Title
Packaging and the Supply Chain: A Look at Transportation

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> *And Man created the plastic bag and the tin and aluminum can and the cellophane wrapper and the paper plate, and this was good because Man could then take his automobile and buy all his food in one place and He could save that which was good to eat in the refrigerator and throw away that which had no further use. And soon the earth was covered with plastic bags and aluminum cans and paper plates and disposable bottles and there was nowhere to sit down or walk, and Man shook his head and cried: 'Look at this Godawful mess.*
>
> Art Buchwald, 1970

Abstract

In the interest of sustainability, many manufacturers have taken steps to analyze the key components of their products and processes across the span of their supply chain. Product packaging—which is an especially pervasive component, spanning across the supply chain of nearly all products—has garnered particular interest in discussions of sustainability. Packaging is not only associated with its own sourcing impacts but also influences the impacts of the product, especially in terms of the shipping impacts of the product. Several organizations have developed tools and guidelines to help manufacturers make greener packaging choices in terms of packaging. Pallet utilization is one practice for improving packaging that has been put forth in these publications and is one of the few practices that consider the impacts of packaging, not only in the context of its own supply chain but also as a component of a product. This study discusses the practice of pallet utilization and identifies the cases in which it would serve as potentially beneficial. These considerations are currently lacking in the recommendations for the adoption of pallet utilization. In addition, an overview of the current methodologies used

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to evaluate the environmental impacts of transportation and to optimize the distribution of the product is provided.

10.1 Introduction

In recent years producers and retailers have shown an increased focus on sustainability. Many manufacturers, both of their own accord, and in catering to the demands of the public, have sought ways to green their products and operations. To achieve these ends, many have taken steps to analyze the key components of their products across the multiple parameters of sustainability. Product packaging has become one such component.

Packaging distinctively represents the pressures that producers face in making more sustainable sourcing choices. Of all possible product components, it is one of the most pervasive, as it spans across the supply chain of nearly all products. Packaging has its own impacts from sourcing, processing, transportation, use, and disposal, and also has the potential to influence the impacts of the product. Also, packaging suffers from a profound image problem. It serves a very significant function by protecting products during transit and storage, thereby reducing the amount of waste that would occur in its absence. This practical function goes by largely unnoticed by the consuming public. Since packaging is often the only part that remains to be disposed of after the product has been consumed, end line consumers may not recognize the purpose it served in the use phase. For them packaging is the embodiment of waste. However, the impacts of the packaging industry are not insignificant. For instance, in Europe, the packaging sector has been attributed with 3.5% of CO_2 emissions [1]. Yet, it is because the utility of packaging occurs primarily before the use phase that it is an ideal candidate for an investigation into the opportunities for sourcing and manufacturing improvements.

Packaging impacts are best analyzed through an investigation into their supply chain. These impacts consist of the direct inputs and outputs of the container, as well as their contributions to the impacts of the product. The two product life cycle phases in which packaging contributes to product impacts are the transportation and use phases. However, it is difficult to generalize the functional needs that packaging must provide over diverse products. For instance, packaging serves a very different purpose over the transport and consumption of perishable food items, as compared to the functional needs it must provide for small electronic goods. Therefore, the transportation phase of the life cycle has been identified as an ideal focus for this study.

Several organizations have developed tools and guidelines to help manufacturers make greener packaging choices. These efforts have laid a necessary foundation for packaging improvements and sustainability practices in general. Out of these works, specific trends in packaging practices have emerged. These various sustainable packaging practices have been understood and achieved with varying degrees of success.

Sustainable packaging practices can be organized into three categories, those relating to their: sourcing, production, and end-of-life. Sourcing practices refer to the type of material that goes into a package. In the context of sustainability, these types of materials include those that have been deemed as "eco-friendly," come from recycled stocks, or have been sourced from regions where there are not particular concerns about impacts to the ecosystem. Production practices are associated with how materials are processed and handled in the creation and distribution of the package. These tactics can typically only be achieved when integrated into the design of the package. Practices that fall under this category are: packaging designed to have a minimal carbon footprint; packaging that helps achieve efficiencies in distribution and logistics (e.g., pallet efficiency); multi-functional packaging that may be incorporated in with other product components; separate auxiliary refill packaging; packaging whose weight has been minimized; and packaging designed to minimize the use of specific materials—such as water or energy—in processing. End-of-life practices deal with what is done with the packaging materials after the product has been consumed. Practices that encompass the end of a package's life cycle include making it so that it can be: biodegraded, composted, recycled, or reused, specifically for another purpose. Pallet utilization and lightweighting are the only two sustainability packaging practices that address the impacts of packaging in relation to the product. The benefits of packaging lightweighting can be achieved broadly, across most products, because the practice leads to reductions simultaneously in the extraction, transport, processing, and disposal of materials, all in all resulting to reductions many times over throughout the supply chain. Alternatively, the applicability of pallet utilization is nuanced; requiring consideration of a container's weight and volume, the logistics of distribution, and the methodology used in environmental impact assessments. This study will be an exploration of these aspects and a discussion of cases in which pallet utilization can be most beneficial.

10.2 Background

10.2.1 The Packaging Supply Chain

The packaging supply chain illustrates the general complexities associated with impact assessments, as essentially two chains must be considered: (1) packaging as a contributing component to the product and (2) packaging as a standalone item that has its own sourcing and logistical aspects. The sustainability of packaging is not solely measured for its own impacts, but also for the potential it has to improve the overall sustainability of the associated product.

10.2.1.1 The Supply Chain of a Container

A typical supply chain for packaging, which includes material extraction and production, and packaging production, distribution, and end-of-life alternatives, is

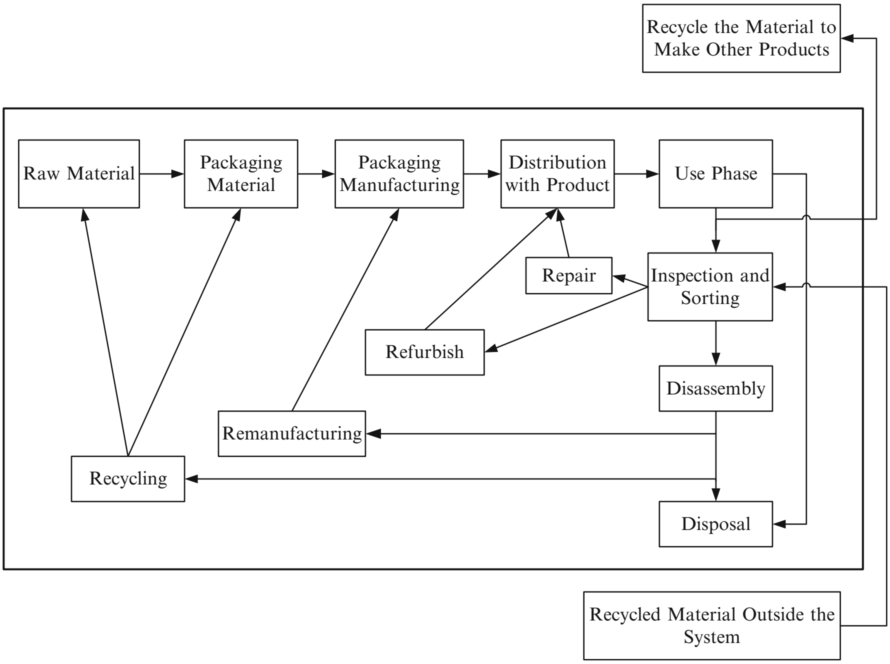

Fig. 10.1 The life cycle of packaging

depicted in Fig. 10.1. The use phase of packaging is often times considerably shorter than that of the product; where packaging's primary function is to protect the product until it is delivered to the consumer. In contrast to industrial packaging, consumer packaging is rarely used after the product has been fully consumed, although this trend is somewhat the result of consumer attitudes and behaviors. While some industrial packaging, such as stretch films, is used only once during its life cycle, most industrial packaging, such as pallets and plastic trays, are typically designed to be used numerous times in the system. These differences between industrial and consumer packaging translates into differences in the drivers and factors that affect their sustainability.

The sustainability of consumer package is mainly driven by the government regulation and societal demand. In addition, emphasis is very rarely placed on the impacts from packaging use because manufacturers have very little control on consumer behavior during this phase. The lack of recycling infrastructure is a common issue for consumer packaging. Consumers generally consider the recyclability of packaging as the main measure of sustainability [2], and as a result when firms attempt to green their packaging they tend to adopt materials that are recyclable. However, the environmental impacts of packaging cannot be evaluated based solely on its recyclability or any other single metric. Take for instance, the illustrative case of Stonyfield and their decision to switch their yogurt cup packaging material in 2001 to one that was recycled at a low rate because of the other benefits it offered. Stonyfield made this choice after conducting a life-cycle assessment (LCA), changing from high density polyethylene, which was recycled at a rate of 18.5% at the time, to polypropylene, a material with negligible recycling rates, because it was the lightest weight option for their product [3]. The switch allowed for the use of less material, as polypropylene provided containers with thinner walls that still maintained the same structural integrity, and resulted in reduced material extraction and processing, and lower transportation and waste impacts. Stonyfield compensated for the fact that most communities do not accept polypropylene for recycling, by partnering with Preserve, a producer that makes household products from 100% recycled materials, to provide consumers with locations to recycle their used yogurt cups.

In contrast to consumer packaging, industrial packaging is typically used in a closed system and kept track of through company accounting. As a result, manufacturers have a financial incentive to improve the efficiency of their industrial packaging system, which often times correlates to improved environmental impacts. The duration of the use phase for the industrial packaging life cycle can also typically be made longer than that of consumer packaging, since companies have more control of the former. Therefore, the sustainability focus for industrial packaging shifts to use efficiency and processes for recycling. In practice, many companies work with their supply chain partners on developing a more sustainable packaging system. In such collaborations manufacturers can more easily design the packaging system which reduces the overall environmental impacts. Verghese and Lewis [4] provide nine case studies in which companies work with their supply chain partners on sustainable industrial packaging system. They conclude that commercial considerations, such as the need to reduce product damage or to improve supply chain efficiency, are the main driver for changing packaging. In addition they determine that the broader benefits can usually be achieved from a well-planned and coordinated project.

An important feature of the packaging industry is that recycled materials are neither sourced from, nor made into, packaging in a closed loop system. In general, any given recycled material is collected from a variety of different products, and reprocessed in China, before it is purchased as feedstock made of recycled content [5–8]. Additionally, because the quality of packaging material degrades with each successive round of recycling, it is down cycled in most cases, meaning that it is made into products that use a lower grade of materials that are completely unlike their original form. For example, in 2008, the primary domestic end market for recycled HDPE was composite lumber, comprising 29% of demand [9]. In comparison, exports made up 57% of demand, while 4% were used in films and sheets in 2008. Trends for recycled HDPE from 2006 through 2008 can be seen in Fig. 10.2. The general trend of downcycling inhibits the possibility of recycling as a long-term solution to packaging because products cannot be infinitely made or downgraded. Eventually these systems will need the further input of raw materials.

Downcycling forms the basis for an open-loop recycling system, which makes the environmental assessment of a packaging more difficult. In LCAs many allocation procedures exist that may be used to assign the proportional shares of environmental burdens associated with a process across multiple products. However, allocation

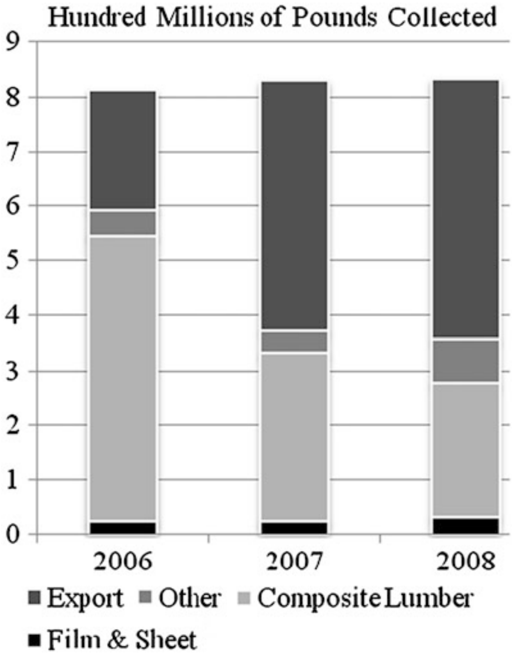

Fig. 10.2 End markets for recovered HDPE. Adapted from Moore Recycling Associates [22–24]

procedures are not standardized, and the lack of consensus on an optimal technique has resulted in a great degree of variability in LCA results, making the process of allocation a continued source of debate over the past two decades [10–15]. Recycling in particular has been regarded as a distinct allocation problem in need of resolution [16], as it represents both waste treatment and secondary material production. Huppes [17] presents a method to assign responsibility according to the economic value of co-products, Frischknecht [18] puts forward an allotment technique based on internal cost accounting, and Ekvall [10] suggests the use of the relative importance of supply and demand of recycled materials as market mechanisms to drive recycling as the means to assigning loads. Generally, credit is given in LCAs for avoided impacts that are associated with the displacement of virgin materials with recovered materials. Evaluations frequently show recycling to be favorable over using virgin materials, particularly for metals [19]. The allocation of recycling credits, either to the product that produces or utilizes the recycled materials, continues to be a point of contention amongst researchers [20, 21].

One simple procedure for allocation in the case of recycling has been suggested by Koltun et al. [25]. They suggested that emissions from the recycling (remanufacturing, reuse) processes and all the resources associated with it should be ascribed to the product, which is produced from these material. Figure 10.3 shows the concept behind this method. As can be seen at the end of a product's life, the environmental burdens from shipping that product to the collection and recycle facility are fully ascribed to that product. After being collected, all of the

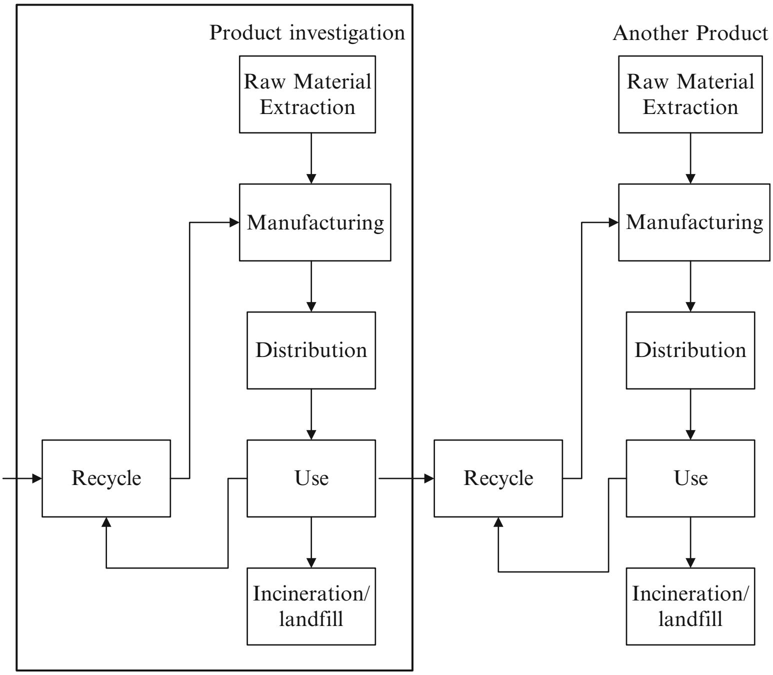

Fig. 10.3 The allocation procedure for open-loop recycling

environmental burdens from processes used to recycle and remanufacture the product into a new item are ascribed to the new product. This also means that if any recycled material is used in the initial manufacturing processes of the original product being considered, then only the environmental burdens from the recycling and remanufacturing process are counted. For any components that cannot be recycled, all the environmental burdens associated with their disposal are ascribed to the original product from which they came. This method can be easily implemented for dividing the environmental burdens of open-loop recycling. It can also avoid predicting future recycling rate and remanufacturing processes. Hence, the uncertainty of the assessments is reduced under this method.

10.2.1.2 The Container as a Component of the Product Supply Chain

In every stage of the product supply chain, packaging plays an important role in protecting it and reducing the waste from damage. Each product generally has three levels of packaging. Primary packaging holds the basic product and is what most people identify as packaging; it is sold by the retailer and disposed of by the consumer. Secondary packaging is designed to contain and protect the primary packaged product and is used to help consumers or retailers load and unload products from shelves. Tertiary packaging is designed to bundle secondary packaging units for transport between facilities. In the past, most people have focused on

Table 10.1 Potential trade-offs of packaging change with logistics activities, adapted from [26]

Packaging changes	Trade-offs		
	Transportation	Inventory	Warehousing
Increased package information	Decreases shipment delays and the tracking of lost shipments.		Decreases order filling time and labor cost
Increased package protection	Decreases damage and theft in transit, but increases package weight and transportation costs.	Decreased theft, damage, insurance; but increases product availability (sales), product value and carrying cost.	Can decrease cube utilization by increasing the size of product dimensions, but can increase it by stacking
Increased standardization	Decreases handling costs, vehicle waiting time for loading and unloading, and the need for specialized transport equipment; but increases modal choices for shippers.		Decreases material handling equipment costs

the levels of primary packaging and ignored the impacts of secondary and tertiary packaging, viewing them as necessary byproducts. However, all packaging associated with a product's life cycle needs to be considered in aggregate to get an accurate indication of the impacts of packaging. Moreover, improvements generally only occur through as a result of a trade-off between these different types of packaging. For example, the shape of the primary package may affect the numbers of product can fit into a secondary package, say, a box, and thus impacts the number of products that can be shipped in one truck. When primary packaging is reduced, secondary packaging may have to be increased if it causes the product to become more fragile. As a result the benefit of reducing primary package is someone offset by a need for more transport packaging and could cause an overall gain in the amount of packaging.

Additionally, all of the activities in a supply chain are linked and any change is accompanied by a trade-off. Gustafsson et al. [26] note that several trade-offs exist between packaging impacts and the cost of logistics, as shown in Table 10.1. While these trade-offs are focus on economic costs, they help to illustrate the nature of the relationships between the different activities. By extension, these considerations can provide useful insights for the evaluation of the sustainability of a product's packaging. For instance, if more packaging material is used to increase product protection thereby decreasing the damage rate, it will result in less total material wasted, since packaging usually requires far less material than the product. These trade-offs within the supply chain are all the more observable for secondary packaging. Take the case of a reusable/returnable transport packaging system, where the reuse rate of a tray or container depends on its durability.

Since any change to the packaging system also affect the other activities in the supply chain, the scope for the packaging assessments should incorporate these aspects of the product supply chain. Not only should resource consumption and associated impacts from packaging be included but those associated with the product also need to be recorded for further assessment. For example, if a company would like to change the packaging of their product by making it lighter in weight, the impact of these changes also need to consider the protection they provide for the product. Otherwise, even if the new packaging is made from fewer resources, the increase in product damage rates may cancel out those benefits. Packaging only comprises a small portion of the life cycle impacts of a product, any company looking to green their operations will conduct these full product assessments in order to identify opportunities. Meanwhile, companies that specialized in packaging must take the functionality of packaging into account if they are to prove the sustainability of their offerings. A possible equation for a particular packaging option is offered below:

$$\frac{\text{The life cycle environmental impact of the packaging}}{(\#\text{ of reuses}) \times (1 - \text{product damage rate}) \times (\text{packaging capacity})}$$

In LCAs, the functional unit defines the unit of the entities being examined. For example, in comparisons of plastic and paper bags, it is not useful to perform evaluations based on the unit of 1 g of bag material. Instead, more insights can be gained if units are defined by their function, say, the number of bags needed for a consumer to carry 1 kg of groceries. Lilienfeld [27] notes that one paper bag is equivalent to one and a half plastic bags. Hence, functional unit evaluations would compare the environmental impacts of 1.5 plastic bags to one paper bag. In general, we can define the functional unit for packaging applications as the amount of packaging that can protect a certain amount of product over a certain period of time. One instance would be as the amount of packaging that can protect a single product during its transportation from warehouse to retailer.

Recently, several big retailers have started to look at the environmental performance of their supply chains. For example, Wal-Mart found that 90% of the carbon emissions associated with their operations (transportation, manufacturing, farming, etc.) come from their suppliers and have started to work on greening their supply chain. As part of their sustainability initiatives, Wal-Mart has set a goal to reduce packaging by 5% of their 2008 baseline globally by 2013. Reduced packaging can not only contribute to greater environmental sustainability but can also lower transportation, inventory, and waste handling costs, and reduce the shelf and storage space needed. As part of their efforts, Wal-Mart has developed a packaging scorecard to help supplier evaluate their packaging. The scorecard will be an additional basis upon which Wal-Mart will evaluate their suppliers and as a result is pressuring suppliers to improve their packaging. While their scorecard has been subjected to criticisms, and in fact may have flaws in its methodology (see more details about metrics in Chap. 2), it serves to show that the whole supply chain is being held responsible for issues of sustainability due to the expectations of downstream customers and the regulation put forth from governments.

10.2.2 Focusing on Transportation Practices

Logistical optimization has been studied and implemented into practice for decades. It has been considered at different levels of detail, from the optimal truckload utilization, shipping frequency, and routing, to the best network design and facility locations. Across these various levels, models have been created either to minimize total cost or maximize total profit, given certain assumption on parameters at other levels. For example, the classical minimum cost network design and facility location problems usually assume a fixed unit transportation cost where the truckload utilization is given. The basic network design models take into account the trade-offs between transportation cost and facility location cost. Other constraints are included in the models, such as the maximum distance from distribution centers to retailer and the maximum number of facilities. In addition to high-level strategic network design problems, real-time routing and scheduling problems have been optimized within the field given known starting and end locations, and assumed time constraints of each shipment. For example, a minimized cost routing problem may specify a certain delivery time for each task. In some cases, companies may want to simultaneously minimize their delay and costs.

Shipment container utilization is one index of efficiency. Full truckload shipments can lower the unit transportation cost per product. However, when the demand is stable, increasing shipping quantity per shipment also implies increasing inventory holding in the facilities. Therefore, depending on the trade-off between inventory holding cost and the fixed ordering transportation cost, one may choose to order fewer products in shipments that are not full. To eliminate the aforementioned problem, companies tend to combined several products into a single order when possible. The joint shipment reduces the transportation cost but increases the complication of ordering policy and may increases the processing time.

Traditionally, cost and service are the major performance factors of logistics system. However, more recently, companies have also begun focusing on integrating sustainability as a goal. Often times the goals of sustainability coincide with the methods of lowering costs and improving service, such as in the case of better routing planning, education of ECO-driving, and coordination of shipments. In addition, several big companies have adopted changes to decrease their transportation emissions by reducing shipment frequencies, changing to lower-carbon transportation modes, and reducing the size and weight of products or its packaging. However, some of the strategies aimed at improving sustainability, may actually result in worse effects on environment. For example, changing the transportation mode may increase the lead time for shipments and further increase the energy consumption at distribution centers due to increased inventory levels. Also, reducing the size of products or packaging may not benefit the environment without ample consolidation of freight flows.

10.2.3 Sustainability Impact Assessments of Transportation

The proportional impacts of transportation vary greatly between products. In one instance, Zhang et al. [28] found that the transportation impacts contribute between 10 and 20% to the emissions for the delivery of a SolFocus concentrator PV technology to its assembly site. Pa et al. [29] found that the oceanic transport of wood pellets from British Columbia to Europe comprised about 45% of the life cycle energy consumption and contributed the greatest amount of pollutants. Meanwhile Weber and Matthews [30] note that for food items, the impacts of transportation can vary between 9 and 50%, depending on how extensive the rest of the supply chain for a particular food item is.

While the significance of transportation impacts can vary immensely between products, aggregate freight-based emissions are fairly significant at the national level. According to the EPA [31] freight transport contributes 11% of all national GHG emissions and 38% of the transportation-specific GHG emissions. In addition, the transportation sector has been a substantial contributor to increases in national emissions, accounting for 28% of the growth of all GHG emissions, and 46% of energy-related emissions, since 1990 [32].

Furthermore, the impacts of freight have become more severe over time, making the need to improve the impacts of transport all the more important. US GHG emissions from freight increased 69% between 1990 and 2005, corresponding to a 30% growth in ton-mileage during this period [33]. Bomberg et al. [33] note that most of the increase in the intensity of freight emissions can be attributed to more energy-intensive modes of transportation. The four major modes of cargo freight, namely truck, rail, air, and water, account for 60, 6, 5, and 13% of freight-related GHG emissions, corresponding to the transport of 28.5, 38.2, 0.3, and 13.0% of freight tonnage, respectively [34]. One shift that has caused a rise in emissions has been a rapid growth in air cargo, which increased 63% from 1993 to 2002, making it the fastest growing mode of freight transport despite only representing a fraction of a percent [34]. However, most of the overall growth in freight GHG intensity has been from the increase in truck market shares at the expense of other, more efficient, modes of transportation [33]. Simultaneously, there has also been a drop in the energy efficiency of freight trucks [35] due to an operational decline in efficiency [33].

The transportation impacts of a product are calculated in the inventory analysis step of LCA, as described in Chap. 3. A variety of methods are used to approximate these impacts, mostly relying on existing research on vehicle emissions factors. The GHG emissions of freight transportation can be approximated as a function of either the cargo's weight or the cargo's volume [36]. Traditionally, researchers have investigated the environmental impacts of different modes of transportation from a life cycle perspective to obtain mode-specific emission factors based on the distance and weight of shipments for specific geographic regions [37, 38]. Models have also been developed which incorporate fuel use, in addition to weight-distance data for different modes of transportation [39].

The benefit of a mode-specific weight-distance based emission factor for assessing transportation impacts is that it allows organizations a simple and standardized way to estimate the life cycle contributions from the distribution of a product. In addition the method allows for the allocation of the multiple factors that comprise a vehicle's life cycle impacts, such as fuel processing and consumption, vehicle manufacturing and maintenance, and the infrastructure needs, across the various products served by the vehicle. However, the weight-distance based methodology also has limitations. For instance the number of vehicle trips needed to transport a given number of products is not considered. To illustrate, under a weight-distance methodology, there is no differentiation between transporting 100 units in one shipment by one vehicle versus transporting them in 100 different vehicle shipments. By standardizing the baseline emissions that occur from commissioning a transportation vehicle across the miles that it travels, weight reduction is the only method that can be measured or easily identified to improve transport efficiency.

Meanwhile, a few researchers have developed methodologies to allocate the impacts of shipping according the volume the item occupies in the shipments. In studies on online shopping, the need for such an evaluation has been identified, out of the necessity to package each order individually, which causes it to take up more space in vehicles [40]. Matthews et al. [41] calculate the energy requirements to ship a book purchased through e-commerce, where transportation impacts are calculated based on volume, the distance traveled, and the fuel efficiency of the vehicle. Williams and Tagami [42] also recognize that shipping individual packages affects the energy efficiency of shipping vehicles because of the volume they take up. Their model for assessing the energy impacts for transporting each unit is similar to Matthews, but also incorporates the number of trips needed to make a successful delivery to the consumer's home. In addition, Williams and Tagami attempt to incorporate the energy impacts of vehicle production based on the proportion energy consumption associated with the production phase, as compared to the use phase of its life cycle. Also, because these models use actual fuel consumption rates, they implicitly incorporate the impacts that the freight's weight has on fuel efficiency.

In addition, extensive research has been dedicated to identifying the multiple aspects that contribute to transportation impacts. Assessments can vary dramatically based on which transportation impact factor is used, and how comprehensive researchers were in their considerations for obtaining these factors. At the base level, many researchers calculate emissions as a function of weight, distance, and fuel use based on vehicle type [30, 43–47]. However, emissions factors may vary depending on the scope of a vehicle impacts. First it should be noted that in addition to variations between vehicle types, or at the inter-modal level, there is also a great degree of variability in emissions impacts within each vehicle type or in intra-modal comparisons. Trains, planes, trucks, and ships all come in a wide range of different models, each of which have different capacities and fuel efficiencies associated with them. Further, in a mode-specific assessment of life cycle emission factors of freight transportation, Facanha and Horvath [45] incorporate the transportation infrastructure and vehicle maintenance needed to support different types of vehicles. Bomberg et al. [33] acknowledge that a vehicle's fuel economy is influenced by aerodynamic drag, rolling resistance, idling losses, accessory loads, and transmission and engine inefficiencies. However, they also identify some technologies that may mitigate some of these factors. In addition, Helms and Labrecht [48] point out that most resistance factors for ground vehicles, such as rolling resistance, gradient resistance, and acceleration resistance, are all linearly dependant on transport weight.

The assumptions about the distance of the trip also play a large role in how impacts are assessed. Foremost is the way in which the transportation distance for delivering a product is calculated. Actual miles driven, routing software, and straight line regression have all been used for these assessments. The difference between these methodologies can lead to large differences in evaluations. Impacts can also vary based on the assumption of whether a vehicle is traveling a long distance or making a short trip [48]. One factor for this, as noted by Büttner and Heyn [49] and Pearce et al. [50], is that the acceleration and deceleration of a vehicle impacts its fuel efficiency. In addition, fuel efficiency is affected by the speed at which the vehicle travels [50]. For instance, Cummins Engine Company points out that decreasing the speed of a vehicle from 65 to 60 mph can improve its fuel economy by 8% [51].

McKinnon and Edwards [52] present a framework for identifying the opportunities to reduce the environmental impacts of delivering products to retailers based on the quantity of goods. This framework, adapted from the work of McKinnon [53], maps the environmental impacts of transporting goods to a retailer based on seven factors. The first parameter is the modal split, which is the total proportion of each mode of transportation vehicle that is used to ship the freight. Another consideration is the average handling factor, or the number of times goods must be handled during their distribution, based on the structure of the logistical system and the number of channels involved. The average length of the haul, determined by the retailer's sourcing strategy as well as the efficiency of routing, also plays a role in determining the environmental impacts of freight transportation. Additionally, the aggregate amount of transport needed can be minimized through the optimal utilization of the vehicle's capacity, as determined by the average load on laden trips, the percentage of empty runs, and the vehicle's carrying capacity by weight and volume. The energy efficiency of the haul, or the energy use per distance traveled, is an important factor that has received a great deal of attention in discussions regarding the environmental impact of transportation. McKinnon and Edwards note that the energy efficiency is affected by the characteristics of the vehicle, as well as the behavior of the driver, and traffic conditions. Similarly, the pollutant content of the energy, or the amount of pollution that is created from the type of fuel that is used by a vehicle, has been identified as an important consideration in transportation decisions. Lastly, McKinnon and

Edwards note the impact of other environmental effects of the transport vehicle not associated with the consumption of energy, such as an increase in noise irritation and accidents. A representational flow diagram of this framework can be found in McKinnon and Edwards.

10.2.4 The Practice of Pallet Utilization

To address the sustainability of packaging and its potential impacts on the supply chain several organizations have developed tools and guidelines to help manufacturers make greener packaging choices. Generally, these recommendations have developed out of the best practices noted by experts and are focused on methodologies for designing or redesigning packaging. These efforts have laid a necessary foundation for further improvements in packaging and sustainability practices in general. Out of these works, general trends in sustainable packaging practices have emerged and have been understood and achieved with varying degrees of success.

Pallet utilization, also known as cube utilization, is one practice that is commonly recommended as a means for improving the sustainability of packaging. Generally, pallet utilization refers to the total space that packaged products take up and the resulting number of units that can fit onto a pallet. The practice of improving pallet utilization consists of two techniques. One method is to redesign packaging elements so that the total product shipment more efficiently utilizes the available space. Another approach is to mix products of different densities in one shipment to exploit more of the space and weight constraints for shipments simultaneously. The latter technique may also involve the redesigning of packaging elements to better achieve the objectives of improved shipping efficiency.

Shipments are restricted by both the weight and volume constraints of the vehicles they will be transport in. Very few shipments simultaneously fulfill both of these capacities, as a load either tends to reach the container's weight limitations, where the shipment is said to "weigh out," or its space restrictions, where the shipment "cubes out," but rarely does both. Although, shipments that cube out frequently only maximize the floor space of a shipping container and leave excess vertical space still unused. In most cases, manufacturers have optimized the logistics of their product shipments along the parameters of weight and size, as these efficiencies lead to cost benefits. However, the employment of these optimizations only considers the current size, shape, and weight of products and does not necessarily imply that further shipping efficiencies cannot be obtained through a redesigning of the product's packaging.

Product packaging is often not designed in a space efficient way, leaving many opportunities for improved pallet utilization to be beneficial. In a survey of the packaging for 468 products sold in selected European countries, Europen [54] found that on average about 80% of the weight of a packed pallet consisted of the product, but only around half of the volume was composed of the product. In many cases product packaging can be improved so that the total number of units that can be included in each shipment can be increased by better fitting the products into a case or by improving the composition of cases on a pallet. For example the shape of packaging can be changed to improve stacking and nesting possibilities for multiple products with more rectangular sections or a more flat surface on top. In other instances, the void space between the product and packaging can be reduced to decrease the total volume of the packaged product. These are the primary concepts behind pallet utilization.

If utilized correctly, pallet utilization can provide manufacturers with a means to achieve cost and environmental benefits. Unlike other sustainable packaging practices related to material sourcing, end-of-life options, and most production practices (with the exception of multipurpose packaging), pallet utilization is one of two sustainable packaging options that considers the influence of a container on the product. More succinctly, pallet utilization automatically affects packaging and product impacts simultaneously, unlike most sustainable packaging practices. In the case of shipments that have reached their volume capacity constraints, pallet utilization can drive down shipping impacts that have already been optimized based on the existing design. If more units are included in each shipment, it will cause reductions in the aggregate amount of fuel, labor, and vehicles needed to transport a manufactured goods.

Low density products in particular are well suited for consideration for improved pallet utilization. For instance, many snack products, such as potato chips, are packaged in bags filled with air to reduce the amount of damage that occurs during shipments. These types of products occupy the entirety of the container's space without using all of its available weight capacity. If improvements were made in the amount of space these packaged products occupy, so that more units fit into each shipment, fewer total shipments would be necessary, and the impacts associated with transit of a greater number of vehicles needed to carry shipments would be mitigated.

However, the packaging for other products, such as those that cannot be stacked, can also benefit from improved pallet utilization. In addition secondary benefits may be gained through the implementation of pallet utilization. In most cases improvements in pallet utilization will result in reductions in secondary packaging for transport and handling. For instance, as more units can be moved in each pallets and boxes, fewer of them are needed. However, there are often trade-offs between primary, secondary, and tertiary packaging, where an increase in one can lead to savings in another. Ideally, any redesign will result in an overall reduction in the total packaging needed. Additionally, the handling and storage needs for the product can also potentially be decreased. As an example, refrigerated or frozen items that are redesigned for better pallet utilization require less fuel and energy, not only for shipping but also for handling and storage as well.

However, these secondary benefits do not necessarily follow from every implementation of pallet utilization. Further, if the primary objective of an application of pallet utilization is one of these secondary benefits, packaging designers would be better served by trying to meet these primary objectives instead. For the remainder of this chapter, the focus of pallet utilization will be on the benefits that occur generally across all products and their packaging, namely: improving shipping efficiency by making better use of the available space.

Given its potential opportunities to provide benefits, pallet utilization is often recommended as a generalized way to improve the sustainability of packaging. For instance, in their packaging scorecard, Wal-Mart has assigned it 15% of the score. In addition, another 10% of their evaluations are assigned to general transportation impacts. Additional sustainable packaging guidelines also recommend pallet utilization. To address the issues of resource scarcity and transport efficiency Envirowise [55] advises improving transport efficiency by choosing packaging sizes and shapes that will maximize the case and pallet utilization. Similarly, WRAP [56] notes that packaging can be used to improve the efficiency of distribution by increasing the number of items per pallet. They also suggest changing the size or shape of the primary packaging to fit more items in a box or on a pallet. Meanwhile INCPEN's [57] *Responsible Packaging Code of Practice* suggests that packaging headspace should be kept to a minimum, but recognizes that in some cases it is needed. Later, in a joint effort with Envirowise, Incpen [58] recommended that packaging be minimized so that "the sales packs fit snugly into the transport packaging, and the transport packaging's dimensions are optimised [sic] to ensure good pallet utilization (unless weight rather than volume is the critical factor for vehicle loading)."

One popular use of pallet utilization has been a redesign of cylindrical containers which have a great amount of void space when combined in cases. For instance, in 2009, Kraft Foods redesigned their Crystal Light Drink Mix canister from a round shape to a more oval design, so that around 10% less material was used in the primary packaging and 25% less was used in the shipping trays [59], improving the pallet efficiency by 33% [60]. Bottles are particularly inefficient because even greater volumes of space around the neck of the bottles are wasted, in addition to the void space around the cylindrical body. With this in mind, the Cyprian company Cubis, in a collaborative effort with the Swedish design studio "Love for Art and Business," have developed a rectangular packaging for water bottles. Similarly, in 2008 Sam's Club and Costco stores adopted a new rectangular-shaped milk jug (see Fig. 10.4). The primary benefit of this new design was that the jugs could be stacked, thereby mitigating the need for crates to transport and store the milk. Instead, containers could be stacked layers four high on a pallet with cardboard sheets between each layer, fitting more gallons of milk on trucks and in coolers. Superior Dairy of Canton, Ohio, which initially launched the design in 1998, estimates that the new jug is 50% more space efficient than traditional containers, fitting 4.5 gallons into a cubic foot versus 3 gallons in the old design [61]. It has been estimated that these savings have reduced the number of deliveries to retailers such as Sam's club store from five to two per week [61].

In addition, several manufactures have integrated the idea of pallet utilization into their overall business strategy, giving them financial and environmental competitive advantage. Twede et al. [62] note that IKEA's success can be attributed to their practice of shipping furniture in the smallest form possible, in which it is broken down into parts for assembly by the consumer. Fully assembled furniture is

Fig. 10.4 Rectangular stackable milk jugs developed by superior dairy [65]. Reprinted with permission from Packaging World magazine and http://www.packworld.com

awkward to handle and usually cannot be done mechanically. According to Twede et al. [62], by breaking down the product into compact packs, IKEA has improved logistical efficiencies and reduced damage rates. Other companies have used pallet utilization to improve the transportation impacts of one or more products. For instance, Snyder's of Hanover, the nation's largest pretzel manufacturer, redesigned their packaging to increase the number of boxes that fit on each pallet, with the help of Georgia-Pacific's Packaging Systems Optimization (PSO) service. Snyder's also upgraded to larger shipping trailers, increasing the capacity for each of their shipments. As a result, the total greenhouse gas emissions were reduced by 32,328 lb/year [63]. Similarly, in 2007, SC Johnson reconfigured their shipments to improve logistical efficiencies. While they did not redesign their packaging, they were able to achieve savings through strategically packing multiple products on the same load to obtain the best space and weight arrangement possible for each truckload. As a result, SC Johnson was able to cut their fleet by 2,098 trucks, their GHG emissions by 1,882 tons, and their costs by $1.6 million annually [64].

While pallet utilization provides a means to improve transportation impacts, current environmental assessment methodologies may not recognize such improvements. As previously mentioned, numerous factors are considered to influence the impacts of freight transportation. While transportation impacts can be calculated along the volume of cargo, a better case can be made for the use of weight as a direct contributor to transportation-related emissions impacts. As per the current techniques commonly used to estimate transportation impacts, as described above, any potential or actual emission reductions achieved through the employment of pallet utilization may not change the outcomes of these assessments. With transportation impacts that are calculated as a function of weight, distance, and vehicle type, evaluations will often times remain unchanged despite actual reductions in shipping as the result of improved pallet utilization, unless these savings are also accompanied by changes in weight. In these cases, only manufactures that are knowledgeable about the distribution of their products and the potential benefits of pallet utilization are likely to make use of the practice to achieve improvements.

The implications of this situation are that the opportunities for pallet utilization may not be easy for manufacturers to identify, and as a result packaging designers may be misguided as to when the practice of pallet utilization would be beneficial. Pallet utilization will become an increasingly significant practice, as many manufacturers and retailers are setting goals to reduce the overall amount of their packaging and as more obvious techniques are exhausted. For this reason, any instance of packaging design for improved pallet utilization serves as examples to others in the industry at this point in time, even if the actual results are less than impressive.

However, there are many instances in which pallet utilization can actually increase transportation impacts. This is often the case when improvements in space utilization are associated with more packaging material needed for a design alternative. For instance, in the case of rectangular milk jugs, like those that have been adopted by Costco and Sam's Club, Singh et al. [66] show that it is not necessarily the practice of pallet utilization, but rather the reduction of secondary packaging, that leads to improvements in transportation impacts. Singh et al. also note that for liquids in general, weight plays a greater role than space as a factor for impacts, as trailers transporting these products "weigh out" before they "cube out." In their study of three different packaging systems—traditional jugs, jugs that have been cubed for better space utilization, and jugs that have been designed to be stackable—they found that in the case of jugs that have been cubed but were not made stackable, pallet utilization was improved but the weight transported per unit increased. This was due to the fact that each container required more material and that while the accompanying shipping crates were lighter, more of them were required, so that their total weight impacts per shipment were also higher. By switching to this container design marginal improvements of 0.8% more units per shipment could be obtained, but only at a trade-off of an increase in weight by 2.2% per unit shipped, resulting in a net increase in shipping impacts. Meanwhile the stackable containers that were designed to mitigate the need for crates resulted in 5.8% more units per shipments and an overall 5.6% weight reduction, despite the fact that the primary packaging material for the jug was increased by 43%. The details of Singh's findings can be seen in Fig. 10.5 and Table 10.2.

Given the opportunities that pallet utilization provides, it is important to distinguish between the cases where the practice is in its own right beneficial and those in which it is not pallet utilization, but the accompanying byproducts—such as weight reductions—that actually causes improvements in shipping. Otherwise, pallet utilization may be applied inappropriately, leaving all that use it vulnerable to accusations of greenwashing. The remainder of this chapter is dedicated to exploring the potential of pallet utilization and determining the specific cases in which it can be most beneficial.

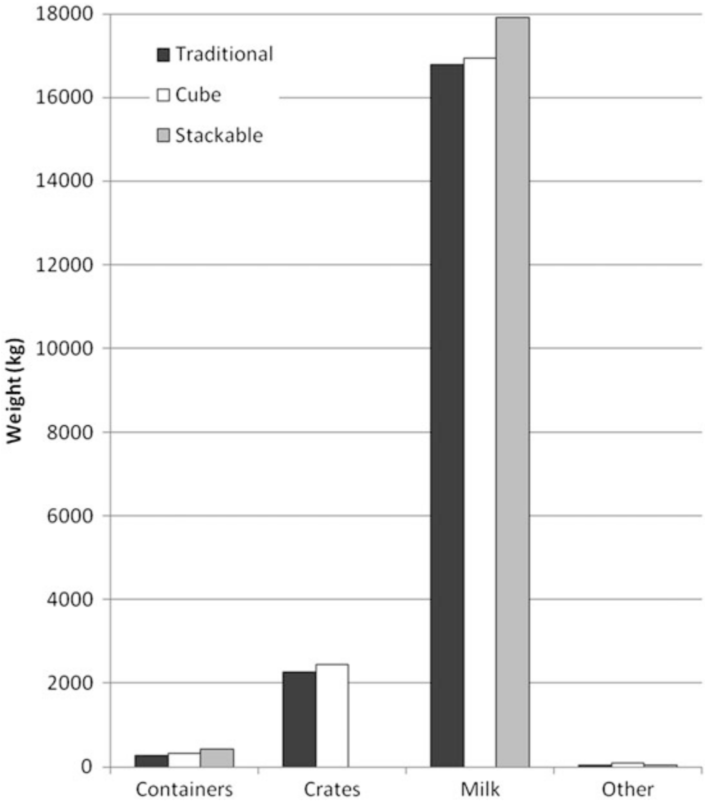

Fig. 10.5 Shipment weight aspects for different container designs for 3.79 l (1 gallon) packaging systems. Adapted from Singh et al. [66]

Table 10.2 Design differences for a 3.79 l (1 gallon) milk packaging systems

	Traditional	Cube	Cube and stackable
Total weight per shipment	19,380	19,800	18,360
Number of units per shipment	4,284	4,320	4,536
Weight per unit	4.52	4.58	4.05

Adapted from Singh et al. [66]

10.3 Recommended Method to Determine Opportunities for Improved Pallet Utilization

10.3.1 Conceptual Overview for the Applicability of Pallet Utilization

As previously noted the practice of lightweighting is generally applicable to most products; in many cases reducing the weight of packaging and products will improve their impacts. In addition, for packaging professionals lightweighting is an easily identifiable opportunity for improvements, especially with the methodology typically used to evaluate transportation impacts. However, lightweighting is not appropriate in all cases and can result in greater overall emissions. This occurs when packaging is reduced to a level that compromises its functionality, causing an increase in product damage.

While lightweighting is a technique that is generally applicable to achieve shipping improvements, the same is not necessarily true for pallet utilization. For items that are heavier, and reach weight restrictions long before space restrictions, improving the use of space is often not beneficial unless it is also paired with improvements in weight. However for these items, pallet utilization can be a helpful means to conceptualize methods to achieve reductions in weight.

Only certain products benefit from a reduction in packaging space occupancy. Discussions on the nuances of pallet utilization are currently lacking, and just a few studies currently exist on average space utilization rates and the potential impacts of improving them in shipping. For instance, Samuelson and Tilanus [67] explored the typical cube utilization rates of trucks in the Netherlands and Sweden. By consulting with industry experts, they discovered that cube utilization rates were typically very low, at approximately 28%. More specifically, while container floor area utilization was generally high, at an average of 80%, load heights were only about 47%. Other researchers have focused on the different techniques to improve cube utilization. Palmer [68] notes that the utilization of shipping containers can be improved by mixing different items according to their densities. For instance, shipping container utilization can be improved by mixing pallets of items that would weigh out a shipment on their own with items that would cube out a shipment. Alternatively, in a study conducted in England, the Department for Transportation [69] found that by expanding truck container space capacity with the use of double-decker trailers, the vehicle-kms, fuel, and CO_2 emissions for shipments were cut almost in half.

What is lacking in research and the guidelines that promote sustainability packaging practices is an identification of the cases in which pallet utilization is most appropriate. Here, we provide a conceptual methodology for designers and producers to determine these cases. The premise upon which potential packaging can be determined as ideal for improved pallet utilization is simple: focus on items whose size prevents more units from fitting on each shipment. While this concept may seem simplistic, it is not one that is specified in recommendations for the adoption of pallet utilization. Items that weigh out a shipment, rather than cube it out, will not benefit from the practice of pallet utilization, unless such applications are accompanied by secondary benefits, such as reductions in secondary or tertiary packaging. For example, it is not generally beneficial to reduce the volume of an item that weighs out a shipping container but only occupies a fraction of the available space, unless such changes are also associated with weight savings.

It should be noted that the focus of this paper is on the practice of pallet utilization in general and not the specific instances in which supplementary effects result from its employment. As was previously discussed, pallet utilization may be associated with reductions in the overall packaging weight. However, this benefit is not insured from the uptake of pallet utilization and can better be achieved by focusing on reductions in the *weight* of packaging rather than the amount of space the packaging takes up. In general, any implementation of pallet utilization that can also lead to shipping weight reductions will benefit most products, as long as the functionality of the packaging is not compromised. However this phenomenon does not occur in all cases and should not be assumed when references are made to the applicability of pallet utilization.

Below is a discussion of the applicability of pallet utilization to the different cases of single product shipment types. The instances considered are shipments that weigh out, cube out, are at floor capacity, and are partially loaded. It is assumed that very few products will cause a shipment to simultaneously max out both the space and weight constraints of a shipping container. Since these circumstances are considered to be negligible, they will not be considered in the discussion below.

10.3.2 Pallet Utilization in the Context of Shipment Density

While the applications of weight and space saving improvements are not mutually exclusive, generally one factor is more important than the other in determining the amount of products that can fit into a shipment. To discuss the concepts behind the weight and space trade-offs in shipping, consider a comparison of the density, or the ratio of weight to volume, for a product shipment and the associated shipping containers that will be used in shipments. For the product, it is assumed that the existing packaged product has already been optimized on pallets to best utilize the container capacity. For instance, if loading a pallet well below capacity allows for better stacking in the shipping container, then it is assumed that this opportunity has been exploited.

The density, or weight versus volume diagram, is shown graphically in Fig. 10.6. For any shipping containers that will be used in product transportation, the density ratio for the container's capacity is represented as the slope of the capacity line, c. Any point on line c corresponds to the percent of the respective weight and space capacity that has been occupied in a shipment. This line also intersects the point where the weight and volume capacity lines cross, represented by the top horizontal line and the far right horizontal line, respectively. Meanwhile, the density for each product can also be represented by a line, upon which the total shipment dimensions will be a point on. While the actual possible shipment weight and volume will be a set of discrete points on the line, that in general are multiplicative factors of the pallet dimensions, the density line aids in conceptualizing the relationship of the product weight and volume in comparison to this relationship in the shipping container's capacity.

Products that weigh out a shipment, such as those represented by line l_1, have a greater density slope than the container capacity line, meaning that they reach the container's weight capacity without crossing the volume capacity line. Another way to conceptualize these items is that for any given volume, the utilization rate of the weight capacity will be greater than that of the volume capacity, since the

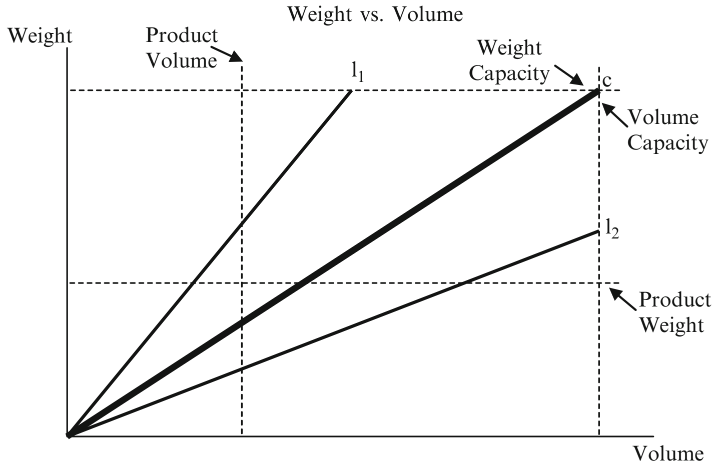

Fig. 10.6 Product and shipping container density comparisons

density ratio of weight to volume is greater than that of line c. Since weight is the limiting factor for the shipment of these items, improvements that focus on reductions in weight would be most beneficial. For these products, lightweighting, and not pallet utilization, should be the primary guiding principle for packaging improvements. Meanwhile products that cube out a shipment, such as those represented by line l_2, have a smaller slope than the capacity line. These items will cross the volume capacity line, but not the weight capacity boundary of the shipping container. Since space is the limiting factor for the shipment of these items, they are potential candidates for improved pallet utilization. It should also be noted that there is also a lower bound for any shipment, corresponding to the minimum weight and volume for shipping products without packaging. However, reducing packaging to these non-existent levels is probably not ideal, as it will most likely result in reduced marketability and increased product damage.

It should be noted that the magnitude of the density, which signifies the utilization rate of the shipping weight capacity in comparison to the utilization rate of the shipping volume capacity, does not reflect on the efficiency of the packaging. Since the density represents the relationship between the weight and the volume, any given density can simultaneously represent products with packaging that is grossly inefficient as well as those with packaging that is highly optimized. In addition, shipping improvements can change the density in either direction. For example, if only the weight per unit is improved for an item that weighs out, then the density will decrease, and as a result more units will fit into each shipment, causing the volume of the shipment to increase. Meanwhile, if such an improvement in weight is also accompanied by a better utilization of the volume, the density could change in any direction, or not at all, depending on the degree of both of these improvements. Therefore, for these purposes, the density primarily signifies which aspect of the capacity is constrained, but not whether this is due to packaging efficiencies.

The density is primarily useful in identifying which constraint is at capacity and which one has excess slack, indicating which factor is more important in determining shipping rates.

10.3.3 Shipment Cases and the Applicability of Pallet Utilization

10.3.3.1 The Applications of Pallet Utilization for Shipments That Weigh Out

For products that weigh out a shipment, the potential benefits from improved pallet utilization are limited, since the greatest restrictions for these items are on their weight. In many cases, pallet utilization also results in changes to shipment weights and can actually result in a decrease in shipping efficiency. One option for items that weigh out is to use pallet utilization to mix heavier products in shipments with those that have a lower density, to better utilize the space capacity. In addition, pallet utilization can be used as a technique to conceptualize ways to lightweight the packaging for these products. In general, though, packaging improvements for items that weigh out should be focused on ways to decrease the weight, regardless of whether pallet utilization is used.

For product shipments that are at or near weight capacity, improved space efficiency can actually decrease the number of units that fit into a shipment. In many cases, improved pallet utilization will result in increases in the total shipment weight and possibly in greater weight per unit. Since pallet utilization allows for more units to fit into the same amount of space, there can also be added weight associated with these extra units. However, aggregate weight changes are also influenced by the weight of the packaging, which can vary depending upon the net change in the primary, secondary, and tertiary packaging, and may even change inversely to the total shipment weight.

To illustrate the potentially adverse effects of improved pallet utilization on a shipment whose weight has been maxed out, consider the following hypothetical scenario. Assume a truck is filled with 100 boxes, each containing 100 units, where the per unit weight of each product and all of its associated packaging is equal to eight pounds, where secondary and tertiary packaging is assigned proportionately to each product. This shipment perfectly meets the 80,000 lb weight capacity of the vehicle, but is assumed to take up only 60% of the available space. Pallet utilization can be used such that 5% more units can fit in each box. This is achieved by maintaining the original shipping case size and shape, elongating the round cylindrical form of the primary package so it better fits in the box, and adding corrugate reinforcement to each box for improved stacking strength. In total the increases in packaging are offset by the fewer number of boxes that are needed in aggregate, so that the weight per unit remains about the same at eight pounds. With this improved pallet utilization, 100 boxes, with 105 units apiece, now exceed the weight limitations of the shipping container. Instead, the maximum number of boxes that will still meet the vehicles weight constraints is 95, with the assumption that only full boxes can be included in each shipment.

Table 10.3 Example scenario illustrating the limitations of pallet utilization for weight-constrained shipments

Scenario	Number of boxes	Number of units per box	Weight per unit (lb)	Total units shipped	Total shipment weight (lb)
Original	100	100	8	1,0000	80,000
Improved pallet utilization	100	105	8	10,500	84,000
	95	105	8	9,975	79,800

With this figure, the maximum number of units that can be shipped is 9,975, which is 25 fewer than were originally in each shipment. In this case, improving pallet utilization makes shipping less efficient and results in greater transportation impacts. These figures can be seen in Table 10.3.

When there is no slack on weight constraints, any improvements in shipping quantities (i.e., an increase in the number of units per shipment) have to be proportionally offset by a reduction in weight, since the total shipment weight is equal to the product of (1) the number of boxes, (2) the number of units per box, and (3) the weight per unit. While this scenario is fictitious, it serves to illustrate how weight constraints can limit the potential benefits from pallet utilization.

As such, the focus for shipments that weigh out should be on the best methods to reduce the weight of the shipment. In many cases pallet utilization can be used as a technique to conceptualize a potential way to decrease the weight. However, weight reductions are not guaranteed with improved pallet utilization. Pallet utilization can also be used to focus on the logistics of the shipment, by combining heavy products with lighter ones that take up more space, to utilize more of this capacity. So, while possibly helpful, the potential for pallet utilization is limited for shipments that weigh out.

10.3.3.2 The Applications of Pallet Utilization for Shipments That Cube Out

For items that cube out, most of the available shipment space is occupied, and so if changes can be made to decrease the shipment's volume they are likely to be beneficial. Since the space capacity is the primary factor that determines how many units can fit into a cubed out shipment, the use of pallet utilization can improve shipping rates. If improvements in design are not a possible means to achieve these goals, pallet utilization can also be used to improve the space utilization through the mixing of products of different densities into a load. It should again be noted that, lightweighting is in general a beneficial way to improve shipping impacts, since the fuel efficiency of transport vehicles is affected by weight. However, under these circumstances, there are instances where it can actually be more advantageous to increase shipment weights. For example, if items are redesigned to take up less space, then more units could potentially fit into shipments, typically resulting in an increase in the aggregate weight of the shipment. In other instances, part of the shipment load could be replaced with different, denser, products to use more of the available space and weight capacity.

While pallet utilization is generally applicable to shipments that cube out, there exist instances in which the details of its implementation could lead to no overall improvements. Unlike products that weigh out shipments, items that cube them out have slack in their weight constraints, and as a result the options for pallet utilization can more often actually be implemented. On the other hand, similarly to shipments that weigh out, the space gained from a redesign may not actually be usable to increase the number of products that can fit into a shipment. In some instances the space gained from improvements may not be substantially enough to fit extra units. Say, for instance, that each box is decreased in height by a few inches, and then if the aggregate reduction in the height of a stack is less than that of a box, an additional row of boxes will not fit in the empty space at the top of the shipment. Depending on what changes are made, pallet utilization can decrease the total number of units that can fit into a cubed out shipment. However, this should only occur in the unlikely instances that pallet utilization is also associated with large increases in weight or when the original shipment is near the container's weight capacity. In general these trade-offs must be considered to determine the best option.

10.3.3.3 The Applications of Pallet Utilization for Shipments at Floor Capacity

Many products maximize the shipping container's available floor space, but not its available weight or space capacity. The main issue with these items is that they have structural restrictions against stacking to the full height of the container. Pallet utilization can help improve the shipping efficiency for many of these items. However, the practice alone does not provide the sole means necessary to improve stacking height for all of these types of items. Instead, deeper considerations as to why a particular item cannot be stacked must be taken into account to ascertain the best possible solution to improve shipping efficiency.

There are three main reasons why products cannot be stacked to utilize all of the available vertical space, they are either: too heavy, too fragile, or too large. Products with a high density are often too heavy to support the stacking beyond a few layers. Conversely, as products and packaging have progressively become lighter in weight, many of these items have also become too fragile to support the stacking of multiple units. Meanwhile, items that take up a lot of space may not allow for many units to simultaneously fit in the space allowed by the container. In addition it should also be noted that a producer may ship only a partial load by choice. However, the assumption for the cases being discussed here is that the best available shipping option for the existing product and packaging designs has been exploited. The applications of pallet utilization for partial load shipments will be discussed later in this chapter.

McKinnon [70] notes several reasons for declines in stacking height over time. These range from the production of lighter and smaller products that are also covered by lightweight packaging to more efficient handling equipment, and even increased health and safety regulations. For example, it has become common in sectors such as electronics, for product stacking heights to be limited by either the increased fragility of the product or the weakening of packaging materials. For these items, shipments are restricted so that they never reach the maximum volume constraint and may not reach the maximum weight constraint.

There are numerous approaches to improve the packaging of these items, so that either their stacking height can be increased or the number of units that can fit within the restricted height can be improved. Where shipping improvements can be obtained, it is likely that pallet utilization will be a helpful method, since space use is an issue for all of these items as the available space is underutilized regardless of weight. However, pallet utilization is only one of several possible techniques to increase the number of units that can fit into the available space. Adjustments can also be made to the weight of packaging so that either each unit is denser, and can potentially bear the weight of more stacked items, or that each unit is lighter, so that there is less pressure on items on the bottom of a stack. Another possible option is to reinforce packaging with additional layers, to improve the structural stability for stacking. The trade-offs between weight and space use associated with any changes must be closely monitored. No one of these particular solutions is appropriate to improve stacking in all cases, and the best solution can only be determined by a deeper consideration of the specific weight and space issues associated with any given product.

10.3.3.4 The Applications of Pallet Utilization for Partial Shipments

In addition, other logistical prerogatives, such as ordering flexibility, can take precedent over maximizing the shipping capacity. McKinnon [70] notes that order picking tends to happen early in the supply chain, causing distribution to be more demand driven. As a result pallet loads frequently consist of mixed products, making them less efficient and harder to stack. Out of this trend new challenges to remedy these shipping inefficiencies have arisen. In these cases, not only is the space and weight occupancy of an item important but also how multiple items can best be combined for a shipment. When improvements are made to partial shipments, it allows for more container capacity for other items or even the use of smaller shipping containers or vehicles. In addition, these improvements usually translate into reduced shipping costs, especially if shipping is outsourced, where the shipment's dimensions is a primary factor in pricing.

However, despite the generally positive impacts that improvements in the shipping efficiency of these items can have, the best method to achieve such efficiencies is often ambiguous. To begin with, determining how any potential changes to product and packaging dimensions will affect shipping impacts is difficult. This is due to the variability in the number of units and the type of accompanying products that will be included in any given shipment. In addition, if the improvement of the space and weight dimensions of a product allows for the inclusion of an increased number of units of another product to fit into a shipment, it is unclear how credit for these improvements is allotted between the products. What is evident for the shipment of these products is that ordering flexibility takes precedent over the impacts of shipping, and any recommendations for distribution changes should not put this option in jeopardy.

Table 10.4 The application of pallet utilization in various shipping cases

Shipment type	General approach to improve shipments
Full shipments	Focus on the capacity constraint that restricts the quantity of units that fit into a shipment. Pallet utilization will be most applicable to shipments that cube out, but can help practitioners conceptualize methods to reduce the weight of weighed out shipments.
At floor capacity shipments	The primary focus should be on the chief aspect that is preventing stacking. However, since space use is an issue, pallet utilization should be considered in all instances.
Partial shipments	Focus on whether marginal changes in weight and space can effect shipping requirements or increase the capacity available for other products. Pallet utilization can be a helpful means to conceptualize possible improvements.

For items that are commonly shipped in a partial load, it is difficult to determine the best method to achieve improved shipping impacts. If a full load of the product would cause a shipment to cube out, space use is the primary determinant of shipping capacity. For these items pallet utilization should be considered as one means to achieve greater shipping efficiency. Again, lightweighting should also be considered, as it will lead to shipping improvements for most products if they can be obtained. For products that would cause a full shipment to weigh out, the best course of action is less clear cut. The weight of these items obviously plays an important role in determining the shipping efficiency. However, the impact of these items on the total shipping efficiency of full load is unknown. The space that these items occupy could be more important than weight in determining the quantities of other products that can fit into a shipment. Therefore, in these cases, it is suggested that potential improvements in both weight and space occupancy be explored.

10.3.4 The General Applicability of Pallet Utilization

The application of pallet utilization is to redesign packaging to be more space efficient in a useful means to improve the shipping capacity for products when such options are possible. However this method is not recommended for products that weigh out shipments. Although, for these and other types of shipments, pallet utilization can be an advantageous way to pair multiple products of different densities into shipments so that they better meet the weight and space constraints of the container simultaneously. In addition, the practices of pallet utilization and lightweighting are neither mutually exclusive nor contradictory. If the shipping impacts of a product can be improved, weight-based changes will be beneficial in most situations. However, the instances in which pallet utilization will be beneficial are more limited. The instances discussed above and the potential for pallet utilization are summarized below as well as in Table 10.4.

For items that cause a shipment to weigh out, pallet utilization will be beneficial when it is applied to specifically: (1) mix products of different densities in shipments and (2) modify space utilization in a way that also results in reductions in weight. For these items, weight is a more important factor limiting the number of units per shipment, even though the amount of space that a shipment occupies can theoretically be improved. In these cases it is primarily the practice of weight reduction, not pallet utilization that will lead to improvements in shipping. Alternatively, for product shipments that space out, pallet utilization will typically provide a beneficial means to improve space efficiency, potentially even in cases it also results in increases in weight. Meanwhile, shipments at floor capacity are best improved by focusing on the particular aspects that prevent the maximum use of the available vertical space. However, with only the floor space filled, and not the volume of weight capacity constraints reached for these shipments, methods to improve the use of space—such as pallet utilization—should be considered, in addition to the specific restraints that exist on stacking. For products that will be shipped in partial loads, capacity constraints are less of an issue. Instead, marginal improvements in shipping can potentially alter shipping costs per unit, the size of shipping containers needed, and the number of units of other products that can be combined into shared shipments. For these items, the impacts of small changes in weight and space should be considered for these potential benefits.

10.4 Discussion

The complexities of the supply chain have been illustrated through a discussion of packaging. The current methodologies to assess and improve impacts have specific limitations, due, in part, to the different interpretations of sustainability. For instance, in general considerations of the functionality of components are often lacking in sustainable assessment methodologies. Also discussed here is the role that packaging plays in logistical optimization, as one of many factors influencing the transportation of freight.

Pallet utilization was identified as a practice that can provide manufacturers with a means to achieve cost and environmental benefits. Unlike most sustainable packaging practices, pallet utilization affects packaging and product impacts simultaneously. However, discussions on the nuances of pallet utilization are currently lacking, and at present require further investigation. Here a conceptual methodology for designers and producers to determine the cases in which pallet utilization is most appropriate was provided. Specifically, redesigning packaging to be more space efficient should be considered in most cases, except for products that cause shipments to weigh out. However, for these and other types of shipments, pallet utilization can be an advantageous way to pair multiple products of different densities into shipments so that they better meet the weight and space constraints of the container simultaneously.

However, while pallet utilization provides a means to improve transportation impacts, current environmental assessment methodologies may not recognize such improvements. This can lead to an improper evaluation of transportation impacts. Another implication of this situation is that the opportunities for pallet utilization may not be easy for manufacturers to identify, and as a result packaging designers may be misguided as to when the practice of pallet utilization would be beneficial.

There are also other sustainable packaging practices that may conflict with the overriding imperative of space minimization of improved pallet utilization. For instance, packaging that is made to be reusable, or out of recycled materials, often requires more material. In one study, Europen [54] found that Italian products had the lowest amount of packaging material per unit weight of product, as compared to other countries, because none of the packaging is reusable. A discussion of the comparative impacts of these conflicting practices is needed to determine which of the existing sustainable packaging practices is more advantageous.

While a substantial degree of research has been executed in the field of green and sustainable supply chains, techniques to improve them are slowly emerging. Future work will involve an assessment of the different evaluative methodologies for supply chains in general, and packaging specifically, to determine the role different considerations play in achieving more sustainable sourcing. Continued research is required on the different sustainability practices to achieve products and packaging that are truly sustainable.

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