets to be delivered in 3 batches by semi-truck (i.e. trucks capable of transporting 33/34 full pallets). Given the unexpectedness of the event, their warehouse has not enough storage space availability and is expected to be empty enough to fit all the pallets over the course of four months. To be covered during this short period of time, they outsourced to a 3PL. The idea is to retrieve a full semi-truck at time as soon as enough space for one is available, so in *outbound* the only allowed handling units are pallets. Given the transitory nature of the service and the no need for granular picking, the pallets in inbound can be treated as a “black box”. It means tracing no information about its content and to consider it as a non-divisible entity, like a base product. Being meaningless tracing the content and even differentiate each pallet one to another, the 3PL could create a general-purpose SKU on their product catalogue table and *store* each pallet under that SKU. When instances like that occurs, transportation companies often offer to retrieve the goods, store at their own warehouse - which most of the times consists of racks full of “black box” pallet managed on spreadsheets - and then deliver at agreed time. It is a service which lacks all the checks a logistics performs during inbound. They move pallets from one place to another for cheaper, a service that comes handy at times but has limited applications.

2.2 Impact on Information Systems

The former paragraph introduced some key concepts about the information systems revolving around third-party logistics. Above all, the idea that each product entering a warehouse must be added first to the product catalogue, that is one of the database tables composing the Warehouse Management System (WMS). It was also explained that there is more than one approach to be chosen from during the database developing process and that the “Distinct root” approach was convenient for many different reasons, while the “Common root” approach should be always disregarded.

This paragraph is about to discuss instead how the “distinct root” approach makes possible and shapes the existence of packaging layers inside the database and details what happen in parallel at an IT level when warehousing operations are performed physically.

The first notion to be learnt is that packaging layers are in a different table respect to the product catalogue. That is so because they are logically different entities, serve a different purpose, is tidier and convenient. From now on, the table containing packaging layers is referred to as “product packaging”. Table 2.2.1 is an advanced example of a product packaging structure whose columns shows the dept of the matter, containing information about products and layers dimensions, packaging typology, the layer multiplier and also the relationship among packaging in case of multi-level pack structure.

ProductId	Sku	Length	Width	Height	Weight	PackType	Quantity	SkuChild
B2JU16083JS-4A	B2JU16083JS-4A	22,80	31,10	1,10	0,07	Base Product	1	2JU16083JS-4A
B2JU16083JS-4A	B2JU16083JS-4A-MC-50	50,20	24,20	25,30	4,04	MasterCase	50	B2JU16083JS-4A
B2JU16083JS-4A	B2JU16083JS-4A-P-1200	80,00	120,00	116,00	107,00	Pallet	1200	B2JU16083JS-4A-MC-50
CODW19JU08-4142	CODW19JU08-4142	22,20	28,10	6,80	0,25	Base Product	1	CODW19JU08-4142
CODW19JU08-4142	CODW19JU08-4142-MC-12	41,00	54,40	23,60	3,83	MasterCase	12	CODW19JU08-4142
CODW19JU08-4142	CODW19JU08-4142-P-288	120,00	80,00	130,00	98,08	Pallet	288	CODW19JU08-4142-MC-12
ELE14498	ELE14498	8,00	28,00	12,00	0,30	Base Product	1	ELE14498
ELE14498	ELE14498-MC-12	30,00	26,00	45,00	4,30	MasterCase	12	ELE14498
ELE14498	ELE14498-MC-6	30,00	26,00	45,00	2,80	MasterCase	6	ELE14498
ELE14498	ELE14498-P-288	120,00	80,00	105,00	115,00	Pallet	288	ELE14498-MC-12
EQ122349	EQ122349	27,00	30,00	10,00	0,15	Base Product	1	EQ122349
EQ122349	EQ122349-MC-20	60,00	40,00	40,00	3,80	MasterCase	20	EQ122349
EQ122349	EQ122349-MC-15	60,00	40,00	40,00	4,50	MasterCase	15	EQ122349
EQ122349	EQ122349-P-240	80,00	120,00	160,00	75,00	Pallet	240	EQ122349-MC-15

Table 2.2.1: Product packaging table

Table 2.2.2 instead is the product catalogue table, and the reported dataset is the counterpart of the dataset in Table 2.2.1

Table 2.2.2: Product catalogue table

Id	Name	Ean	SupplierId
B2JU16083JS-4A	T-SHIRT YELLOW 3D	8054609478984	208
CODW19JU08-4142	MEN SLIPPERS	8019219159852	208
ELE14498	TOY TRUCK	8436573614498	208
EQ122349	TRAVEL PILLOW	8436573614215	208

The relationship between the Product catalogue table (from now on referred to as "Products" for brevity) and the Product packaging table (from now on referred to as "ProdPack" for brevity) is based on the relation between the **Id** column of Products (primary key) and the **ProductId** field of ProdPack (foreign key). The relationship between the two tables is of the type 1 : N (one to many), implying that a single product can have multiple packaging configurations (i.e. base product, Master Carton, Pallet, etc.).

Using technical notation, the relationship schema is the following:

1. Primary Key (PK): […].[Products].[Id]
2. Foreign Key (FK): […].[ProdPack].[ProductId]

ProdPack is the table containing the volumetric information of each layer of packaging in centimeters and kilos, dedicating to them four columns. Dimensions play a key role in the Split Volume Cost Model (SVCM), affecting many points as will be extensively demonstrated in the next paragraph. In general, many relevant aspects in warehouse management go through packaging layers measurements:

- *Warehouse space utilization index:* An efficiency indicator showing the percentage of available space that is effectively used for storing goods and is computed through the following formula:

$$WSU = \frac{Total\ Volume\ of\ stored\ items}{Total\ Storage\ Capacity}$$

Thanks to dimensional data, assessing the numerator means summing the volume of the N stored unit (could be base product, master case etc.) multiplied by the relative quantity. In formula:

$$Total\ Volume\ of\ stored\ items = \sum_{n=1}^{N} (V_n q_n\ )$$

The total storage capacity instead, is the sum of the usable volume of each storage unit (i.e. racks, shelves etc.). The optimal value of WSU is considered to be 80% - 85% because it indicates that the warehouse space is well-utilized without being overcrowded[4]. Values above 85% may suggest overloading, worsening the chance of product damages and reducing operational efficiency. 70% - 80% is acceptable, especially in contexts presenting seasonality or general demand variability. Below 70% it may be

[4] Amsc-usa. Warehouse Capacity: How to Calculate & Maximize Storage Space. https://www.amsc-usa.com/blog/warehouse-capacity/#:~:text=Set%20your%20ideal%20warehouse%20utilization,on%20why%20we%20recommend%2080%25.

an indicator of inefficiencies and wasted space and might be necessary to reorganize the warehouse layout or implement more effective space management strategies. It is important to note that the optimal value is also context-dependent: for example, automated warehouses can operate efficiently with high WSU, at the price of higher rigidity as extensively seen in paragraph 1.2.

- *Shipping packaging optimization:* Dimensional data availability, along with a good order records track, allows making an educated guess, for example, during the shipping material reorder process and can also be used to help the warehouse operator during the packing phase, suggesting the choice of a certain cardboard box because it optimally fits - or at least is the best middle ground for - the order to fulfill. In fairness, even with dimensional data availability, shipping packaging optimization is a hard subject. For example, consider a warehouse operating in a B2C context run by a 3PL which stores the inventory of ten different companies in different industries (i.e. clothing, automotive, toys, electronics) for a total of 5000 different base products to be potentially shipped. Recalling Chapter 2.1 – Scenario 1, consider 1,3 as the average units per order received, implying that most of the orders are one-shot (1 unit/order) but there are also multi-quantity orders to be accounted for. A multi-quantity order could consist in more than 1x of the same base product or a combination of different base products from the same company or from different companies. For each SKU the dimensional data is available. Given a pool of 20 different cardboard boxes to choose from, it is relatively easy to implement an algorithm which selects the optimal box for one-shot orders, that is the smallest in volume which verifies that *length box > length SKU* and *width box > width SKU* and *height box > height SKU* and *box load capacity > weight SKU.* The output is correct for most of the products; a source of exceptions is for example that case where conditions are slightly verified and so there is not enough room to accommodate protective packing material such as bubble wrap or packing peanuts. To account for that, it could be used a 1.15-1.2 multiplier on each SKU dimension for example. The real engineering challenge starts from orders containing 2 or more units because of the different ways they can be arranged and combined in the 3D space. To grasp the depth of the problem, the reader is encouraged to take hold of any two arbitrary objects and begin moving them relative to one another to visualize the various combinations in which they can be positioned, and the more objects are added, the more complex it gets. Engineering an algorithm which computes the best arrangement among products and subsequently chooses the best cardboard box to ship them, given all the possible orders combination, is costly and computationally heavy. If one wishes to give a suggestion to the warehouse operator during packing, the first algorithm addresses most scenarios and for orders > 2 units, just let the operator to be independent, in some cases they know better than any overcomplicated set of formulas, or buy a commercial software.

- *Inbound and Picking route optimization:* In B2B contexts where orders present a higher average number of products and quantities, there is a higher chance that heavy and light products are requested within the same order. Product dimension availability allows to suggest the usage of the proper handling equipment (e.g. heavy loads can be handled by a restricted set of forklifts) and then allows also the prioritization of retrieving heaviest items first during picking, minimizing handling and reducing the time required for the task. The same reasoning could be applied during the inbound, where the WMS can recommend optimal storage locations according also to product dimensions.

- *Order waving optimization:* Order waving is a procedure implemented in warehouse management to optimize the order fulfillment process. It involves grouping similar orders into "waves" to be processed together. Recalling the 3PL presented in the *shipping packaging optimization* bullet point, once all the orders are imported on the WMS, one way to group them is by dimensions because it might be convenient to organize packing workstations to process a fixed order range size so that the shipping materials could be prepared in advance, the operator must not decide most of the times which cardboard box to use and gets also familiar with dealing with a certain order dimension; furthermore, some protective packing material is more suitable for products in certain dimensions range etc. Order size is not the only waving discriminant; it depends also on the context, and it can greatly vary by the day. Orders can be waved by priority for example, i.e. high priority vs standard; they can be waved by product type, which has similar implications to size and weight waving; in B2B contexts the geographic location could play a key role, waving together orders destined for the same or nearby locations to optimize transportation routes. Orders can be waved according to the shipping method (e.g. ground, air) to align with carrier schedules, or by warehouse zones, allowing pickers to focus on one area at a time, reducing travel time which is one of the most time-consuming activities in order fulfillment (50% of picker's time)[5]. Waves can also be scheduled based on the availability of labor and material handling equipment, in an effort to avoid bottlenecks causing idle time.

It is now clear *why* dimensions are important in warehousing management but *how* the data is collected and maintained is worth a digression. Should the reader not be familiar with SQL tables, they can span over 20 columns; ProdPack as presented as Table 2.2.1. is a shortened version where many columns were hidden for formatting reasons. Table 2.2.3. below is also a shortened version showing the dimensional columns only. A total of 8 different columns are dedicated to measurements: the first four (i.e. length, width, height, weight) are inserted into the database manually by the data entry operator or retrieved automatically by the agreed data interchange during the product packaging creation process. They represent dimensions declared by the producer. Given the importance of that data, in warehousing outsourcing the 3PL should not fully trust those numbers and reserve itself the possibility to conduct further investigations. That is so because there are many companies having low-quality measurements datasets, or alternatively they could have consciously inserted wrong or made-up figures just for the sake of completing the task.

[5] Ehsan Ardjmand, Shakeri Heman, Manjeet Singh, Omid Sanei Bajgiran (2018). Minimizing Order Picking Makespan with Multiple Pickers in a Wave Picking Warehouse. Frostburg State University, Kansas State University, DHL Supply Chain, University of Toronto Scarborough

Table 2.2.3: ProdPack dimensional columns

Sku	Length	Width	Height	Weight	Length Real	Width Real	Height Real	Weight Real
ELE14498	8,0	28,0	12,0	0,30	8,1	28,2	12,1	0,31
ELE14498-MC-12	30,0	26,0	45,0	4,30	30,3	25,9	44,8	4,34
ELE14498-MC-6	30,0	26,0	45,0	2,80	30,3	44,8	25,9	2,86
ELE14498-P-288	120,0	80,0	105,0	115,0	120,0	80,0	105,3	114,16
EQ122349	27,0	30,0	10,0	0,15	27,3	29,8	9,9	0,15
EQ122349-MC-15	60,0	40,0	40,0	3,80	60,8	40,9	40,2	3,81
EQ122349-MC-20	60,0	40,0	40,0	4,50	60,1	40,1	40,3	4,57
EQ122349-P-240	80,0	120,0	160,0	75,0	120,0	80,0	160,0	75,7

Moreover, it is not certain that irregular-shaped products are measured following the "top encumbrance" method, that considers the dimensions of irregular objects as those of the smallest parallelepiped which encloses them. Although is debatable, the top encumbrance gives a widely used in the industry and objective method to perform SKU measurements.

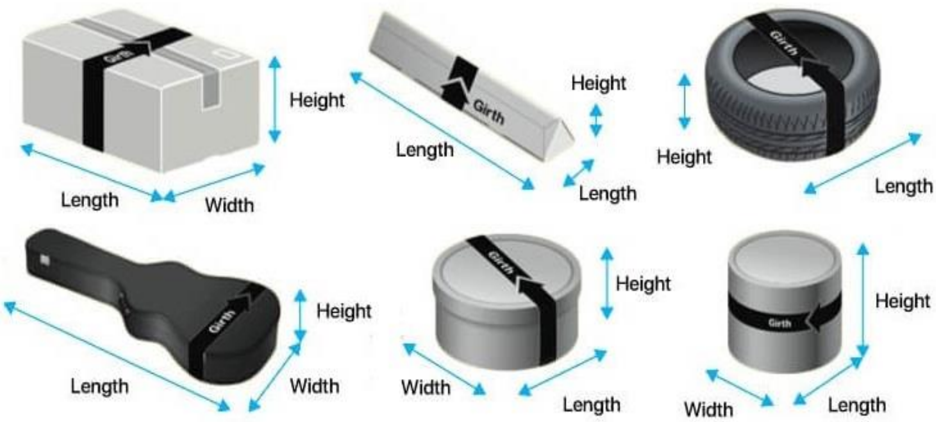


Figure 2.2.1: Irregular shapes measurements – "Top encumbrance" method

To avoid spreading incorrect dimensions downstream, the 3PL must take extra precautions and perform measurements itself when new products are inbounded for the first time. The columns in Table 2.2.3 respectively called LengthReal, WidthReal, HeightReal and WeightReal serve the purpose to store the new measurements taken by the 3PL. The interesting part is how those data are inserted into the ProdPack table. Manual data collection is very impractical: the warehouse operator should tape-measure each dimension, then use a scale for weighing and then they could either pass the data to IT or learn how to perform data insert themselves. The alternative is to make use of a volumetric scale. Although it requires an initial investment to buy the hardware, it needs to be integrated so that data interchange is enabled and it also requires training to warehouse operators, in the long run is the optimal means to retrieve high quality dimensional data.

Figure 2.2.2: Volumetric scale for base products and cases measurements

The functioning of a volumetric scale is straightforward: as shown in Figure 2.2.2, the scale presents one sensor on each axis for length, width and height detection and a scale pan for weighting. It features also a display and a barcode scanner. The operator scans the barcode first – either of the base product or of the master case according to what they want to measure – and then places the object in the correct position onto the scale pan (see Figure 2.2.2.). They can check the measurement in real time on the screen and doing so is a good practice given that the sensors may incorrectly detect dimensions from time to time: transparent plastic bags reflect the sensor signal and are a first source of error that can be overcome by using further solid supports; a second source of error are thin objects, an instance where the accuracy of a volumetric scale can decrease significantly. Should everything look normal, the operator can confirm the dimensions through the screen, which are then sent to a SQL table as raw data, ready to be furtherly inserted into the ProdPack, populating respectively LengthReal, WidthReal, HeightReal and WeightReal. Data pairing occurs via barcode. Should multiple measurement be taken, the ProdPack must be updated each time with the last detection, assuming that it is always the most accurate and accounts for pack modifications.

Although the introduction of a volumetric scale severely shortens and improve the measurement process, it requires time and labor. A relatively safe option opposed to systematic dimension detection consist in using an approach similar to the one detailed in Appendix 1 in the inbound risk management context, where data was used to support decision making. The assessment this time regards the quality of the producer-declared measurements (columns length, width, height, weight) and the idea is to use statistics to avoid, when possible, measuring each new SKU entering the warehouse. Before deciding the criterion to assess if a dataset is trustworthy or unreliable, it is necessary to decide how many measurements needs to be taken (i.e. sample size).

From statistics, when dealing with a finite population, the formula to compute the proper sample size is the following:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}}$$

Where:

- n_0 is the sample size if the population is infinite
- N is population size

n_0 is obtained:

$$n_0 = \frac{Z^2 p(1-p)}{E^2}$$

Where:

- Z is the value related to the confidence level (1.96 for 95%)
- p the prevalence, assumed to be 0,5 when no data is available
- E is the margin of error. 0,05 can be considered as acceptable

Therefore, should the dataset be composed of 2000 SKU, with a margin of error of 0,05 and a confidence level of 95%, n_0 is approximately 385 and n = 323, meaning that 16,15% of the overall products must be properly measured through the volumetric scale to get an idea about the reliability of the producer dimensions. Once the measurement process is completed, 323 SKU have all of their eight dimensional columns populated. An exact correspondence at centesimal level between each dimension and its "real" counterpart is very unlikely due to the variability of the process, so a criterion that accounts for tolerances is necessary: the "paired samples t-test". The paired samples t-test, also known as the dependent samples t-test or paired t-test, is a data analysis tool used to determine if the mean difference between two sets of observations is zero. In a paired samples t-test, each subject or entity is measured twice, yielding pairs of observations. Common applications include repeated measures designs, as in our scenario[6]. The idea is to compare the measurements provided by the producer with those obtained using a volumetric scale, and then analyze the mean difference through the test. The paired samples t-test involves two competing hypotheses: the null and the alternative hypothesis. The null hypothesis assumes that the true mean difference between the paired samples is zero ($H_0 : \bar{h}_d = 0$), so any observed difference is attributed to random variations. The alternative hypothesis posits that the true mean difference between the paired samples is not zero ($H_0 : \bar{h}_d \neq 0$). Since the variation in measurements can be either positive or negative, a two-tailed hypothesis is used. The paired samples t-test must meet four assumptions:

1. *The dependent variable should be continuous.*
2. *The observations are independent of each other.*
3. *The dependent variable should be normally distributed.*
4. *The dependent variable should not contain outliers.*

[6] Statistics Solutions. Paired T-Test. https://www.statisticssolutions.com/free-resources/directory-of-statistical-analyses/paired-sample-t-test/#:~:text=Paired%20T%2DTest-,Paired%20T%2DTest,resulting%20in%20pairs%20of%20observations.

The dependent variable is the Δ measurement, so the assumption of continuous variable is verified since one is dealing with dimensions; observations are independent because the two measurements are performed in separate contexts. Normality can be assessed using various methods, with the simplest being a visual inspection of the data using a histogram, but there are also online free calculators. Data inspection also helps with outliers. Given the presence of four kinds of dimensions, the algorithm must be executed for each dimension type separately. It is written using arbitrarily the height but is the exact same across all types. The paired samples t-test algorithm steps are the following:

- Calculate first the sample mean difference by doing:

$$\bar{h}_d = \frac{1}{n}\sum_{i=1}^{n}\left(h_{p_i} - h_{l_i}\right)$$

- Calculate second the sample standard deviation by doing:

$$\hat{\sigma}_d = \sqrt{\frac{\sum_{i=1}^{n}\left(h_{p_i} - h_{l_i}\right)^2 - n \cdot \bar{h}_d^{\,2}}{n-1}}$$

- Calculate the test statistic t and compare with T, the critical value of a t-distribution with $(n-1)$ degrees of freedom:

$$t = \frac{\bar{h}_d}{\frac{\hat{\sigma}_d}{\sqrt{n}}}$$

The value of T is retrieved by software or by table and is affected by the degrees of freedom but also by the significance level α, which represents the probability to reject the null hypothesis when is actually true. In our case means accepting that 1/20 of times the mean difference between the producer measurement and the logistics measurements could not be zero when it actually could be, so further investigations are conducted when not necessary. About the test and t and T comparisons:

- Should $|t| \leq T\alpha/_2$ then failure to reject $H_0 : \bar{h}_d = 0$
- Should $|t| > T\alpha/_2$ then reject $H_0 : \bar{h}_d = 0$

In practical terms, the first bullet point does not rule out the chance that the differences between the producer measurements and the logistics measurements are statistical noise; the second suggests that probably is not noise and producer measurement are off. Another way to conduct the test is by checking the confidence interval; should it contain the value zero, then failure to reject H_0

$$CI_{95\%} = \bar{h}_d \pm T\alpha/_2 \cdot \frac{\hat{\sigma}_d}{\sqrt{n}}$$

Appendix 2 contains a numerical example based on real data to provide greater depth and clarity to the presented theory. It includes as well insightful considerations and printed graphs.

Going back to the Table 2.2.1 analysis, **PackType** is self-explanatory, while the column **Quantity** refers the units of base product contained in the layer, so a layer multiplier coefficient. **SkuChild** is an essential column whose purpose is to link each layer to the one immediately below in the hierarchical structure. It enables the coexistence of more than one entry of a given layer referred to the same ProductId and allows automatic layer conversions on the WMS. The best way to unfold the matter is through an example. Table 2.2.4 shows a made-up hierarchy, deliberately "intricate" for academic purposes, where the same Base Product branches in different layer configurations, as depicted more clearly by Figure 2.2.3. In real life, it would be unlikely given the strong tendency toward standardization in packaging and logistics. Typically, a unique carton size and pallet are engineered to be optimal for each product, taking into account factors such as storage efficiency, transport costs and handling ease, minimizing variability and simplifying the supply chain.

Table 2.2.4: ProdPack hierarchical columns

ProductId	Sku	Quantity	SkuChild
ELE14498	ELE14498	1	ELE14498
ELE14498	ELE14498-MC-12	12	ELE14498
ELE14498	ELE14498-MC-6	6	ELE14498
ELE14498	ELE14498-P-288	288	ELE14498-MC-12
ELE14498	ELE14498-P-100	100	ELE14498

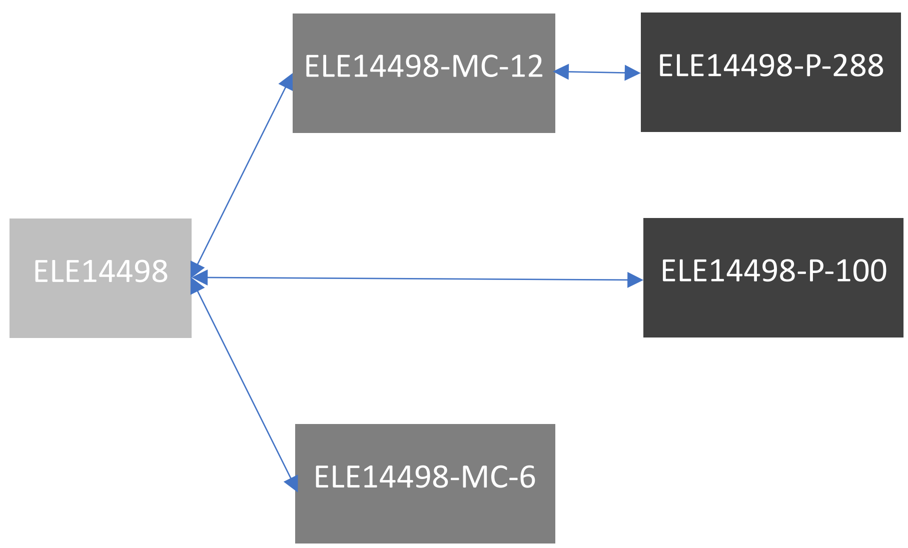


Figure 2.2.3: Packaging layers hierarchy diagram

Regarding the coexistence of more than one entry of a given layer referred to the same ProductId, assume that at a given time, the inventory of ELE14498 consist of 1 master pallet of 288 units (i.e. 1 unit of ELE14498-P-288), 1 master pallet of 100 units (i.e. 1 unit of ELE14498-P-100) and 1 master case of 6 units (i.e. 1 unit of ELE14498-MC-6):

Sku	Initial Inventory
ELE14498-MC-6	1
ELE14498-P-288	1
ELE14498-P-100	1
ELE14498	0

Should an order of 5 units be received, it could be fulfilled by picking the units from any of the three layers. One is clearly more convenient than the others but assume for the moment they are equivalent. Given that the requested quantity is smaller than any of the current layer in stock, a layer conversion is required:

Scenario A: Picking from the master case. Should the 5 units be picked from the master case, thanks to the column SkuChild it is understood that there are no intermediate layers between the master case and the base product (it could have been an inner case), so the layer conversion brings the inventory of ELE14498-MC-6 from 1 to 0 and the inventory of ELE14498 for 0 to 6. Subsequently the 5 units of base product are subtracted, obtaining:

Sku	Final Inventory
ELE14498-MC-6	0
ELE14498-P-288	1
ELE14498-P-100	1
ELE14498	1

Scenario B: Picking from the 100 units pallet. Similar to Scenario A given the absence of intermediate layers. It is important to stress that layers are not an abstract concept, but they reflect the physicality, so in Scenario B there are 100 units laying on a pallet and no carton to contain them. The layer conversion brings the inventory of ELE14498-P-100 from 1 to 0 and the inventory of ELE14498 for 0 to 100. Subsequently, the 5 units of base product are subtracted, bringing the following ending result after picking:

Sku	Final Inventory
ELE14498-MC-6	1
ELE14498-P-288	1
ELE14498-P-100	0
ELE14498	95

Scenario C: Picking from the 288 units pallet. The shape of the order and the presence of an intermediate layer forces a double conversion in scenario C. The inventory of ELE14498-P-288 goes from 1 to 0, whereas ELE14498-MC-12 goes from 0 to 24 $(288|12 = 24)$ at first, and then 1 unit of ELE14498-MC-12 is furtherly converted in 12 base products so that the order can finally be fulfilled, bringing the ending inventory as follows:

Sku	Final Inventory
ELE14498-MC-6	1
ELE14498-P-288	0
ELE14498-P-100	1
ELE14498	7
ELE14498-MC-12	23

The necessity to convert all the way down to the base product was driven by the request. Should 100 units be ordered instead, no conversion would have been performed because the full pallet

ELE14498-P-100 could have been shipped. Another instance is a 12 units order; in that case it could either have been shipped 2 units of ELE14498-MC-6 if available, of 1 unit of ELE14498-MC-12, entailing a one-step conversion from ELE14498-P-288.

As seen, implementing layers in warehousing provides opportunities but also choices to be made. Opportunities because a master case or a pallet is – by definition – a single entity which – necessarily – is stored in a single location, allowing the picking of larger quantities in one fell swoop. Choices because as seen, fulfilling an order can be done in different ways if multiple layers are available for the same base product, entailing different states of the final inventory. Layer conversion on the WMS must be demanded to an algorithm, which could be then implemented in a programming language of choice, depending on the company.

The following is a detailed outline of a layer conversion algorithm: it is an iterative model that starts by checking if there is enough inventory across all the layers to fulfill the order and then a second check is done to verify whether on the current inventory a layer conversion is needed and, should it be the case, performs it. The only instance where conversion is mandatory occurs when the ordered quantity is lower than the smallest layer multiplier of any SKU in stock. The algorithm continues by confronting the ordered quantity with the inventory of every layer and chooses the one that fits best without overshooting the request. In other terms, the model allows layer conversion only at the beginning of each iteration and only if is the only option. Although the minimization of conversions may lead in some cases to sub-optimal solutions from an operational standpoint, it was chosen for economic reason towards the customer, because this algorithm is part of a warehousing outsourcing context ruled cost-wise by the split volume cost model, that is detailed in the next paragraph and concludes the whole master's thesis.

After the proper amount of the selected layer for the first iteration is computed, the algorithm updates the stock and then checks whether the order is fulfilled entirely or whether a second iteration in necessary. It does it by subtracting the allocated quantity to the ordered quantity. Should the result be zero, the order is fulfilled so algorithm ends; conversely, it sets the residual quantity as the new ordered quantity and it cycles back to the beginning, starting a new iteration. Below, its mathematical formulation.

The variables involved are:

QO	$Order\ Quantity$
m	$Layer\ multiplier$
I	$Inventory$
QR	$Residual\ Quantity$
QA	$Allocated\ Quantity$
SOL	$Solution$
i	$Iteration\ Coefficient$
j	$Row\ Coefficient$

Inventory check across all the layers is given by the following:

$$QO \leq \sum_{J} I_J \cdot m_j$$

Should it be *false*, the order cannot be fulfilled as-is and further actions are required based on the context. Unless automatic partial order fulfillment is agreed as standard practice, it is usually necessary to pass the case to the customer service that informs the customer which, in turn, may ask for a total refund and order cancellation or partial refund and partial order fulfillment or may even ask to postpone shipping until the whole order is fulfillable.

Should it be *true* instead, the algorithm can begin its cycle:

0) It starts by computing for each SKU the following ratio:

$$\frac{QO_i}{m_j} \qquad \forall\, j$$

- If $\forall j \;\; with \;\; I_{i,j} > 0\,,\;\; \frac{QO_i}{m_j} < 1 \quad \Rightarrow$ Conversion
- Else, skip to 1)

Conversion is performed on the SKU that verifies the condition:

$$max\left(\frac{QO_i}{m_j}\middle|\; I_{i,j} > 0\right)$$

As seen, doing a conversion means changing the inventory. The upper (or father) layer stock is decreased by 1:

$$I'_{i,father} = I_{i,father} - 1 \;\; then \;\; set \;\; I'_{i,father} = I_{i,father}$$

The lower (or child) layer linked to the father by the column SkuChild, undergoes the following stock variation:

$$I_{i,child} = \frac{m_{father}}{m_{child}}$$

1) Now, it is ensured the existence of one or more SKU to be selected in the iteration. The best fit is given by:

$$min\left(\frac{QO_i}{m_j}\middle|\ I_{i,j} > 0 \ \wedge \ \frac{QO_i}{m_j} \geq 1\right)$$

- If $min\left(\frac{QO_i}{m_j}\middle|\ I_{i,j} > 0 \ \wedge \ \frac{QO_i}{m_j} \geq 1\right) < \ I_{i,j} \Longrightarrow SOL_{i,j} = SKU_j \cdot \left\lfloor\frac{QO_i}{m_j}\right\rfloor$

- If $min\left(\frac{QO_i}{m_j}\middle|\ I_{i,j} > 0 \ \wedge \ \frac{QO_i}{m_j} \geq 1\right) \geq \ I_{i,j} \Longrightarrow SOL_{i,j} = SKU_j \cdot \ I_{i,j}$

Where $\lfloor\frac{QO_i}{m_j}\rfloor$ is the floor function. Then, set for all the other layers:

$$SOL_{i,j} = 0$$

By combining all the SOL contributes, the iteration solution is:

$$SOL_i = \sum_J SOL_{i,j}$$

2) Proceed to update the Inventory of each SKU

$$I'_{i,j} = I_{i,j} - \left(\frac{SOL_{i,j}}{SKU_j}\right) \forall j \ then \ set \ I'_{i,j} = I_{i,j}$$

3) To assess whether another iteration is needed, compute the allocated quantity by doing:

$$QA_i = \sum_J \frac{SOL_{i,j} \cdot m_j}{SKU_j}$$

Then check the residual order quantity to fulfill, if any:

$$QR_i = QO_i - QA_i$$

- If $QR_i = 0 \quad \rightarrow \quad end$, order fulfilled
- If $QR_i > 0 \quad \rightarrow \quad i++$ further iteration

Should a further iteration be needed, set $QO_{i+1} = QR_i$ and start from 0). The general equation of solution array is the following:

$$SOL_{i+1} = SOL_i + \sum_J SOL_{i+1,j}$$

Appendix 3 contains a numerical example that follows the algorithm and brings some further clarity and concreteness.

The paragraphs 2.1 and 2.2 introduced many concepts. They presented packaging layers, explaining what they are, how they should be implemented and handled, their effect on the inventory, how they can improve efficiency, why they should be measured etc. Each information will be deployed in the last paragraph, where the Split Volume Cost Model – that involves layers – for warehousing outsourcing, is explained.

2.3 SVCM: Split Volume Cost Model

Before diving into the matter, some initial preambles and clarifications are due. The following discussion regards a context where a 3PL performs standard warehousing activities on behalf of another company that opted for outsourcing. By standard activities are meant the ones presented at the beginning of paragraph 2.1: *inbound, storage, outbound.* About the outbound, a B2C context is assumed; the 3PL fulfills orders from online marketplaces where the average unit/order is 1,3. Basically, the *Scenario 1* presented on Paragraph 2.1. It is worth mentioning that the split volume cost model could be applied also to any of the other presented scenarios, there are no limitations in general; *Scenario 1* was selected simply because it is the one featuring the most depth in terms of layers involved and, in turn, a wider variety of volumes and weights. The "split volume" part derives from one of the key concepts on which was developed around: the idea that in a warehouse there are some storage locations which are more valuable than others. The layout in Figure 2.3.1 provides a great basis to understand the reasons why. Suppose that the 3PL regarded in *Scenario 1* runs the depicted facility, where the order packing stations are somewhere in the lower area along with the loading bays. The middle section presents infrastructural low ceilings and because of that the goods are stored on shelves, so the whole area is subjected almost entirely to manual picking non-assisted by handling equipment because the height and the average order allow it (see Figure 2.3.2a). Areas set up for loose picking activities are defined in warehousing science as "*pick* *face*" or alternatively as "*forward-picking locations*". It makes sense to have it located near packing and shipping areas and it makes even to sense to store high-demand items in easily accessible locations.

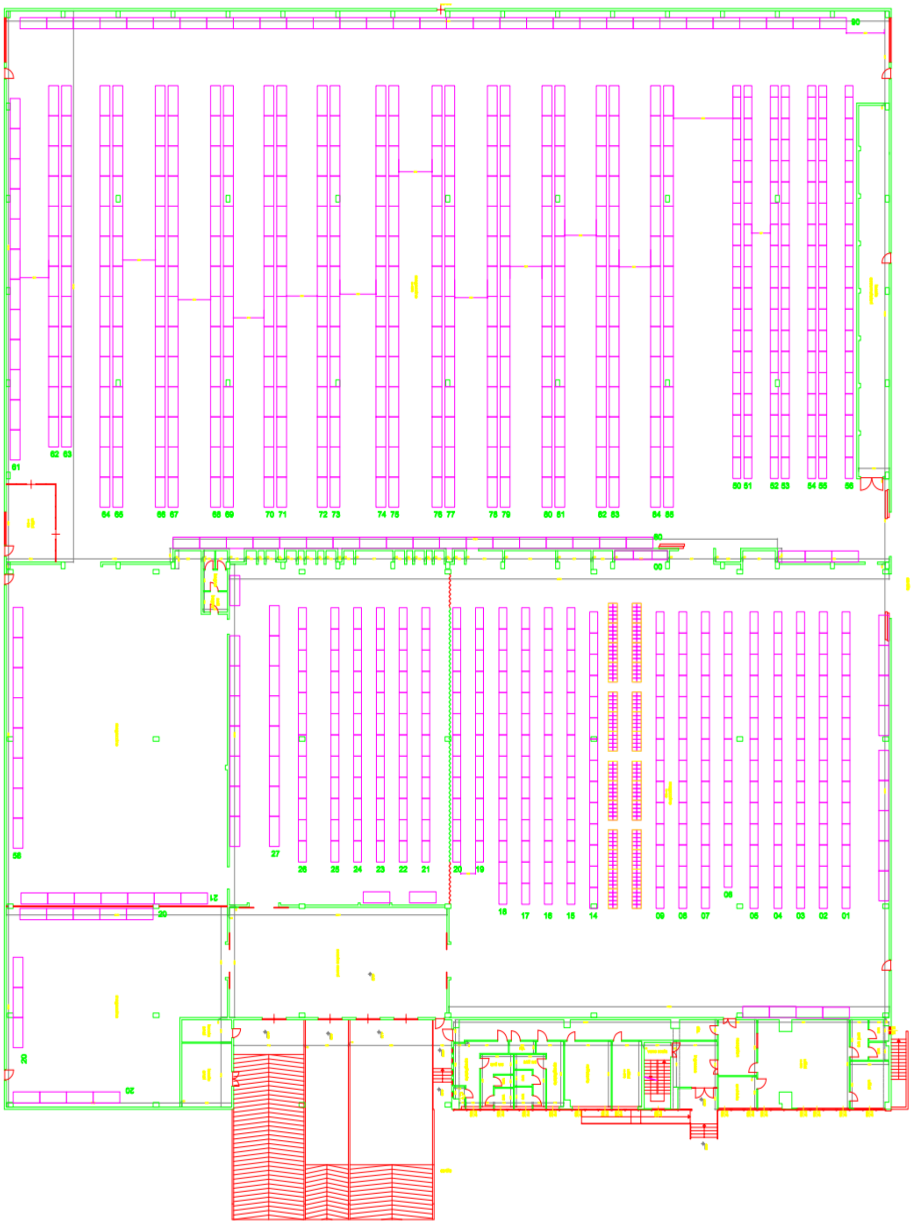


Figure 2.3.1: Warehouse layout

The pick face needs to be regularly restocked to ensure a steady supply of products ready for picking. The products are sourced from the “*bulk storage area*”, depicted in Figure 2.3.2b.

Figure 2.3.2a and Figure 2.3.2b: Pick face (left) – Bulk storage (right)

The *bulk storage area* is the one located in the upper part of Figure 2.3.1. In a warehouse is a designated space where large quantities of products or materials are stored in bulk before they are needed for processing, picking or distribution. Unlike the pick face, which is optimized for quick access to individual items, the bulk storage area focuses on maximizing storage capacity. This area is typically used for holding inventory that is not immediately required for order fulfillment, so items are often stored on pallets or stacked to make efficient use of vertical space. Translating in packaging layers, pick face is the area where base products (also called “eaches” in warehousing science) are stored along with some residual inner packs (if any), whereas the bulk storage area contains only pallets and master cases. Professionals in the warehousing field know there are usually deviations to this ideal case; for example, there is no point in keeping low-rotating base products within the pick face, especially when the area is highly saturated. For the sake of the theory about to be presented, assume that the ideal separation among "eaches" and master cartons/pallets is true, which is also true in real applications for the majority of cases. Circling back to the idea that in a warehouse there are some storage locations which are more valuable than others, is quite intuitive to imagine that in the case of a B2C order fulfillment context, is the pick face to be the most precious. A first way to look at it is *scarcity*: pick face has less storage capacity per square meter by books and in no case the total capacity of pick face is greater than the total capacity of its relative bulk storage area, it would defeat the point. A second view is also inferable by the definition of forward-picking locations area: being the closest to order packing stations and loading bays, it maximizes picking efficiency/minimizes picking costs, that, combined with the previous concept of scarcity, reinforces the idea of most valuable area. However, the increased picking efficiency is attainable by facing the upstream cost of replenishment: imagine two identical pallets entering the same warehouse at the same time; they are put away in two adjacent location in the bulk stock area but one of them leaves the facility as a whole pallet after a while to fulfill a large order, whereas the other is converted overtime in master cases and "eaches" to replenish the pick face, undergoing more handling operations, which sums inevitably to higher costs. It should be clear at this point that a 3PL must bill somehow the storage in the pick face at higher price than the bulk area.

It is easier said than done: there are constraints and best-practice principles to be accounted for when developing a new cost model:

- *Scalability*: It should be able to handle growth, whether it regards an increase in transactions or complexity, and be flexible enough to respond to future changes without requiring a complete redesign. It is always recommended to think it thoroughly during the early stages specifically to avoid rollbacks from something it could have been foreseen.

- *Transferability and context-independence:* The model should not rely on specific attributes which would make its general assumptions debunked as soon as one tries to transfer it to a similar context but in a different structure: imagine a 3PL's warehousing outsourcing cost model engineered in one of their facilities which does not structurally hold when reapplied to a second facility of the same company. A context dependent model would also translate in lines of programming code to be completely rewritten if transferred, which is poor engineering.

- *Ease of Implementation*: The cost schema should be easily translated into code for automated billing; manual invoicing must be avoided or strongly discouraged. Simplicity in design is not always possible, there are aspects which are complex even in their basic form but having easiness in mind when designing can help reduce errors and make the system more maintainable and also more reliable.

- *Transparency*: The cost structure should be clear and easy to understand for customers. Hidden fees or overly complicated pricing can lead to dissatisfaction and a lack of trust: it also makes awkward the introductory meeting.

- *Fairness*: The pricing model should reflect the value provided and be fair to all customers but also to the 3PL, avoiding scenarios where certain users are overcharged or undercharged. Fairness is one of the features that fluctuates the most in some traditional warehousing outsourcing cost model. As it will be seen later, it goes both ways: sometimes the customer is undercharged, sometimes overcharged.

- *Flexibility*: The model should have room for variations so that the schema can be adapted to different customer needs and preferences without any major modification.

- *Regulatory Compliance*: The cost model must comply to any legal or regulatory requirement, such as tax laws or industry-specific regulations.

- *Cost-effectiveness*: The schema should balance profitability for the business and affordability for customers, ensuring it supports both business objectives and customer retention.

- *Monitoring and Adjustability*: A detailed punctual cost progression should be set up, so that both the 3PL and the customer have the possibility to make fair adjustments should conditions vary over the course of time.

In light of the above considerations, it looks like setting up a cost model which can be easily translated into programming code for automatic invoicing, that can discern pick face and bulk storage but is also able to be context independent, is impossible because areas separation and context independency are contrasting. One may argue that is not hard to map a warehouse and create a table where each storage location has an attribute assigning it to pick face or bulk, and then build the cost model around it; should it be applied to another facility, proceed to map those locations as well and it is done. However, this approach is odd because first, it requires additional maintenance: should new storage locations be created, the map table must be updated and is not granted, one may forget for a while and the company may lose the revenues related to the items stored in those forgotten location; of course it can be fixed though credit note, but going backwards for invoicing is always tedious and it is an occurrence which should be prevented by making better design choices. Then, there is the greater risk of developing code around a certain location identifiers structure, which can spiral out and create troubles. The worst two implications of the approach by far, are the amount of data to account for with this method and the high risk of breaching the fairness principle. Billing the storage of each unit based on locations means involving each time the current location and eventual re-locations within the warehouse, burdening the algorithm dedicated to calculations and potentially invoicing multiple unit price for the same SKU in the same month, which is strange and unprofessional. Suppose then two different customers having a similar product with comparable rotation indexes, but one of them has it stored in the pick face and the other in the bulk storage just because a warehouse operator decided so: it would not be fair at all. The locations path is an example of bad design. Having ruled out the idea of involving locations, the necessity to discern cost-wise between pick face and bulk storage still remains. As seen, it was previously assumed that “eaches” are stored in the forward-picking locations while pallets and master cases in the bulk storage area, so one may wonder whether layers are a suitable candidate to base a cost model on. A large portion of the master’s thesis is dedicated to packaging layers, so one may also expect at this point that they are, but the answer is no, although they are heavily involved indeed. The reason why the direct concept of layer is not suitable to base a cost model on, is once again the principle of fairness. One necklace and one car windshield are both base products but as one may imagine, they are not the same: they require different handling, they occupy different space, hence they cannot be billed at same price because they are two “eaches”. The most suitable driver - on which it was also developed the split volume cost model (hereafter referred to also as “SVCM” for brevity) for warehousing outsourcing - is the **volume of packaging layers.** The SVCM is a *tiered model* where the bounds of each tier are two volumes values, hence the naming. Each tier has a corresponding storage cost, and each packaging layer is assigned to the tier containing its respective volume value. The “pick face vs bulk storage area” price discrimination is proxied by assigning a higher cost per liter (see Table 2.3.1) to smaller tiers. The following schema is the *storage* side of SVCM:

Table 2.3.1: Split Volume Cost Model - Storage

SVCM – Storage				
Tier	Lower Bound [liter]	Upper Bound [liter]	Monthly Unit Cost [€]	Cost per liter [€/liter]
1	0,01	0,1	0,05 €	5,00 - 0,50
2	0,1	0,3	0,08 €	0,80 - 0,27
3	0,3	1	0,15 €	0,50 - 0,15
4	1	3	0,20 €	0,20 - 0,07
5	3	10	0,50 €	0,17 - 0,05
6	10	30	1,00 €	0,10 - 0,04
7	30	100	2,00 €	0,07 - 0,02
8	100	300	3,50 €	0,04 - 0,02
9	300	1000	7,00 €	0,03 - 0,01
10	1000	1300	9,50 €	0,01 - 0,01
11	1300	1800	12,00 €	0,01 - 0,01

As said, to invoice storage, the model is applied to the volume of each layer in inventory. Tiers 1 – 4 are usually the ones comprehending most of base products, Tiers 5 – 8 are associated mostly to master cases while Tiers 9 – 11 to pallets, but again, the layer per se is not a cost driver, its volume is. The column "monthly cost" means that, should 1 unit of SKU be in storage for whole 30 days, it would pay the full monthly cost according to the proper tier deriving from its volume. However, a warehouse is – hopefully – a dynamic system where the goods can be also stocked for a fraction of the month. Some cost models are designed around the "indivisible month" concept: it means that even if a unit is stored inside a facility for half a day, the full month is billed; those models usually counterbalance this feature by being cheaper in other cost entries, otherwise they would not be competitive -

making them irrelevant - however there is a high chance to violate the fairness principle, then is less appealing to the customer etc. When applying the SVCM is highly recommended to set up a table on the DB where each day the stock of every single layer is saved at set time: for computation purposes, the final stock of today is the initial stock of tomorrow if the warehouse shuts down daily, or it could be any fixed time otherwise. The monthly cost in Table 2.3.1 is divided by 30, obtaining a daily storage cost per unit, which is then applied to the daily inventory, obtaining the daily cost. At the end of the month, only the actual storage days are invoiced to the customer as the sum of all the daily contributions. The approach forces to potentially save a large dataset over the course of time, but thanks to the proper technology, it can be handled and is highly valued in the eyes of the customer. A small example can help understanding the storage part of SVCM; it refers to a single day for a certain ProductId:

SKU	Inventory [pz]	Volume [liter]	Monthly Unit Cost	Daily Unit Cost	Daily Inv Cost
ELE14498-MC-6	6	35,16	2,00€	0,07€	0,40€
ELE14498-P-288	1	1010,88	9,50€	0,32€	0,32€
ELE14498	10	2,76	0,20€	0,01€	0,07€

As shown, to obtain the daily cost for each layer, it is sufficient to multiply the daily unit cost to the daily inventory. To obtain the monthly cost, each daily contribution is summed ad then billed. The presented monthly unit costs are indicative: the master's thesis point is only to show how the model works because few years from now, the numbers could completely not make any sense. However, no matter the time when anyone is reading, there are some general principles which can be followed when deciding tiers prices. First, one should look for recent data about average incidence of warehousing cost respect to sales revenues, preferably in a context comparable to the one of the customer that has to receive a quotation; as seen in paragraph 1.3, the average incidence in 2024 is 13% of sales revenues, so warehousing-only could be 5%-7%. Then, consider the volumetric distribution of the customer products because also tiers boundaries can be adjusted consequentially. Should the customer have no dimensional data available, make a quotation based on a qualitative description of the good, then take measurements as suggested in paragraph 2.2 and try to obtain a clause in the contract where is stated that after 4 to 6 months, the tariffs are reviewed together and possibly adjusted. The clause should be included even when dimensions are available. The last advice on storage regards "eaches": the model could lead to unjustifiably high cost if a customer has B2C necessities, but its cartons have high multipliers. This usually means that its layer structure was probably not engineered for B2C and should probably be changed, but it is not compulsory. One way to work around this problem could be to collect historical data on "eaches" and on that basis come up with a monthly fixed cost according to the overall average "eaches" quantity but is not ideal and the risk of breaching fairness is high; one could also design a parallel tier pricing applied to a restricted set. No matter how, the model is flexible enough to provide many outs to different needs.

The handling side of the SVCM deals with the other two macro-operations in warehousing: outbound and inbound. As visible in table 2.3.2, it is also tier-based.

Table 2.3.2: Split Volume Cost Model – Handling

SVCM – Handling				
Tier	**Lower Bound [kg]**	**Upper Bound [kg]**	**Unit Cost [€]**	**Cost per kilo [€/kg]**
1	0,01	0,1	0,05 €	5,00 - 0,50
2	0,1	0,3	0,10 €	1,00 - 0,33
3	0,3	1	0,20 €	0,67 - 0,20
4	1	3	0,30 €	0,30 - 0,10
5	3	10	0,50 €	0,17 - 0,05
6	10	30	1,30 €	0,13 - 0,04
7	30	100	2,50 €	0,08 - 0,03
8	100	300	3,50 €	0,04 - 0,01
9	300	1000	5,00 €	0,02 - 0,01
10	1000	*	7,50 €	0,01 - *

The table is unique for simplicity, so its costs apply to the packaging layers, which determine both the inflow and outflow of goods in the warehouse. It can be noted also that the boundaries of tiers are the exact same as storage, however the cost driver is not volume anymore, but something else measured in kg. It is not taxed the actual weight of the layer but its volumetric weight, which is determined as follows for each packaging layer entering or exiting the facility:

- Density is calculated first as is the ratio between weight [kg] and volume [m3].
- Should the density be greater than or equal to 200 [kg/m3], the volumetric weight corresponds to the actual weight.
- Should it be less, the volumetric weight is obtained by multiplying the volume [m3] of the item by 200 [kg/m3].

It may feel abstract at first glance - because it is - however the use of volumetric weight is the cost driver that couriers use to bill shipments. They do it because volumetric weight more accurately reflects the space a package occupies in their vehicles rather than just its physical weight. This is important because, especially in transportation, space is a valuable resource. If billing were solely based on actual weight, large but lightweight packages would occupy significant space without contributing much to the total weight, leading unfair low revenue for the courier. The SVCM mimics this typical shipper dynamics by doing an analogy between vehicles of carriers and warehouse handling equipment.

Handling overall is easier to understand it also considers layers and the tabled cost refers to one unit, which could be a full pallet, a master case or an "each". See Appendix 4 for SVCM application

SKU	Handled units [pz]	Density [kg/m^3]	Volum. Weight [kg]	Unit Cost [€]	Total hand. Cost [€]
ELE14498-MC-6	6	81,35	7,03	0,50€	3,00€
ELE14498-P-288	1	112,93	202,18	3,50€	3,50€
ELE14498	10	112,16	0,55	0,05€	0,50€

3. APPENDIX

3.1 Appendix 1: Inbound Risk Management

Suppose a 3PL is facing an emergency but it is mandatory due to an imminent collection launch, to complete the inbound of 3 loads from 3 different manufacturers, called respectively Alfa, Beta and Gamma. The 3PL has enough workforce to perform in due time a complete unit count on two loads and the third is put away hoping that the declared units by the producer are correct. The counting task is performed manually by two warehouse operators having the same hourly cost of 24€, no further equipment required. By contract, at the end of each fiscal year the 3PL must perform an inventory supervised by the contractor personnel, where for each missing unit they need to reimburse 25% of the relative full industrial cost. Counting a unit takes 2 seconds flat ($5{,}55 * 10^{-4}$ hours). The 3PL has collected enough data about the accuracy of Alfa, Beta and Gamma:

Manuf. Company	Units to inbound	Manuf. accuracy	Unit ind. Cost
Alfa	1000	99,0%	35,00€
Beta	750	99,5%	45,00€
Gamma	800	99,2%	20,00€

There is more than one approach to evaluate which unchecked load, statistically, would lead to the smallest loss. One of them is to compute for each scenario both the **expected loss if count is not performed** and the **cost of punctual counting**; dividing the first number by the second provides an indicator similar to the ROI (Return on Investment) because it basically represents how many euros are saved in expected loss by investing 1€ in asking the warehouse operator to count each unit. The load presenting the lowest ROI is the one where risks are going to be taken.

Manuf. Company	**Expected Loss [pc]***	**Expected Loss [€] ****	**Counting time [h]*****	**Counting cost [€] ********
Alfa	10	87,50€	0,56	13,33€
Beta	3,75	42,19€	0,41	10,00€
Gamma	6,4	32,00€	0,44	10,67€

* Expected Loss [pc] = Units to inbound [pc] * (1 - Manufacturer accuracy)

** Expected Loss [€] = Expected Loss [pc] * Unit ind. Cost [€] * Penalty %

*** Counting time [h] = Unit counting time [h/pc] * Units to inbound [pc]

****Counting cost [€] = Counting time [h] * hourly wage [€/h]

Manuf. Company	**ROI**
Alfa	6,56€
Beta	4,22€
Gamma	3,00€

Based on data – assuming they were collected correctly in the first place – the 3PL should focus on Alfa and Beta and take risks with Gamma.

3.2 Appendix 2: Paired Samples t-test

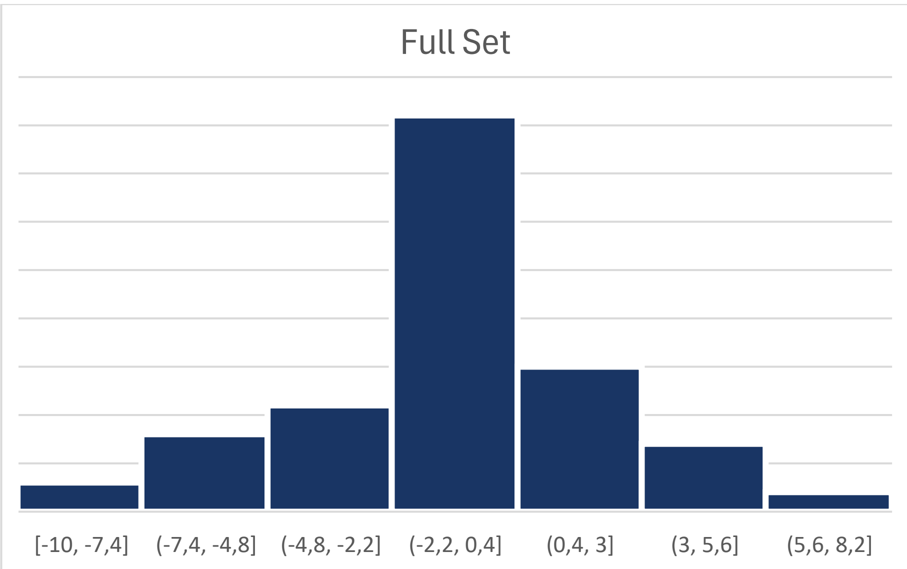
SKU	Height	HeightReal	Δ Height	SKU	Height	HeightReal	Δ Height
SKU_1	120,0	130,0	-10,0	SKU_38	31,7	32,9	-1,2
SKU_2	21,5	30,9	-9,4	SKU_39	22,2	23,3	-1,2
SKU_3	15,3	24,4	-9,1	SKU_40	22,2	23,3	-1,2
SKU_4	15,3	24,4	-9,1	SKU_41	16,0	17,1	-1,1
SKU_5	17,5	24,9	-7,4	SKU_42	14,5	15,6	-1,1
SKU_6	17,5	24,9	-7,4	SKU_43	18,0	19,0	-1,0
SKU_7	17,5	24,6	-7,1	SKU_44	18,7	19,7	-1,0
SKU_8	17,5	24,5	-7,0	SKU_45	24,0	24,9	-0,9
SKU_9	12,2	19,1	-6,9	SKU_46	21,7	22,5	-0,8
SKU_10	16,0	22,4	-6,4	SKU_47	40,0	40,8	-0,8
SKU_11	14,1	20,3	-6,2	SKU_48	19,3	20,0	-0,7
SKU_12	18,0	24,2	-6,2	SKU_49	18,5	19,2	-0,7
SKU_13	30,4	36,5	-6,1	SKU_50	27,0	27,7	-0,7
SKU_14	32,0	36,6	-4,6	SKU_51	24,0	24,6	-0,6
SKU_15	31,7	36,1	-4,4	SKU_52	31,7	32,3	-0,6
SKU_16	34,1	38,4	-4,3	SKU_53	21,5	22,0	-0,5
SKU_17	8,9	13,1	-4,2	SKU_54	13,5	14,0	-0,5
SKU_18	33,0	36,3	-3,3	SKU_55	21,7	22,2	-0,5
SKU_19	33,0	36,3	-3,3	SKU_56	23,7	24,1	-0,5
SKU_20	33,0	36,2	-3,2	SKU_57	24,0	24,4	-0,4
SKU_21	20,2	23,4	-3,2	SKU_58	28,0	28,3	-0,3
SKU_22	33,0	36,1	-3,1	SKU_59	21,5	21,8	-0,3
SKU_23	19,0	22,1	-3,1	SKU_60	22,0	22,3	-0,3
SKU_24	19,0	22,0	-3,0	SKU_61	22,0	22,3	-0,3
SKU_25	33,0	36,0	-3,0	SKU_62	22,0	22,3	-0,3
SKU_26	30,4	33,4	-3,0	SKU_63	14,2	14,5	-0,3
SKU_27	16,0	18,9	-2,9	SKU_64	22,2	22,4	-0,3
SKU_28	33,5	35,9	-2,4	SKU_65	12,2	12,4	-0,2
SKU_29	30,4	32,4	-2,0	SKU_66	17,0	17,2	-0,2
SKU_30	22,2	24,1	-2,0	SKU_67	20,8	21,0	-0,2
SKU_31	79,0	80,9	-1,9	SKU_68	23,7	23,8	-0,2
SKU_32	16,0	17,9	-1,9	SKU_69	22,7	22,8	-0,1
SKU_33	14,5	16,4	-1,9	SKU_70	22,7	22,8	-0,1
SKU_34	22,2	23,8	-1,7	SKU_71	22,0	22,1	-0,1
SKU_35	14,5	16,1	-1,6	SKU_72	22,0	22,1	-0,1
SKU_36	19,5	21,0	-1,5	SKU_73	22,7	22,8	-0,1
SKU_37	17,9	19,1	-1,2	SKU_74	18,4	18,5	-0,1

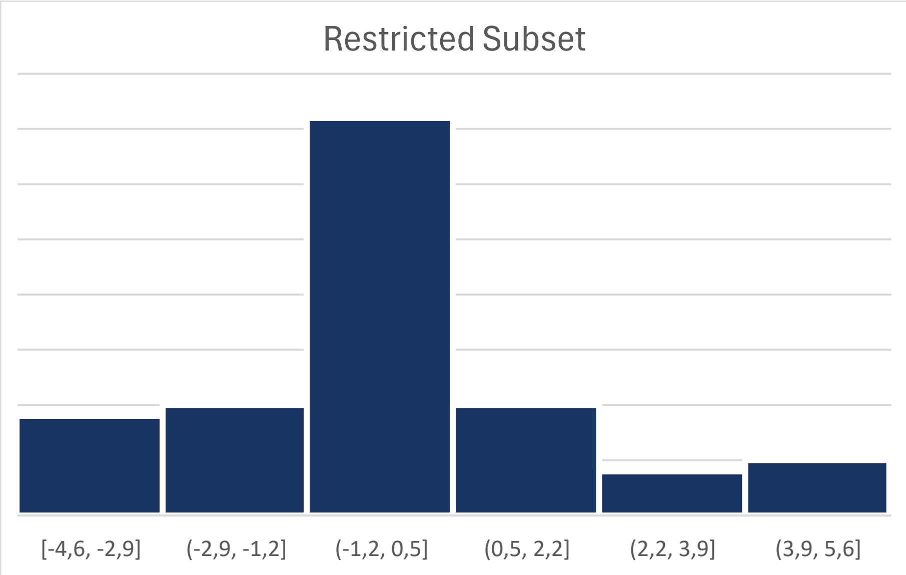
SKU	Height	HeightReal	Δ Height
SKU_75	17,0	17,1	-0,1
SKU_76	17,0	17,1	-0,1
SKU_77	10,9	11,0	-0,1
SKU_78	27,3	27,4	-0,1
SKU_79	26,8	26,9	-0,1
SKU_80	22,0	22,0	0,0
SKU_81	22,0	22,0	0,0
SKU_82	20,8	20,8	0,0
SKU_83	22,0	22,0	0,0
SKU_84	57,6	57,6	0,0
SKU_85	57,9	57,9	0,0
SKU_86	58,2	58,2	0,0
SKU_87	58,4	58,4	0,0
SKU_88	59,0	59,0	0,0
SKU_89	56,4	56,4	0,0
SKU_90	57,2	57,2	0,0
SKU_91	58,9	58,9	0,0
SKU_92	15,3	15,3	0,0
SKU_93	15,3	15,3	0,0
SKU_94	34,8	34,8	0,0
SKU_95	34,7	34,7	0,0
SKU_96	26,3	26,3	0,0
SKU_97	35,1	35,1	0,0
SKU_98	37,1	37,1	0,0
SKU_99	34,1	34,1	0,0
SKU_100	47,6	47,6	0,0
SKU_101	150,0	150,0	0,0
SKU_102	49,3	49,3	0,0
SKU_103	79,8	79,7	0,1
SKU_104	22,7	22,6	0,1
SKU_105	19,0	18,9	0,1
SKU_106	22,0	21,9	0,1
SKU_107	48,7	48,6	0,1
SKU_108	23,5	23,4	0,1
SKU_109	23,7	23,5	0,1
SKU_110	17,5	17,3	0,2
SKU_111	14,1	13,9	0,2

SKU	Height	HeightReal	Δ Height
SKU_112	22,7	22,5	0,2
SKU_113	22,7	22,5	0,2
SKU_114	17,0	16,8	0,2
SKU_115	22,0	21,8	0,2
SKU_116	22,7	22,5	0,2
SKU_117	22,7	22,5	0,2
SKU_118	23,5	23,3	0,2
SKU_119	23,5	23,3	0,2
SKU_120	48,7	48,5	0,2
SKU_121	23,7	23,4	0,3
SKU_122	30,2	29,9	0,3
SKU_123	79,8	79,5	0,3
SKU_124	26,8	26,5	0,3
SKU_125	23,5	23,2	0,3
SKU_126	23,5	23,2	0,3
SKU_127	23,5	23,2	0,3
SKU_128	23,5	23,2	0,3
SKU_129	24,0	23,6	0,4
SKU_130	22,7	22,3	0,4
SKU_131	33,0	32,6	0,4
SKU_132	30,0	29,6	0,4
SKU_133	60,8	60,4	0,4
SKU_134	27,3	26,9	0,4
SKU_135	38,7	38,3	0,4
SKU_136	30,2	29,7	0,4
SKU_137	23,7	23,2	0,4
SKU_138	23,7	23,2	0,4
SKU_139	20,0	19,5	0,5
SKU_140	22,0	21,5	0,5
SKU_141	32,5	32,0	0,5
SKU_142	23,7	23,1	0,5
SKU_143	21,5	20,9	0,6
SKU_144	20,5	19,9	0,6
SKU_145	16,8	16,2	0,6
SKU_146	60,5	59,9	0,6
SKU_147	34,8	34,1	0,7
SKU_148	22,2	21,5	0,7

SKU	Height	HeightReal	Δ Height	SKU	Height	HeightReal	Δ Height
SKU_149	20,5	19,8	0,7	SKU_161	12,2	9,5	2,7
SKU_150	22,7	22,0	0,7	SKU_162	12,2	9,2	3,0
SKU_151	24,0	23,3	0,7	SKU_163	12,2	9,0	3,2
SKU_152	15,7	14,9	0,8	SKU_164	34,1	30,5	3,6
SKU_153	24,0	23,2	0,8	SKU_165	30,4	26,3	4,1
SKU_154	28,0	27,1	0,9	SKU_166	30,4	26,2	4,2
SKU_155	30,4	29,5	0,9	SKU_167	25,0	20,5	4,5
SKU_156	34,8	33,9	0,9	SKU_168	39,4	34,9	4,5
SKU_157	16,3	15,3	1,0	SKU_169	27,0	22,3	4,7
SKU_158	30,4	29,4	1,0	SKU_170	27,0	22,2	4,8
SKU_159	33,0	31,5	1,5	SKU_171	38,6	31,8	6,8
SKU_160	21,0	19,5	1,5	SKU_172	30,4	22,9	7,5

The data table contains a real-life example of the height of 172 product codes. Columns Height is the data declared by the producer while HeightReal is the data collected through a volumetric scale. The paired sample t-test is run twice: the first time using the whole set, the second the restricted sub-set [SKU_14;SKU_170]. The first step is to visually check whether the assumption of normal distribution of the Δ Height holds by plotting the relative histograms.





Although the visual check does not guarantee the normality of the data and more rigorous tests should be performed, it is assumed that the assumption holds, and the analysis is carried on.

	Full Set	**Subset**
$\bar{h}_d = \frac{1}{n}\sum_{i=1}^{n}(h_{p_i} - h_{l_i})$	-0,61	-0,13
$\hat{\sigma}_d = \sqrt{\frac{\sum_{i=1}^{n}(h_{p_i} - h_{l_i})^2 - n \cdot \bar{h}_d^{\,2}}{n-1}}$	2,65	1,59
$t = \frac{\bar{h}_d}{\frac{\hat{\sigma}_d}{\sqrt{n}}}$	-3,00	-1,02
$CI_{95\%} = \bar{h}_d \pm T_{\alpha/2} \cdot \frac{\hat{\sigma}_d}{\sqrt{n}}$	[-0,21;-1,00]	[0,12;-0,38]

The result led by the full set is to reject $H_0 : \bar{h}_d = 0$ but by restricting to subset it shifts toward failing to reject $H_0 : \bar{h}_d = 0$.

It is important to note that the subset is made up by differences in measurements not greater than $\pm$ 5 cm while the full set goes up to $\pm$ 10 cm. This could trick into thinking that a less dispersed dataset is crucial; although it plays a role, one should also consider that by restricting the dataset, there is also a change in the degree of freedom, which impacts T, so truth is that each case has to be treated cautiously. As a matter of fact, by restricting the dataset furtherly, leaving only Δ height $\pm$ 0,9 cm, the test shows the same results as the full set.

3.3 Appendix 3: Layer Conversion Algorithm

Assume the existence of the following layer structure and stock status, paired with the need to fulfill an order of 263 units.

ProductId	**Sku**	**SkuChild**	$\boldsymbol{m}$	$\boldsymbol{I}$
ELE14498	ELE14498	ELE14498	1	0
ELE14498	ELE14498-MC-12	ELE14498	12	0
ELE14498	ELE14498-MC-6	ELE14498	6	0
ELE14498	ELE14498-P-288	ELE14498-MC-12	288	2
ELE14498	ELE14498-P-100	ELE14498	100	0

The order is fulfillable as a whole because it is verified that:

$$QO \le \sum_J I_J \cdot m_j \quad true\ because \quad 263 \le 576$$

The first iteration can start, so set $i = 1$ and compute $\frac{QO_1}{m_j}\ \forall j$

ProductId	**Sku**	$\boldsymbol{\frac{QO_1}{m_j}}$	$\boldsymbol{m}$	$\boldsymbol{I_1}$
ELE14498	ELE14498	263	1	0
ELE14498	ELE14498-MC-12	21,92	12	0
ELE14498	ELE14498-MC-6	43,83	6	0
ELE14498	ELE14498-P-288	0,91	288	2
ELE14498	ELE14498-P-100	2,63	100	0

The current inventory meets the conversion requirement, that is:

$$\forall j \ \ with \ \ I_{1,j} > 0\,, \quad \frac{QO_1}{m_j} < 1$$

The only SKU showing a positive stock is ELE14498-P-288, meaning that is also the only one to be chosen from for conversion.

In general, the choice is delegated to the following condition:

$$max\left(\frac{QO_1}{m_j}\middle|\ I_{1,j} > 0\right)$$

ELE14498-P-288, which is the father in this case, is updated:

$$I'_{1,father} = I_{1,father} - 1 = 2 - 1 = 1$$

$$I'_{1,father} = I_{1,father} = 1$$

ELE14498-MC-12, which is the child in this case, is also updated:

$$I_{1,child} = \frac{m_{father}}{m_{child}} = \frac{288}{12} = 24$$

After conversion, inventory status is the following:

ProductId	Sku	$\frac{QO_1}{m_j}$	m	I_1
ELE14498	ELE14498	263	1	0
ELE14498	ELE14498-MC-12	21,92	12	24
ELE14498	ELE14498-MC-6	43,83	6	0
ELE14498	ELE14498-P-288	0,91	288	1
ELE14498	ELE14498-P-100	2,63	100	0

Even in this case, there is only one row that verifies both the conditions of the best fit choice formula, ELE14498-MC-12:

$$min\left(\frac{QO_1}{m_j}\middle|\ I_{1,j} > 0 \land \frac{QO_1}{m_j} \geq 1\right)$$

And given that its ratio $\frac{QO_1}{m_j} < I_{1,j}$ because 21,92 < 24 then:

$$SOL_{1,j} = \left\lfloor\frac{QO_1}{m_j}\right\rfloor \cdot SKU_j = 21\ \cdot\ ELE14498 - MC - 12$$

Any other layer provides no contribution in this iteration, so their respective SOL variable is set to be zero ($SOL_{1,j} = 0$). The solution deriving by the first iteration is:

$$SOL_1 = \sum_J SOL_{1,j} = 21 \cdot (ELE14498 - MC - 12)$$

The inventory reserved for fulfilling the first portion of the order is obviously no longer available and that needs to be accounted for, entailing one last inventory update for the first iteration:

$$I'_{1,j} = I_{1,j} - \left(\frac{SOL_{1,j}}{SKU_j}\right) \forall j \ then \ set \ I'_{1,j} = I_{1,j}$$

ProductId	**Sku**	$\frac{QO_1}{m_j}$	m	I_1
ELE14498	ELE14498	263	1	0
ELE14498	ELE14498-MC-12	21,92	12	3
ELE14498	ELE14498-MC-6	43,83	6	0
ELE14498	ELE14498-P-288	0,91	288	1
ELE14498	ELE14498-P-100	2,63	100	0

The allocated and residual quantities after the first iteration are:

$$QA_1 = \sum_J \frac{SOL_{1,j} \cdot m_j}{SKU_j} = \frac{21 \cdot (ELE14498 - MC - 12) \cdot 12}{ELE14498 - MC - 12} = 252$$

$$QR_i = QO_i - QA_i = 263 - 252 = 11 > 0 \Rightarrow i++$$

The iteration coefficient is incremented by 1 so that a new iteration can start, the ordered quantity and $\frac{QO_2}{m_j}$ $\forall j$ are updated:

$i = 2$

$QO_2 = QR_1 = 11$

ProductId	**Sku**	$\boldsymbol{\frac{QO_2}{m_j}}$	$\boldsymbol{m}$	$\boldsymbol{I_2}$
ELE14498	ELE14498	11	1	0
ELE14498	ELE14498-MC-12	0,92	12	3
ELE14498	ELE14498-MC-6	1,83	6	0
ELE14498	ELE14498-P-288	0,04	288	1
ELE14498	ELE14498-P-100	0,11	100	0

Conversion is required once again. This time the involved layer is ELE14498-MC-12 because 0,92 > 0,04. The stock is brought to:

ProductId	**Sku**	$\boldsymbol{\frac{QO_2}{m_j}}$	$\boldsymbol{m}$	$\boldsymbol{I_2}$
ELE14498	ELE14498	11	1	12
ELE14498	ELE14498-MC-12	0,92	12	2
ELE14498	ELE14498-MC-6	1,83	6	0
ELE14498	ELE14498-P-288	0,04	288	1
ELE14498	ELE14498-P-100	0,11	100	0

The best fit involves ELE14498 and its related solution is:

$$SOL_{2,j} = \left\lfloor \frac{QO_2}{m_j} \right\rfloor \cdot SKU_j = 11 \cdot (ELE14498)$$

Any other layer provides no contribution in this iteration, so their respective SOL variable is set to be zero ($SOL_{2,j} = 0$).

So, the solution deriving by the second iteration only is:

$$SOL_2 = \sum_J SOL_{2,j} = 11 \cdot (ELE14498)$$

The further stock update brings inventory level to the following:

ProductId	**Sku**	$\frac{QO_2}{m_j}$	m	I_2
ELE14498	ELE14498	11	1	1
ELE14498	ELE14498-MC-12	0,92	12	2
ELE14498	ELE14498-MC-6	1,83	6	0
ELE14498	ELE14498-P-288	0,04	288	1
ELE14498	ELE14498-P-100	0,11	100	0

The allocated and residual quantity after the second iteration are:

$$QA_2 = \sum_J \frac{SOL_{2,j} \cdot m_j}{SKU_j} = \frac{11 \cdot (ELE14498) \cdot 1}{ELE14498} = 11$$

$$QR_i = QO_i - QA_i = 11 - 11 = 0 \Rightarrow end$$

The order is fulfilled entirely and the algorithm can exit the cycle. The overall final solution is:

$$SOL = SOL_2 = SOL_1 + \sum_J SOL_{2,j}$$

$$SOL = 21 \cdot (ELE14498 - MC - 12) + 11 \cdot (ELE14498)$$

The best combination for order fulfillment under the algorithm conditions consist in 21 master cases of 12 units and 11 “eaches”

3.4 Appendix 4: Real-life SVCM Application

The trends in Appendix Figure 4.1 are obtained from real-life warehouse data collected over the course of one year. Providing detailed actual figures is forbidden due to confidentiality and it also does not affect the validity of discussion, so each set was necessarily normalized to 1. Just for the sake of context, daily stock peaked somewhere above 500.000 units, whereas yearly revenues from sales have significantly exceeded €5M.

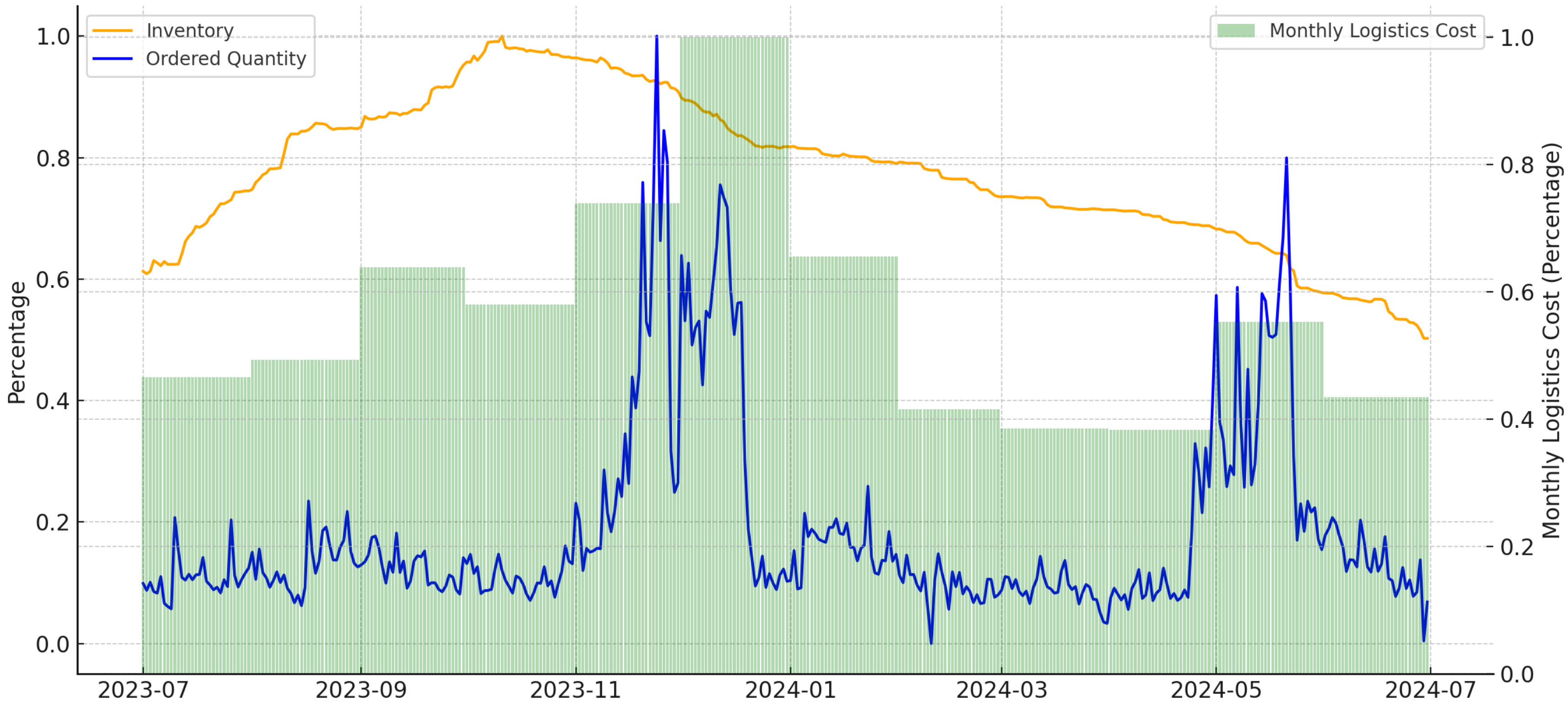
The data refers to a 3PL performing logistics outsourcing activities on behalf of another company, using the SVCM (Split Volume Cost Model) as the foundation for invoicing. It would be unlikely that the SVCM as presented in paragraph 2.3 can cover all the aspects of an outsourcing involving M€ in revenues: as a matter of fact, the actual contract and also the cost scheme are way more elaborate, but regarding *storage,* it was applied the SVCM exactly as presented, whereas for *handling-in* and *out* – or *inbound* and *outbound* – it was used a slightly different version of SVCM which accounts for some specificities, but they are neglectable at the moment. Using the SVCM means working with packaging layers and they were fully deployed. The orange trend refers to the overall total units stored each day including every layer, so for example, the contribution of a master case of 12 units is 12.

The yearly average packaging split was: 39% base products (or "eaches"), 40% master cases, 22% pallets. It means that on average, only 22% of the total inventory was stored in a layered pallet. The split is by far from ideal, however there are many reasons behind it: the former 3PL had a reckless stock management for many years given the absence of a WMS, let alone the concept of packaging layers. During phase-in from former warehouse, pallets of mixed cartons in bad shape were common, hence the high percentage of “eaches”. Moreover, the customer had a non-neglectable portion of its products manufactured from an environment of local companies which were not used to carton standardization and/or sufficient ordered quantity to supply full pallets.

Orders were acquired online, so a B2C context, where the average order was 1,7 units. From the timeline, by looking at the ordered quantity progression in blue, the main peak occurred in November-December, suggesting that the stock is mainly consumers good to be gifted on Christmas and/or bought during the Black Friday rush. The second peak in May was instead induced by a prolonged and significant discount over 15 SKUs available in large quantities. The high availability was due to the unexpected underperformance of a sales campaign for which the products had been designed. Prices were reduced by 90% for output maximization, significantly stimulating demand even in an off-season month like May. Although production costs are not available, it is safe to assume that those items were sold at loss, which is not ideal but sometimes it is a good recovery action because it allows to get back some liquidity to reinvest in more promising projects and saves further costs originated by the stock being almost still, on top of being a gift for loyal customers.

On the other hand, restocking time from producers was well managed: the warehouse was progressively filled until October, right before orders peak for cost minimization, and then deflated by orders overtime. The green area represents the full monthly outsourcing invoice, where the average SVCM contribution to the total is 55%, whereas average shipping accounts for an additional 30% and the rest are specificities, customizations, work orders and miscellany. It can be noted how the cost progression mimics the warehouse activities, as it should.

One last remark is left about benchmarking: as shown in paragraph 1.2, the 2024 study conducted on a sample of companies states that the average logistics expenditure was 13% of revenues from sales. In our case is tricky to compute the exact ratio because although the warehouse is highly used for B2C order fulfillment - of which sales data are available - the contract was set up for a full outsourcing, so the stock is also shared for retailers replenishment and a portion of operations were performed for B2B needs. If one disregards the B2B aspect and overcharges the whole invoices on B2C sales revenues, the incidence is 18%. Given the available data, a solid approximation to break up B2C costs so that they are comparable with sales revenues, considers: Handling-out B2C, Handling-in (considered in full, it does not affect much the result), pick face storage and a customization for online sales. That cost, which is pure warehousing, compared to online sales revenues is 6,5%; adding B2C shipping cost provides a good approximation of the full logistics cost for online order fulfillment and the percentage goes up to 12,45%, which is an impressive result obtained by the SVCM, which proved to be perfectly calibrated to be in line with industry standards.



Appendix Figure 4.1 : Inventory, Ordered quantity and Monthly Logistics Cost

CONCLUSION

An attentive reader takes away from this master's thesis a clear portrait of how lengthy and challenging is undertaking a logistics externalization process, what the features of a modern logistics are and how is shaped a modern logistics outsourcing tariff scheme, so that whoever should be involved is a similar context, at least knows what to expect, the big mistakes to avoid and some tools to make a deliberate choice. To really show the depth of the matter, the set up leading to outsourcing was broken down in macro-tasks in the initial chapter, highlighting the involvement of professionals from different fields, spanning from technical personnel in the logistics area and extending to legals, information technology, finance, strategic department etc. All the different steps were commented, examined and, when possible, enriched with niche technical suggestions for more advanced readers in the logistics field. Another takeaway from first chapter is the idea that in the modern supply chain, processes are strictly intertwined with information technology - a concept that poses the foundation for the second chapter too - and also clarifies that IT is a current competitive differentiator for third party logistics companies that strives to expand their business, in an industry where their main services could be nearly considered as a commodity. In the second chapter the focus was restricted to one key feature of a modern logistics, that is warehouse management through the deployment of packaging layers, which in turn are the backbone of a modern tariff scheme for logistics outsourcing, the SVCM. The packaging layers were extensively tackled from all the angles: it was explained what they are, how they should be implemented in a database, how their deployment can enhance warehouse performances but also the strain they put on a company that decided to implement their use, in terms of preliminary operations to put them in place, the effort to maintain their effectiveness and the investments required. The master's thesis author has been working for five years in a 3PL where a packaging layer structure was implemented on the WMS and was there when the structure was considering switching to this approach, so he assisted and contributed to the whole process. The development was performed by the internal IT department and the software is fully owned by the company, which means more responsibilities but also more freedom. Considering all the time and effort spent of packaging layers, the biggest pros of the approach on operations are the increased put away and picking efficiency and a tidier warehouse overall because it denies by design to the operator, to open (physically, with the cutter) a layer when there is enough inventory to fulfill the order in a lower layer. A positive side effect is that it also dictates somehow the most optimal area for everything entering the facility, having the "eaches" in the forward-pick and pallets and cases in the bulk area. The biggest con of the model by far is that not every manufacturing company has switched to layers. For those instances, it means that during inbound there are extra steps to be performed: first, each carton is inspected to assess whether some cases are eligible master cartons; if so, they need to be added to the database, then labelled and measured and weighted, consuming time and labor. Should any student or researcher be interested in deepening the matter and continue the study, can get in contact anytime: while the presented thesis put significant effort in explaining the foundations of everything, it would be interesting if anyone would want to measure the performances of a warehouse managed through layers versus the same warehouse without layers and provide more critics, considerations and improvements. Regarding the SVMC, it was also developed internally. It may look not much, in the end it is just a tiered model, but in reality is the result of hours of simulations by a mathematician that tackled the problem of finding a robust tariff scheme for logistics outsourcing that relies on the volumetric characteristics of layers. The model was overly complicated at the beginning; there were many tries relying on different mathematical functions and although there were better solutions than the tiered model, they would have been way too complicated to explain to potential customers. Overall, the model is fair because it bills the occupied volume for storage and the dimensional weight for handling, and only the actual days in stock are paid by the customer. There are probably no better cost drivers. The only con is the amount of data the model needs to be fed: the stock of each layer needs to be saved daily, which can build up to a massive dataset in no time. Some other aspects which would be interesting to deepen could regard possible variations: for example, applying the SVCM as-is to a clothing stockist was not considered because its catalogue changes multiple times a year with no volumetric data available, so the 3PL should have kept measuring products entering the facility just once. Instead of using volumes, the tiers were based on product categories by one developer in half a day, showing also the versatility of the SVCM.

Thanks for reading. For inquiries and more details feel free to send an email to francesco.ianni@wejo.it or antonio@wejo.it

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COMPANY HISTORY

This thesis was developed within WEJO S.r.l., a company for which I hold great affection. I would like to express my deepest and most sincere gratitude to the organization for the invaluable support and opportunity it has provided throughout this journey.

Ad maiora!

Wejo is an LLC based in San Mauro Torinese (Turin) founded in the 2000s by Mr. Antonio Ruffo and Mr. Fabrizio Tibollo, two engineering students from Politecnico di Torino. What began as a side project selling items on eBay for fun, gradually evolved into a business. Initially, they focused on selling modern antiques, honing their photography skills to ensure high-quality listings. As they became more familiar with the marketplace, one founder's passion for electronics led them to shift their focus to camera batteries. At the time, they were able to import batteries from Germany and resell them in Italy at double the cost.

The business showed promise and soon storage space became a growing concern. During this period, they built a strong relationship with a sales representative from a carrier, who introduced them to IART, a traditional logistics group owned by Mrs. Rossana Rossi. Wejo was eventually acquired by IART, which allowed them to scale their battery business and launch two new brands manufactured in China. As IART's e-commerce division, Wejo invested significant effort into adapting one of their warehouses for B2C order fulfillment.

It quickly became clear that managing a larger online catalog required specialized software. Recognizing the need for technical solutions, Wejo began developing software tailored to the complexities of e-fulfillment. Initially, their focus was on tools for bulk uploads, but over time, they created a comprehensive framework to manage logistics, sales, order processing and customer service data.

Today, Wejo continues to enhance its framework, becoming an official eBay partner and integrating with numerous marketplaces via APIs. Their goal is to create a software solution that covers every aspect of online sales and traditional logistics. Thanks to this software, Wejo now partners with several companies that rely on them for outsourced e-commerce services and logistics.

RINGRAZIAMENTI

Non ho molto da scrivere. Non ho una lista di persone da ringraziare singolarmente per strappare un sorriso. Chi è nel mio cuore lo sa. Chi è al mio fianco lo sa. Mi sento fortunato.
Sono vecchio per la laurea, ho 30 anni. Mi chiedo se sia stata vigliaccheria o timore, ma voglio vedere il buono in questo. Qualche anno fa non avrei apprezzato il momento, mi sarebbe scivolato addosso. L'età aggiunge peso ma anche consapevolezza. Ho interiorizzato la bellezza dell'amore e compreso a fondo che non è gratuito. Amare la madre, un amico, un amante, costa e presenta il conto. La scelta è fuggire o pagarlo e io ho deciso di pagarlo, sempre. Ne approfitto per dire che sono fiero di me, al punto che mentre scrivo si gonfiano gli occhi e scoppia il petto.

Domani andrò in ufficio, come sempre. Chi scappa dalla routine vendendo il mito della vita in vacanza, ha delle questioni irrisolte. A me piace la routine e la stabilità e so arricchirla di angoli che la riempiono e le danno un significato. Sono in pace. Non mi sento arrivato, ho solo capito che non lo sarò mai. Resto l'unico a cui veramente rendere conto. Resto il mio critico più apro ma anche il migliore alleato. Non necessariamente il mio migliore amico.

Nell'ultimo anno sono stato a lungo turbato dallo scorrere del tempo e proprio in uno dei suoi ragionamenti collaterali ho trovato la forza di iniziare questa tesi dopo il fermo accademico.
Quello del tempo è stato un rovello da cui ne sono uscito uomo.
E ingegnere. Il PoliTO è stato bello, lo rifarei. Tutta la vita rifarei.

A chi si sente perso e senza uno scopo, consiglio di avviare un qualsiasi progetto che possa suscitare interesse. Basta borbottare. A chi è perso nelle ostilità, consiglio di deporre le armi e investire quelle energie in un progetto. Non c'è un obiettivo finale e anche se ci fosse, non sarebbe certamente perseguibile con rabbia e rancore. C'è l'oggi. Ci sono le persone a cui vuoi bene e a cui devi dimostrarlo, facendolo nel modo che sai tu. Ci sono le persone che non ci sono più, a cui non puoi più dimostrare nulla, ma che continueranno a vivere dentro di te e che verranno a darti un bacio accorciandoti il fiato quando le penserai troppo intensamente. Ci sei tu con i tuoi sogni, se mai ne hai avuti e se te ne sono rimasti. Va bene non avere un sogno, non va bene non avere un obiettivo, anche piccolo, pe' mo. Non so cosa mi attende ora ma il coraggio non manca. "Mai disperare" dice mio padre. E adesso ti svelo un segreto: quando vedo una stella cadente, la uso sempre per lo stesso desiderio.

Grazie di tutto.
Thank you.
Vi voglio bene.

Vostro e Mio,
Francesco Ianni

Torino, 08/09/2024