2A Packaged-Products Weighing 150 lb. (68 kg) or Less

2B Packaged-Products Weighing Over 150 lb. (68 kg)

2C Furniture Packages

3 Series: General Simulation Performance Tests

Designed to provide a laboratory simulation of the general damage-producing motions, forces, conditions and sequences of transport environments. Applicable across broad sets of circumstances, such as a variety of vehicle types and routes or a varying number of handling exposures. Characteristics include simple shaped random vibration, different drop heights applied to the sample package, and/or atmospheric conditioning.

3A Packaged-Products for Parcel Delivery System Shipment, 150 lb. (70 kg) or Less

3B Packaged-Products for Less-than-Truckload (LTL) Shipment

3E Similar Packaged Products in Unitized Loads for Truckload Shipment

3F Packaged Products for Distribution Center to Retail Outlet Shipment, 100 lb. (45 kg) or Less

3H Mechanically Handled Bulk Transport Containers

3K Fast-Moving Consumer Goods in the European Retail Supply Chain

4 Series: Enhanced Simulation Performance Tests

Tailoring testing elements to individual situations while using up-to-date and specific hazard profiles and parameters enables an Enhanced Simulation. ISTA 4AB and PackSight, ISTA's online test planner and report-generating platform, allow users to generate custom test plans that closely tie the tests and sequence to a user-defined pattern of distribution. It includes a broad range of current and quantitative information on distribution environment hazards.

4AB Project: Enhanced Simulation Test of Packaged-Products for Shipment in Known Distribution Channels

PackSight ISTA's online test planner and report-generating platform

6 Series: Member Performance Tests

ISTA 6-Series protocols are Member Performance Tests created to reflect supply chain elements of Global 500 Retailers or Carriers determined by ISTA's Standards Council to be unique, and therefore do not translate well to industry standardization. The tests may be completely original or modifications or variations of ISTA Procedures or Projects or other published and accepted tests.

6-Amazon.com-Over Boxing e-Commerce Fulfillment for Parcel Delivery Shipment

6-Amazon.com-SIOC Ships in Own Container (SIOC) for Amazon.com Distribution System Shipment

6-FEDEX-A FedEx Procedures for Testing Packaged Products Weighing Up To 150 lb. (domestic and in-

	ternational)
6-FEDEX-B	FedEx Procedures for Testing Packaged Products Weighing Over 150 lb. (domestic and international)
6-SAMSCLUB	Project: Packaged-Products for Sam's Club Distribution System Shipment

7 Series: Development Tests

These tests are used in the development of transport packages. They can be used to compare the relative performance of two or more container designs, but are not intended to evaluate the protection afforded packaged products.

7D	Temperature Test for Transport Packaging
7E	Testing Standard for Thermal Transport Packaging Used in Parcel Delivery System Shipment

ASTM Preshipment Testing Procedures

In response to the need for predictive preshipment testing methods, the ASTM developed a set of simulation tests in an all-encompassing D4169, Standard Practice for Performance Testing of Shipping Containers and Systems.

The ASTM method recognizes that different distribution elements impose different hazards on the product and package. It further recognizes that different products might require different levels of assurance against product damage. (See Figure 17.13) A 1% loss of household cleaning sponges may not warrant an increase in packaging, whereas a 1% loss of large flat-screen monitors might be a financial disaster.

The ASTM procedure essentially outlines the elements needed to tailor a preshipment test procedure to a specific need.

To use the procedure, you first identify the nature of the distribution environment you wish to simulate in the laboratory and what the shipping unit will be for different stages of the journey. For example, a unit load may constitute the test unit for part of the program, and an individual container may be used for the remainder.

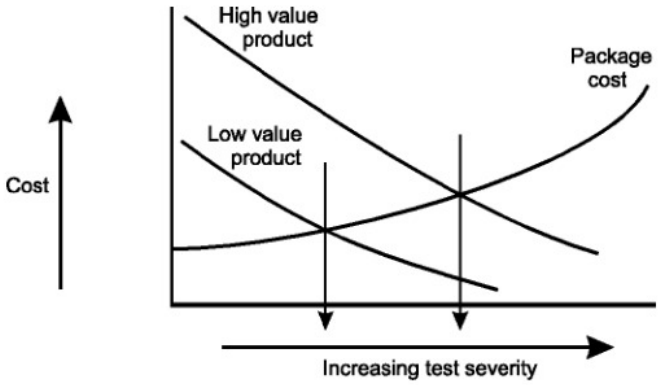


Figure 17.13
Preshipment test severity is related to the value of the contained product, or in the instance of certain hazardous products, the negative consequences of a package failure.

The elements representing those events anticipated in the identified shipping environment and the appropriate assurance level are then selected. A decision as to what constitutes an unacceptable level of damage must be made. The test procedure describes different shipping modes or elements and provides for introducing atmospheric factors at any point in the test program.

ASTM D4169 covers all of the following distribution scenarios:

DC#	Distribution Cycle
1.	General Cycle—undefined distribution system.
2.	Specially defined distribution system, user-specified.
3.	Single package without pallet or skid, LTL motor freight.
4.	Single package with pallet or skid, LTL motor freight.
5.	Motor freight, TL, not unitized.
6.	Motor freight, TL or LTL—unitized.
7.	Rail only, bulk loaded.
8.	Rail only, unitized.
9.	Rail and motor freight, not unitized.
10.	Rail and motor freight, unitized.
11.	Rail, TOFC and COFC.
12.	Air (intercity) and motor freight (local), over 100 lb. (45.4 kg), unitized.
13.	Air (intercity) and motor freight (local), single package up to 100 lb. (45.4 kg).
14.	Warehousing (partial cycle to be added to other cycles as needed).
15.	Export/import shipment for intermodal container or roll-on/roll-off trailer (partial cycle to be added to other cycles as needed).

Table 17.7
Summary of ASTM D4169 distribution testing elements.

Shipping Occurrence	Hazard Element
Handling—manual and mechanical	drop, impact, stability
Warehouse stacking	compression
Vehicle stacking	compression
Stacked vibration	vibration
Vehicle vibration	vibration
Loose-load vibration	repetitive shock
Rail switching	longitudinal shock
Environmental hazard	

16. Export/import shipment for palletized cargo ship (partial cycle to be added to other cycles as needed).
17. Export/import shipment for break bulk cargo ship (partial cycle to be added to other cycles as needed).
18. Non-Commercial Government shipments per MIL-STD-2073-1.

The entire sequential test would be performed when evaluating a new shipping container. Where the package response to a single condition might be needed, only that element needs to be performed. The operator has the option of designing a custom sequence or using one of the 17 predesigned sequences describing the most common distribution cycles.

Table 17.7 shows the Distribution Cycle shipping occurrence and the type of distribution hazards associated with each.

Table 17.8 shows an example of a custom-designed ASTM test cycle for an 11.4-kg (25-lb.) box. Each distribution element has an appropriate simulation of the hazard associated with it. For this example, test conditions are taken from Assurance Level 2, the most commonly used Assurance Level for general merchandise. Assurance Level 1, the most severe, would require drops from 21 inches while Assurance Level 3 would require 8-inch drops. All other test conditions would be similarly adjusted to match the desired Assurance Level.

Table 17.8
Distribution Cycle 2 Custom-Designed Cycle.

Distribution Element	Test Simulation
Manually palletized	5 drops from 13 inches
Warehoused	compression at 4.5 times anticipated load
Road transport of unitized product	vibration: 3–100 hertz—10-minute dwell at resonance points
Rail transport	longitudinal shock: two at 6 mph and one at 4 mph
Warehoused	compression at 4.5 times anticipated load
Manual handling	5 drops from 13 inches
Road transport (loose load)	repetitive shock for 40 minutes
Manual handling	5 drops from 13 inches

REVIEW QUESTIONS

1. At what point in a package design program should distribution packaging be considered?
2. Discuss the dangers of using a sequential approach to package design.
3. What do we mean by the term "fragility" when describing a product? Give specific examples.
4. Define "distribution environment."
5. What do we mean when we say that a load is 87% area-efficient?
6. List some of the considerations you would take into account when designing a distribution package.
7. Shock and vibration are typical distribution environment hazards. List six more.
8. Package damage and loss are normally greater in summer than in winter. Explain why.
9. How would you ensure that your distribution packages are neither overdesigned nor underdesigned?
10. What is the standard pallet size set by the Grocery Manufacturers of America?
11. Under what distribution circumstances might the planned shipping container not be used?
12. The distribution packaging cost is not just the cost of the distribution package. Explain.
13. What problem is inherent to odd-shaped shipping containers?
14. Name three methods of unitized load handling, and comment on the advantages and disadvantages of each.
15. Why should pallet overhang be avoided?
16. What are the extra costs incurred when a product has poor pallet area utilization?
17. List methods of increasing the shipping stability of a palletized unit load.
18. What should be the minimum storage capability of a pallet load according to the Food Marketing Institute?
19. What are the advantages of using ASTM D4169 or an ISTA General Simulation test over ship tests?
20. You are investigating a product that has a poor shipping history. There are three things that might be changed to improve the shipping experience. What are they?
21. What are the ASTM test designations for Vibrating Testing of Shipping Containers, Drop Test of Loaded Containers and Mechanical Shock Fragility of Products?

22. What regulation describes performance requirements of containers for hazardous materials in the United States?

23. Who requires container materials to meet minimum specifications and under what rules?

SHOCK, VIBRATION AND COMPRESSION

18

CONTENTS

Shock

Shock resulting from drops, shock during rail transportation, other shock conditions.

Quantifying Shock Fragility

Forces, acceleration of gravity, ratio of observed acceleration and acceleration of gravity, "*G*," practical effects of *G*, examples of the acceleration and *G* calculation, reducing *G* with resilient materials.

Cushioning Against Shock

Basic shock-cushioning principles, estimating required deflection, static stress, dynamic cushioning curves, required information for calculating protective cushioning geometry, cushioning materials, basic selection criteria.

Vibration

Vibration damage due to relative motion, vibration resonance, stack resonance, random vibration, isolating vibration.

Compression

Static and dynamic compression, compression strength and warehouse stack duration, compression strength and humidity, other factors influencing box stack strength, contents' effect on compression strength, plastic bottle stacking factors.

Estimating Required Compression Strength

Using safety or stacking factors, typical industry stacking factors.

SHOCK, VIBRATION AND COMPRESSION 18

SHOCK

"Shock" is defined as an impact, characterized by a short-duration, relatively high-intensity dynamic event with a sudden change in velocity. For example, a dropped object gains velocity on its way down, then suddenly stops moving when it meets the floor.

Shock is encountered in many places in the distribution environment:

- Accidental and deliberate drops during manual handling.
- Drops from chutes, conveyors and other machinery.
- Falls from pallet loads.
- Sudden arrests on conveyors.
- Impacts occurring when vehicles hit potholes, curbs or railroad tracks.
- Impacts occurring when a package is rolled or tipped over.
- Impacts occurring from package-to-package interaction in various sortation systems.
- Shock due to rail shunting.

Shock Resulting from Drops

Free-fall drops, regardless of the cause, are identical in effect and can be treated as manual drops. Thousands of detailed observations—using instrumented packages or by direct and discreet visual monitoring—determine typical manual handling patterns in a range of shipping situations. (See Figure 18.1) This and other studies show a basic predictability in package handling. Details vary somewhat from study to study in the actual number of drops experienced and the drop heights encountered. These reflect differences in handling modes and practices in the actual distribution environment.

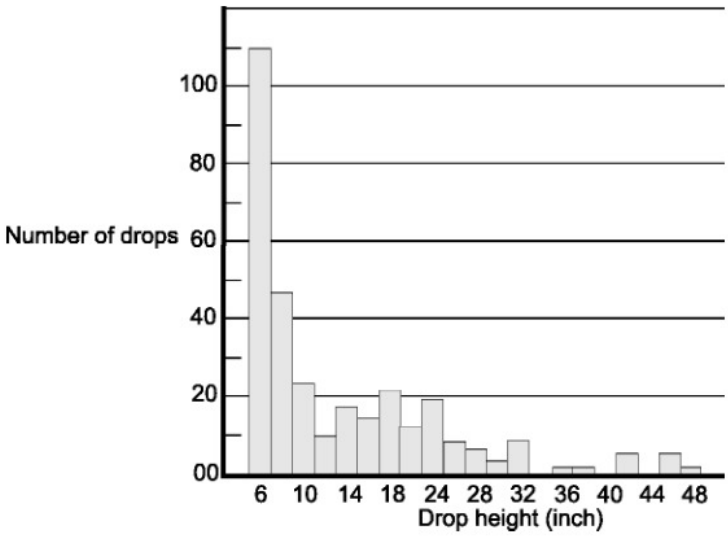


Figure 18.1
Drop height vs. occurrence for a 25-lb. fiberboard box, 16 x 12 x 20 in. Data summarizes 15 test packages sent on 80 trips through various shipping modes. (Source: Ostrem, F. and Godshall, W., FPL Report 22.)

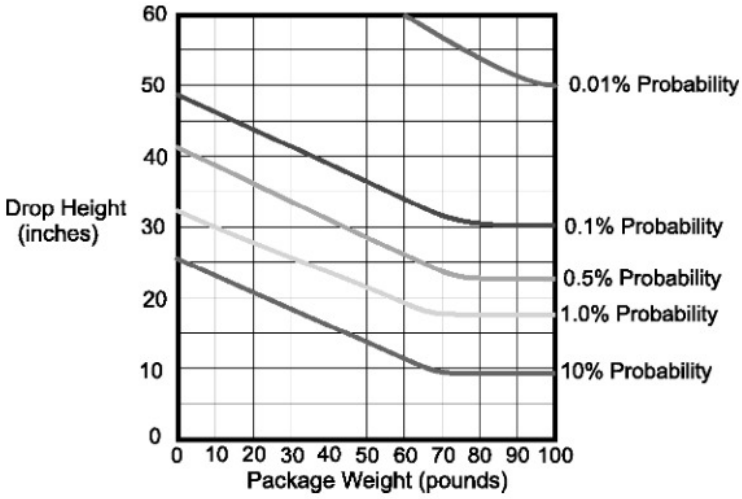


Figure 18.2
Generalized drop-height probability curves. The curves flatten at the point where mechanical handling predominates.

Many such studies have been combined to provide generalized drop probability curves. (See Figure 18.2) This figure illustrates another predictable feature of manual handling: the lighter the package, the higher the probable drop height. This reflects human nature: Lighter packages are more likely to be carried in groups and more likely to be tossed or thrown. Heavy packages cannot be thrown far and usually are handled more carefully to avoid personal injury.

Figure 18.2 and similar correlations determine the probable drop height a given package should be designed to withstand. They are also the basis of preshipment test procedures and provide information for the development of protective packaging systems.

Fundamental lessons learned from such studies are as follows:

- The probability that packages will be dropped from a height of greater than 1 meter (m) (40 inches) is minimal.

- Packages receive many drops from low heights, while few receive more than one drop from greater heights.
- Palletized, wrapped or otherwise unitized loads are subject to fewer drops than individual packages.
- There is little control over drop orientation with small packages. With larger packages, about half of the drops are on the base.
- A heavier package has a lower probable drop height.
- The larger or bulkier the package, the lower the probable drop height.
- Handholds reduce the probable drop height by lowering the container relative to the floor.
- Cautionary labeling (e.g., "Fragile," "This side up," "Handle with care") has only a minor effect. Cautionary labeling does not make up for inadequate packaging.
- Address labels tend to orient the drop to a label-up position, regardless of other instructions.

The usual results of drops and shocks fall into two categories:

- Damage to the package that reduces its protective or containment qualities.
- Damage to the product, typified by bending, distortion, or ultimately, breakage.

Typically, the greatest damage to the container is from edge or corner drops. The greatest damage to the contents is from a flat drop onto one of the faces. Shock frequently can damage the contents without adversely affecting the enclosing container. Usually, this suggests the need for greater cushioning protection rather than an increase in the strength of the enclosing container.

Shock During Rail Transportation

A special shock condition is experienced during railcar coupling. Boxcars are assembled into trains by moving individual cars at some speed against other cars. The average "shunting speed" is 8.4 kilometers per hour (km/hr) (5.2 miles/hr). This is the average speed: Some impacts are at greater speeds! (See Figure 18.3)

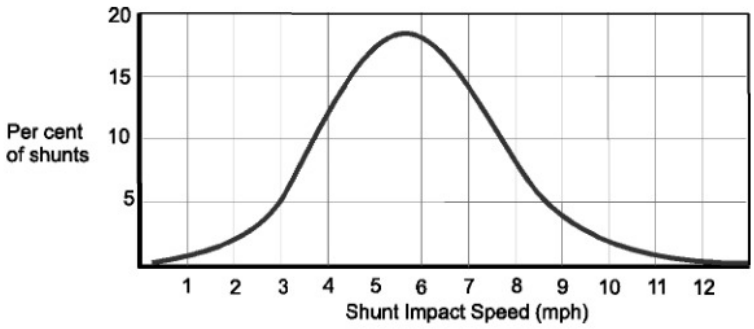


Figure 18.3
Distribution of rail coupling speeds. (Source: New York Central Railway.)

Rail damages are probably due more to load shifts and the effects of dynamic compression than actual shock forces. Good loading, bracing and securing practices can reduce rail damage substantially. Trailer-on-flat-car (TOFC) shipping may be gentler than regular boxcar shipping, because TOFC trains are not assembled by shunting. Instead, they are loaded after the cars have been assembled into a train.

Other Shock Conditions

Shock also occurs during the bumps and bangs typical of mechanical handling and transport. Usually, the degree of shock is not as great as that experienced during manual handling and free-fall drops. Generally, a package that will withstand manual handling shocks will survive mechanical handling.

"Repetitive shock" describes the low-frequency bouncing or rattling around that a product experiences if shipped as an unsecured load. The shock input of "loose-load" conditions is low and not likely to cause typical shock damage. However, abrasion can occur, and if the product is in resonance with the input frequency, various forms of mechanical damage may develop. These, however, are better described as vibration-induced damage.

The small-parcel shipping environment (parcel post and parcel courier) represents a special environment. The packages are almost always less than 20 kg (44 lb.) and not unitized. They undergo considerable manual handling, resulting in a higher average number of impacts and drops. This presents both the user and transporter with the most unfavorable situation possible. The use of highly automated conveying and sorting systems complicates matters further. Automatic handling systems do not read cautionary labeling.

QUANTIFYING SHOCK FRAGILITY

Essential to the design of packages that will provide protection against shock damage is the knowledge of the product's fragility or sturdiness. A suitable, cost-effective cushioning system is an engineered structure based on the product's quantified ability to withstand shock.

One way to quantify shock fragility is to measure the drop height at which damage starts to occur. However, quantifying shock fragility in terms of drop height is useful only if no additional protection is anticipated. This is helpful for products that may experience drops in their use environment, such as cell phones, consumer electronics and laptop computers.

For products that are to be cushioned, packaging engineers use "critical acceleration" or "*G*" levels to describe an object's tendency to break when subjected to shock. An object will break when it is subjected to a force greater than its structure can bear:

$$F = ma$$

Where: F = force, m = mass, a = acceleration.

Acceleration and deceleration are measures of the time rate of velocity change, and the forces are the same whether the object is accelerating or decelerating; only

the direction changes. The most common measure of acceleration is "*g*," or gravity, determined to be 9.81 meters/second squared (m/sec^2) or 32.2 feet/sec^2).

G is the ratio of observed acceleration to the acceleration due to gravity:

$$G = \frac{\text{observed acceleration}}{\text{acceleration of gravity}}$$

A person encountering 2 *G* would experience an acceleration twice that of normal gravity. The physical sensation would be a feeling of weighing twice as much as normal. At 3 *G*, a person would experience three times his or her normal weight. Since mass is constant for a given packaging problem, force is directly proportional to *G*.

If a 0.2-kg (7-oz.) coffee cup were dropped from 1 m (39 inches), at the moment it reached the floor, its velocity would be 4.43 m/sec. If in hitting the floor, it lost its velocity (decelerated) in 0.002 sec, the deceleration could be calculated to be 2,215 m/sec. Expressing this as a ratio to normal gravity would give a *G* level of 225. At the moment of impact, the cup would, in effect, weigh 225 times normal—44.8 kg. Unless it was a very unusual cup, it would break.

If the cup were dropped onto a sponge pad, the impact velocity would remain the same. However, on impact the sponge pad would deflect, and the time over which the cup lost velocity would be extended. The deceleration would not be as severe, the stop not as abrupt. If the cup now stopped in 0.008 sec, the *G* level would be 56. Another sponge layer might increase the deceleration time to 0.01 sec, and the cup would experience 45 *G*. Adding still more layers would eventually reduce the *G* level to the point where the cup would not break. This would be one way of determining what cushioning protection the cup needed to protect it from a 1-m drop.

However, if the *G* level that would break the cup were known in advance, that is, if its fragility factor in *G* were known, it would not be necessary to conduct the drop experiments. The cushioning needed could be determined by simple mathematics. The cup example shows that time is needed over which to dissipate the impact velocity, and that this time is gained by the deflection of a resilient cushioning material. This is the basic principle of cushioning against shock.

A quick estimate of cushioning material thickness can be made if the cushion material is treated as a linear, undampened spring. The deflection necessary to maintain a desired acceleration is calculated as follows:

$$D = \frac{2h}{(G - 2)}$$

Where:

D = required deflection,
h = anticipated drop height,
G = fragility level (critical acceleration)

This formula provides the minimum distance over which the deceleration must take place in order not to exceed the critical acceleration. For example, for a product with a fragility factor of 40 *G* and an anticipated 1-m drop,

$$D = \frac{2 \times 1\text{m}}{(40 - 2)} = 0.053\text{m } (2.1 \text{ in.})$$

The 53-millimeter (mm) (2.1-inch) deflection is the minimum stopping distance consistent with maintaining 40 *G* or less. Stopping in any lesser distance would raise acceleration to more than 40 *G* and cause damage. The 53-mm deflection is the theoretical deflection distance, not the cushion thickness. To determine actual cushion thickness, it is necessary to know how far the proposed material will compress before reaching maximum strength, or "bottoming out."

"Static-stress working range" refers to the load-per-unit area that will cause a resilient material to deflect, but not flatten completely. Static-load ranges can be found in supplier technical data sheets. With the correct static-stress level, the cushion estimate can be completed. For this example, typical optimum strains for three commonly used cushioning materials are on the order of the following:

Expanded polystyrene	40%
Expanded polyethylene	50%
Expanded polyurethane	70%

The theoretical deflection distance arrived at above now can be used to estimate the required thickness for three materials: 132 mm (5.2 inches) of polystyrene, 106 mm (4.2 inches) of polyethylene or 76 mm (3 inches) of polyurethane foam.

More accurate estimates of cushioning thickness can be made using dynamic-cushioning curves available for most cushioning materials. The information necessary to make these calculations using dynamic cushioning curves is:

- Product size and mass.
- Product fragility, expressed in *G*.
- Anticipated drop height.

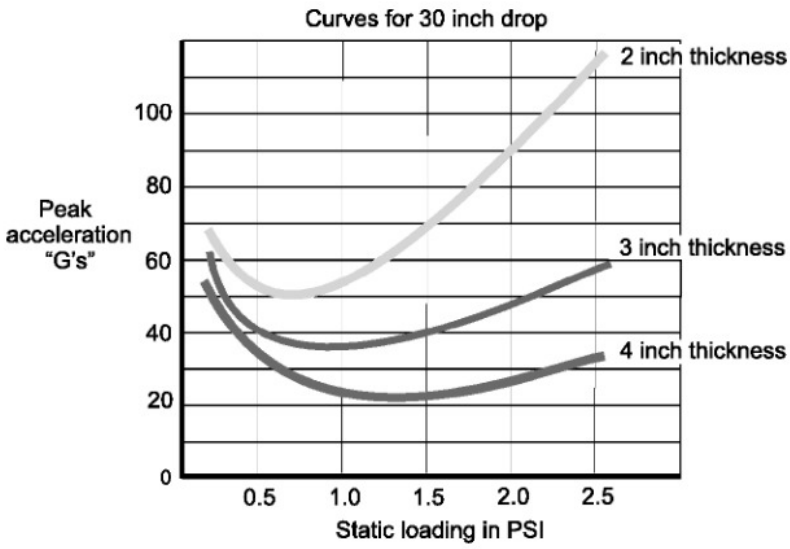


Figure 18.4
An example of a dynamic-cushioning curve. A complete set of curves would have dynamic-cushioning curves for a range of drop heights.

Table 18.1
Typical fragility factor classes. A manufacturer would be advised to consider redesign of any product with a fragility level of less than about 30 *G*.

G Factor	Classed as	Examples
15–25 *G*	Extremely fragile	Precision instruments, early computer hard drives
25–40 *G*	Fragile	Bench top, floor-standing instruments, electronics
40–60 *G*	Stable	Cash registers, office equipment, desktop computers
65–85 *G*	Durable	Television sets, appliances, printers
85–110 *G*	Rugged	Machinery, durable appliances, power supplies, monitors
110 *G*	Portable	Laptop computers, optical readers
150 *G*	Handheld	Calculators, telephones, microphones, radios

Source: Robert M. Fiedler, Robert M. Fiedler and Associates.

To use dynamic-cushioning curves, locate the curve that is crossed in two places by the critical acceleration (*G*) line. For example, if a device had a critical acceleration of 50 *G*, then the 3-inch curve would be selected from the curves in Figure 18.4. This curve tells us that a 3-inch thickness of the cushioning material represented by the curve would provide the required protection, providing that the material was loaded to at least 0.4 lb. per square inch (psi) (the first crossing of the *G* line), but not more than 1.8 psi (the second crossing of the *G* line).

If a chosen cushion area resulted in less than a 0.4-psi load, then the product would not have enough mass to cause the cushion to deflect. On the other hand, if a small cushioning material area gave a loading of more than 1.8 psi, then the cushion would be partially or completely flattened and no longer capable of sufficient deflection. For this example, we might choose to load the cushioning material to 1.5 psi. If the product weighed 15 lb., then a cushioning area of 18 square inches would provide the required deflection.

Understanding shock and *G* will help you to understand many shipping damages. For example, a refrigerator shipped by rail has a compressor-motor assembly weighing 15 kg (33 lb.). The designer felt safe in securing this assembly to the frame with three fasteners capable of holding 120 kg (264 lb.), an ample safety factor. However, during shipping, the refrigerator experiences a 10-*G* shock, and during that brief moment, the motor behaves as if it had a mass of 150 kg (330 lb.). Since the three mounting fasteners can hold only a total of 120 kg (264 lb.), they may shear off.

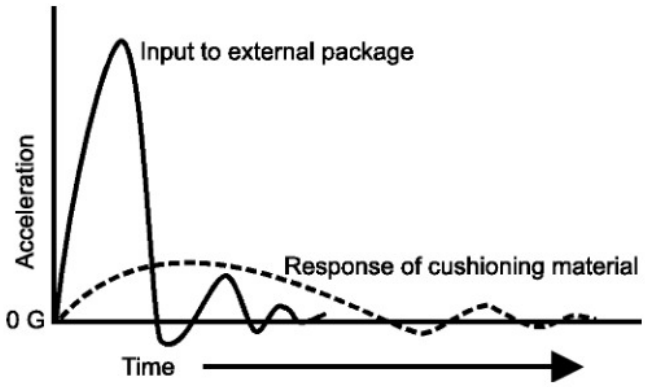


Figure 18.5
A cushioning material attenuates the initial shock pulse at the package's surface, so that the product's response takes place over a longer period of time. The areas under the curves represent energy.

The refrigerator sidewall, with a bearing area of 1.5 square meters (15.7 square feet), and the shipping box are able to distribute the load of a unit suddenly weighing 10 times more. With no external evidence of damage, the refrigerator is accepted at the receiver's dock and by the retailer. The problem is discovered only when the consumer plugs it in.

Sophisticated manufacturers know the *G* factor for all their products. In many instances, they will redesign products to accept higher *G* levels, knowing that savings in protective materials, and the goodwill generated by satisfied customers, will more than repay the added engineering costs. Table 18.1 shows some typical *G* factor ranges.

Fragility may greatly depend on how the force is transmitted to the product. And egg on a flat surface has a fragility of 35 to 50 *G*, depending on the axis of the impact. If the egg is supported to a conforming surface, its fragility can exceed 150 *G*.

CUSHIONING AGAINST SHOCK

Any material that will deflect under applied load can act as a cushioning material. By deflecting, the cushioning material attenuates the peak *G* level experience by the product compared with the shock pulse at the package surface. (See Figure 18.5) Many materials are capable of attenuating shock. Limitations imposed by the product, process or environment generally reduce the choices to a manageable few.

Premolded shapes are one option, but the cost of molds, typically starting at $12,000, restricts their use to high-volume production. Fabricated shapes, those cut and assembled from flat planks, are usually the choice for intermediate volumes. Loose-fill, foam-in-place and bubble pads are used for low-volume requirements or situations where nearly every shipment is unique.

Cushioning materials can be divided into those based on cellulosic materials and on synthetic or polymeric materials. Cellulose-based cushioning materials are generally the most economical and include:

cellulose wadding	excelsior fill	corrugated inserts
molded pulp	indented kraft	newspaper

CAUTIONARY NOTE

The explanations for shock provided in this text are simplified. Proper consideration of shock protection takes into account not only peak *G* but also velocity changes. (These two factors usually are represented by a "damage-boundary curve." For more information on damage-boundary curves, see ASTM D3332.) The proper method of quantifying shock fragility is through the use of a shock test machine. This device is capable of providing a shock pulse of an accurately defined amplitude, duration and shape.

The shock absorption, resiliency and cleanliness of these materials range from poor to fair. Some paper-based products are corrosive and should not be used with bare metal parts. Since all cellulose materials are hygroscopic, the cushioning characteristics will change as humidity changes.

Many cellulose-based materials, particularly corrugated fiberboard, are quite abrasive and can scuff or polish finished surfaces. Corrugated fiberboard and rigid foams provide product protection by virtue of their own collapse. Their effectiveness is reduced after one major shock.

Polymeric-based materials include:

- expanded polyethylene
- expanded polystyrene
- air bubble sheet
- foam-in-place polyurethane
- expanded polypropylene
- polystyrene loose-fill
- expanded polyurethane foam

Polymeric materials have wide design latitude, and most polymeric cushioning materials can be produced in a range of densities and resiliencies. As a class, they are clean materials and have few or no corrosive properties. All plastic materials contribute to static problems unless they are specially treated. The resiliency of some plastic materials can change dramatically with temperature and altitude.

Polymeric cushioning materials are not hygroscopic; however, some open-cell foams (typically polyurethane) will absorb liquid if they are wetted.

Loose-fills are useful for random product packing, but difficult to place under large overhangs and subject to settling during transport. In some instances, loose-fill can be recovered for reuse. In response to environmental issues, loose-fills based on expanded starches have been proposed. Starch-based fills have shortcomings similar to cellulose-based products, plus may attract rodents and other vermin.

Foam-in-place urethane cushioning material is made by mixing two reactive liquid chemicals (an isocyanate and a glycol) as they are ejected through an applicator. The two materials react almost immediately and begin to expand into a foam-like structure. During the foaming stage, the urethane is soft and pliable, but quickly stiffens to a more semirigid state.

In use, urethane would be sprayed into the bottom of a box, and a protective plastic film would be draped over it. (See Figure 18.6) The object to be enclosed would be pressed into the still-soft, yielding foam. A second protective sheet would then be draped over the object and more foam applied to create the protective form's top half.

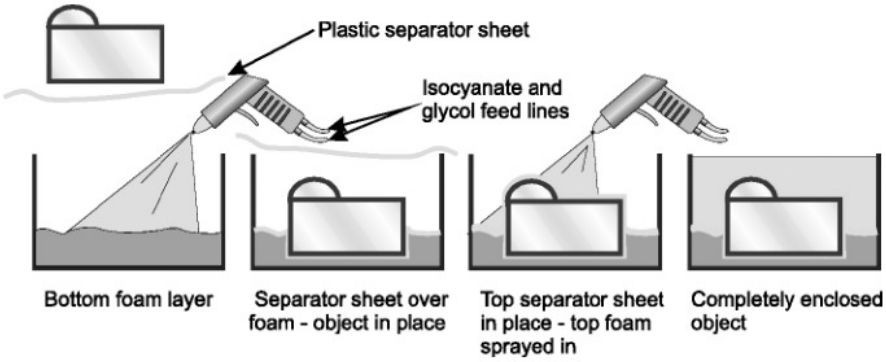


Figure 18.6
Application of foamed-in-place urethane cushioning.

Foam-in-place urethane cushioning is versatile and custom-made; form-fitting shapes are easily fabricated. However, it is labor intensive and generally used only in lower volume or "one-off" applications.

VIBRATION

"Vibration" describes an oscillation or motion about a fixed reference point. The distance moved about the reference point is the "amplitude," and the number of oscillations per second, expressed as hertz, is the "frequency."

Vibration is associated with all transportation modes, with each mode having characteristic frequencies and amplitudes. Typically, the higher the frequency, the lower the amplitude. Frequencies above 100 hertz are of little concern to most packagers, because in most packaging situations, the product will be isolated (i.e., its vibrational output will be less than the input received) at these higher frequencies. The most troublesome frequencies are below 30 hertz, because they are the most prevalent in vehicles, and it is difficult to isolate products from them.

Vehicle vibrations come from many sources. Truck vibrations occur predominantly at the natural frequencies of the load on the suspension system, of the unsprung mass of the tires against the suspension system and of the trailer and body structure. (See Figure 18.7) They are excited by the condition and irregularities of the

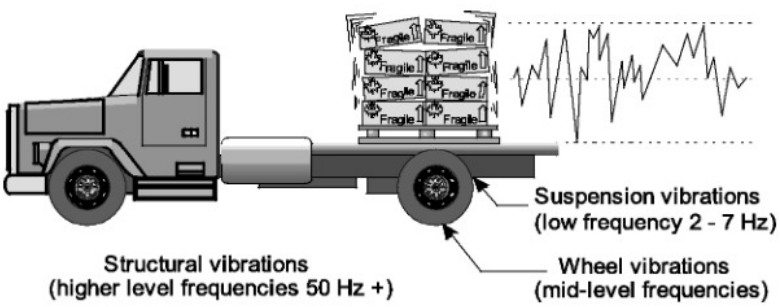


Figure 18.7
Typical sources of truck-bed vibrations.

roadbed, the engine and drive train, tire and wheel imbalance, and the dynamics of lading (freight).

During vibration, an object is constantly being accelerated and decelerated as it moves through the vibration cycle. Since an acceleration can be described by its *G* level, one dimension of vibration is its *G* level. Vibrations at identical frequencies will have greater *G* levels at greater displacements or amplitudes.

Vibration Damage Due to Relative Motion

Vibration damage can take several forms. Scuffing and abrasion can occur when one part is free to move against another. Designs affording point contact and those allowing movement against corrugated fiberboard surfaces are particularly prone to abrasion. Abrasion is sometimes aided by external substances, often dust from the product itself (e.g., detergent powders). Scuffing is primarily objectionable on labels and graphics.

Reducing or eliminating relative motion lessens this type of vibration damage. Tight box dimensions, particularly in the vertical axis, are preferred wherever this is compatible with top-load compression of the product and package. Good bottle design incorporates recessed label areas. In other instances, hard surface varnishes protect graphics. Some printing inks are soft and particularly prone to scuffing. In designs where scuffing may be a problem, these inks should be avoided or protected.

Soft, nonabrasive plastic or cellulose wraps can protect finished and painted parts. Coatings are available to reduce the abrasive character of corrugated board surfaces. Wax coating is the simplest and most economical of these, but is less common today because it affects the recyclability of the corrugated.

Many particulate products sift or settle when vibrated. This leaves open voids at the tops of bottles and paperboard cartons that consumers invariably interpret as an underfill. Many products are shipped inverted so that settling and compaction take place against the container top. Consumers opening such containers usually see a fill almost level with the top.

Vibration Resonance

The spring/mass relationship between an input vibration and the response of a mass can have three outcomes:

- Output equals input — direct coupling (e.g., input amplitude = 6 mm, output amplitude = 6 mm).
- Output is greater than input — resonance (e.g., input amplitude = 6 mm, output amplitude = 12 mm).
- Output is less than input — isolation (e.g., input amplitude = 6 mm, output amplitude = 0).

"Resonance," the condition where a vibration input is amplified, is the key packaging concern. In some instances, the end result is an output out of all proportion to the input. For example, at resonance, a 10-mm (3/8-inch) input amplitude might be amplified to produce a movement of 25 to 40 mm (1 to 1.5 inch).

A property of all spring/mass systems is that they have a unique frequency at which they will go into resonance. Resonance occurs whenever the "forcing" (input) frequency is the same as the product's or packaging system's natural resonance frequency. Resonance exists not only for the total assembly, but also for parts or subsections within the total structure.

For protective packaging purposes, all resonance points should be located and quantified. This is done by subjecting the product to a range of frequencies using a programmable vibration table and observing the frequencies at which resonance occurs. For packaging, a typical resonance search might sweep frequencies between 3 hertz and 100 hertz at 0.5 to 1.0 octave per minute (refer to ASTM D999). The search should be done in all axes.

Identifying resonance damage is usually straightforward once the principles are understood. As with shock, resonance damage can occur without visible external signs of abuse.

The energy developed on the output side during resonance can:

- Fatigue and eventually fracture metal cans and pails.
- Flex and crack delicate circuits on circuit boards.
- Disintegrate or otherwise alter the texture of food products.
- Separate and settle granular components in a food product or settle loose protective fill.
- Aggravate scuffing and abrasion problems by several orders of magnitude.
- Cause individual containers or components to bang into one another.
- Disturb pallet patterns or dunnage (load-securing) systems.
- Initiate stack resonance.
- Unscrew bottle caps and threaded fasteners.

The greatest vibration input in a typical truck is directly over the rear wheels and tailgate. If damage is restricted to or is the severest in this section of the vehicle, vibrational inputs are almost certainly the cause. Vibrational inputs are usually the source if damage seems to occur only in the product layer next to the pallet or on the top layers.

Damage caused by resonance vibration can be difficult to resolve. The problem is complicated in that all cushioning materials are resilient, and while acting to attenuate shock, they also are acting as a spring in response to vibrational input. For many applications, redesigning the product to eliminate critical resonance points is the most cost-effective method of decreasing damage. The last resort is a vibration-isolating cushioning system.

Stack Resonance

Occasionally, entire loads go into a "stack resonance" condition, where each succeeding container goes into resonance with the previous container until the entire stack is bouncing, creating conditions of extraordinary destructiveness. (See Figure 18.8)

For example, if a truck bed moves at an amplitude of 5 mm and the bottom container goes into resonance, it might reach an amplitude of 10 mm. The input

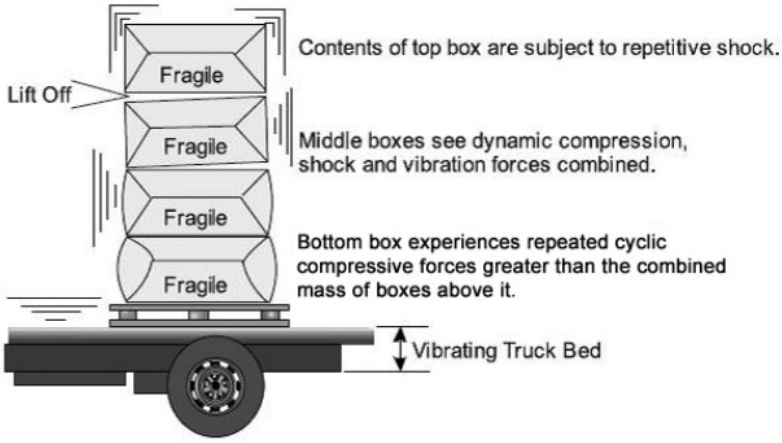


Figure 18.8
In stack resonance, the entire stack is bouncing, creating a destructive condition.

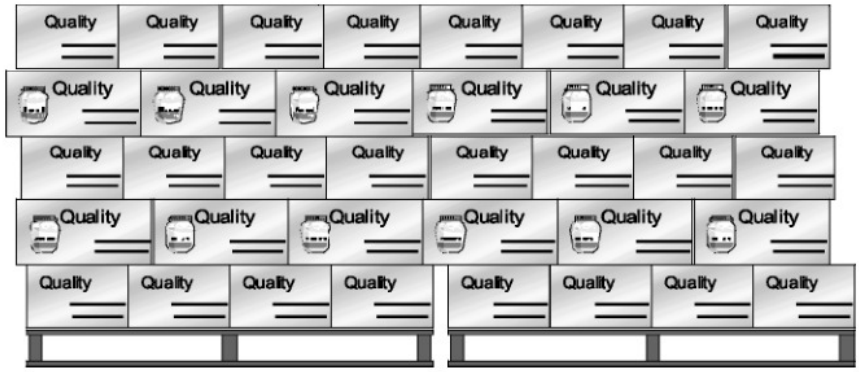


Figure 18.9
Skewing of a load may cause boxes in adjacent loads to interlock.

into the second container in the stack is now 10 mm, and when it goes into resonance, movement might be 20 mm. That amplitude is multiplied as it goes up the stack until the top container actually bounces off the top of the load.

The dynamic load on the bottom container in such a system can be several orders of magnitude greater than the actual weight resting on it. The top container is subjected to extremes of repetitive shock and vibrations. Since the top layer in a unitized load is essentially weightless for short periods of time, small side loads, such as a bump from the side, will cause it to "float," or move. In a stretch-wrapped load, this tendency for the top layer to move can lean or skew the entire pallet load to one side. Individual boxes sometimes will interlock into the adjacent pallet, making it difficult to pick up a pallet without disrupting or damaging neighboring loads. (See Figure 18.9)

Random Vibration

Vibration in transport vehicles is not sinusoidal, or discrete, but is a mixture of frequencies and amplitudes. The frequencies are constantly changing, as are the intensities, as the speed and road or other factors change.

General characteristics have emerged as various modes of transport have been analyzed. Random vibration profiles have been developed in the form of power spectral density (PSD) plots, which show the average vibration intensity vs. frequency. These are used in the test lab to simulate the effects of vibration in transit. Figure 18.10 is an example of actual vehicle vibration as measured in a trailer moving at highway speeds on an interstate road.

Isolating Vibration

Materials used to isolate vibration are for the most part the same as those used to isolate shock. However, cushioning materials, like all other springs, also have characteristic resonance points. Vibrational response curves are available for many resilient materials.

A material with the characteristics such as those shown in Figure 18.10 could be used effectively to isolate vibrational inputs over 100 hertz. The amplification between 40 and 100 hertz is not necessarily a problem, provided the product has no response in that range. If by bad choice this is where the product resonates, damage is almost certain. Below 40 hertz there is direct coupling, and the product will not see any worse vibration than the input level.

A properly selected isolation material resonates at an input frequency that is less than half of the product's resonance frequency. For example, if a product has a major resonance at 48 hertz, the isolation material should resonate at less than 24 hertz.

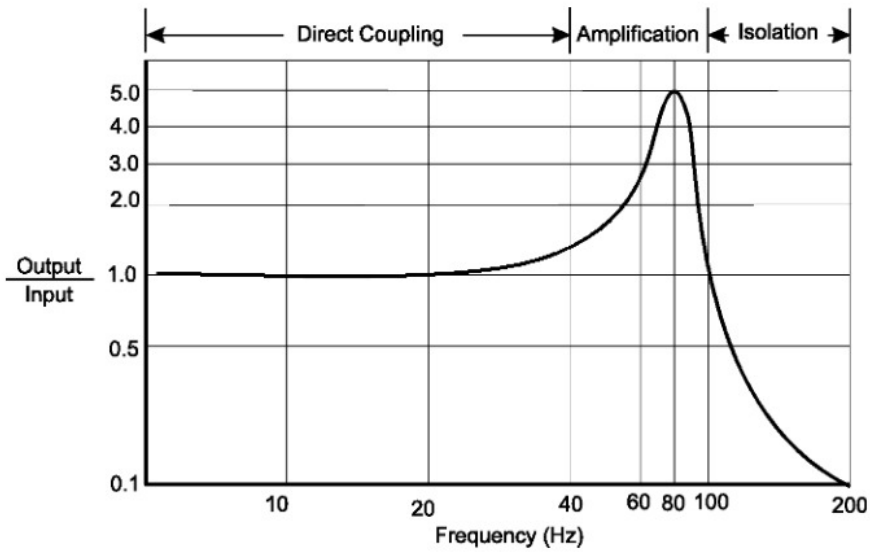


Figure 18.10
Vibration response curve for 175-lb., C-flute pad at 0.5-psi static load. The three conditions—direct coupling, resonance (amplification) and isolation—can be identified clearly.

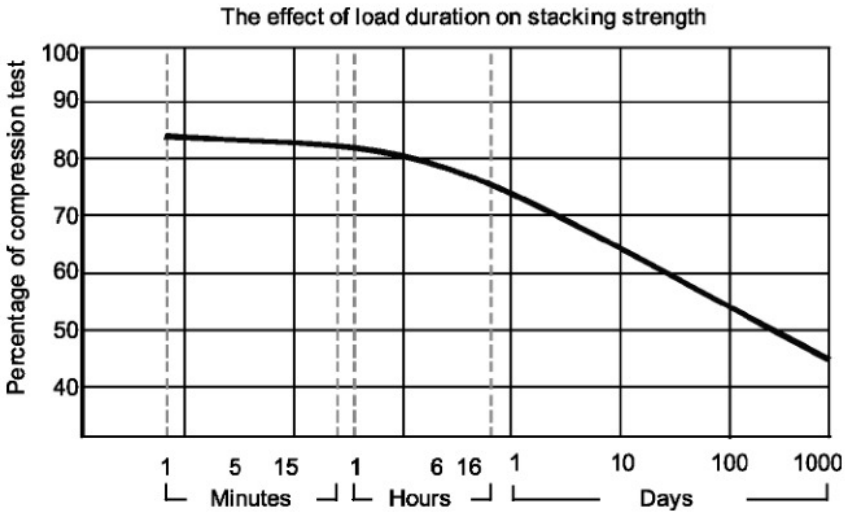


Figure 18.11
The compression strength of corrugated board falls off with time. This graph relates dynamic compression (laboratory) to static compression (warehouse) (Source: Kellicutt and Landt, *Basic Design Data for the Use of Fiberboard Shipping Containers*, Forest Products Laboratory, Madison, Wis. FPL D 1911.)

COMPRESSION

Static and Dynamic Compression

Most products are stacked during warehousing and shipping. It is important for a container to bear static compression loads safely without damage to the product or container. Static compression is determined by conducting dead-load stacking tests.

"Dynamic compression" describes a condition where the compression load is applied at a rapid rate. Dynamic compression is experienced during clamp-truck operations, rail shipping and stack resonance, as well as during normal transit. According to railroad authorities, longitudinal dynamic compression forces, developed by the movement of backload against a railcar bulkhead, can exceed 1,400 lb. per square foot in a standard draft boxcar at typical shunting speeds.

Most standard laboratory compression tests are dynamic in nature. Fiberboard containers are able to bear dynamic loads almost as high as the determined compression strength, but only for a short duration.

Apparent compression strength is affected by the load application rate. Rapidly loading a viscoelastic material will give a higher apparent strength than when the material is loaded slowly. To ensure that data are comparable among laboratories, compression test load rates have been standardized to 12.7 mm per minute (/min), ± 2.5 mm (5.0 inch/min ± 0.1 inch).

Compression Strength and Warehouse Stack Duration

The warehouse condition is one of static loading over time, and a true test would involve replicating the warehouse condition. However, quick answers are usually needed for predicting safe warehouse stack duration or evaluating new container designs. The laboratory compression test is completed within minutes; it is a dynamic test.

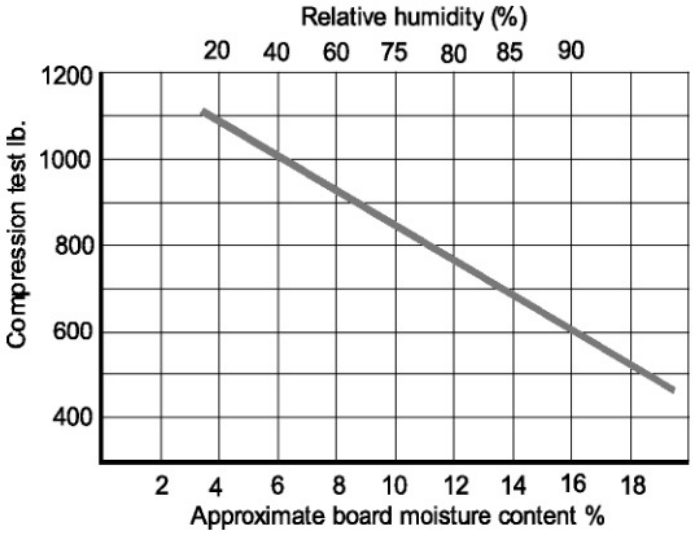


Figure 18.12
The compression strength of a corrugated box drops off rapidly as humidity (and corresponding board moisture content) rises.

Compression strength (a dynamic value) is not the load that can safely be applied in the warehouse. Stacking strength (a static value) for a given situation can be estimated from Figure 18.11, which relates dynamic and static loading conditions. The initial part of the figure's curve shows what the container will bear under dynamic, or short-term, load applications. If 85 kg of product were stacked on a box with a compression strength of 100-kg load, the box would fail after about 10 minutes. The same container would fail in about 10 days if loaded to 60 kg. If the container is to last 100 days, the stack load should not exceed 55% of the dynamic compression-test value.

Compression Strength and Humidity

Paper is a hygroscopic material, and the paper's moisture content can range from about 3% to more than 18%, depending on the humidity of the surrounding atmosphere. A change in relative humidity (R.H.) from 40% to 90% can result in a loss of about 50% of a corrugated container's stack strength. (See Figure 18.12) Corrugated containers destined for humid conditions may need excess stack strength to compensate for this loss.

Since the physical properties of paper change dramatically with moisture content, all paper tests are conducted at standard temperature and humidity conditions. Container compression strength is normally given as a load to failure at 50% R.H. and 23°C.

Figure 18.13 is a chart for estimating the compression strength of corrugated board at different moisture levels. To use this chart, make a line from the compression strength to the board moisture content. Mark the point where the line crosses the pivot line. Now project the line from the new moisture content through the pivot line mark, and read the new compression strength. (The moisture content of paper at different R.H. levels can be found in Chapter 6, Paper and Paperboard, Table 6.3.)

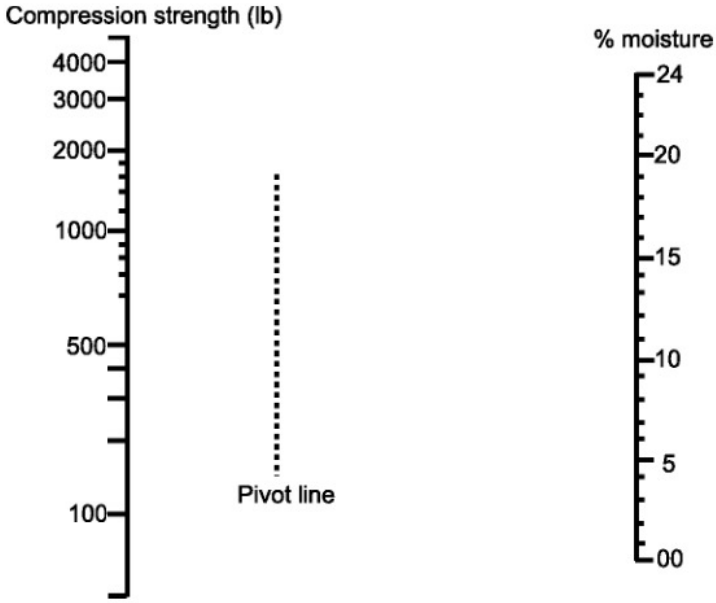


Figure 18.13
Chart for estimating compression strengths at different board moisture levels. (Source: FPL.)

Other Factors Influencing Box Stack Strength

In situations where the contents do not contribute to the compression strength of a container, compression strength is mostly a function of the wall perimeter, with the greatest contribution being made by the four corners. (See Figure 18.14) A box will fail at loads far below the measured compression strength if loads are applied unevenly at points away from corners or in a concentrated area. Thus, in addition to the total compressive load, one must consider the load per unit perimeter length and load distribution.

Laboratory compression tests are conducted on new, undamaged containers. Consider, however, the effect on stack strength of clamp-truck handling that creases container side panels or of strapping used to secure the pallet load that cuts into the edges of all corner boxes. Such damage, precisely at the container's most important point, dramatically reduces available load-bearing ability. Higher initial compression strength is needed when warehousing follows a long journey or rough handling, since the container will have experienced attrition factors that will have an accumulated effect on load-bearing ability. Lower initial compression strengths can be used only in those instances where the product has a short distribution cycle.

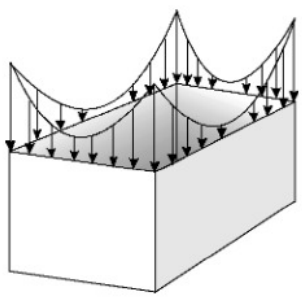
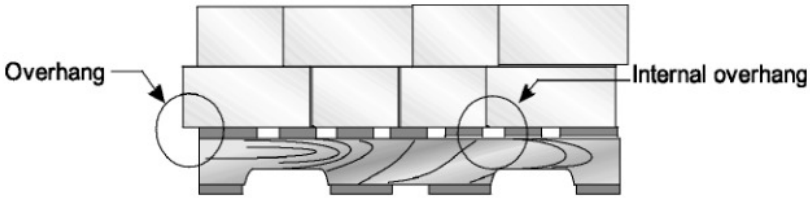


Figure 18.14
Distribution of load-bearing ability around a box perimeter. The length of the arrow is proportional to the load-bearing strength at that point.



Degree of Overhang	% Loss
1 inch one side	14 - 34
2 inch one side	22 - 43
1 inch one end	4 - 28
2 inch one end	9 - 46
1 inch side & end	27 - 43
2 inch side & end	34 - 46

Figure 18.15
Effect of overhang on compression stack strength.

Compression strengths normally are measured as the full bearing area on both the container top and bottom. However, most pallets are decked with boards, and therefore, the bottom container does not have full support over its base. Without this full support, a proportion of the stack strength is lost. Single-face pallet stringers produce a much greater unit-area load on the topmost container of a pallet underneath it. Such loads may be three to four times greater than that assumed for the bottom container in a stack, resulting in unanticipated damage.

Most shipping containers are designed to provide maximum vertical stack strength, since this is the common warehouse condition. Dynamic compression by clamp trucks and rail shunting is in the longitudinal direction, normally the container's weaker axis.

The best possible use of container load-bearing ability is when boxes are stacked directly on top of each other in a vertical column. Unfortunately, column stacking is the least stable technique, and other stacking patterns are used to provide better load stability or cube utilization. Each palletizing pattern has a different total stacking strength.

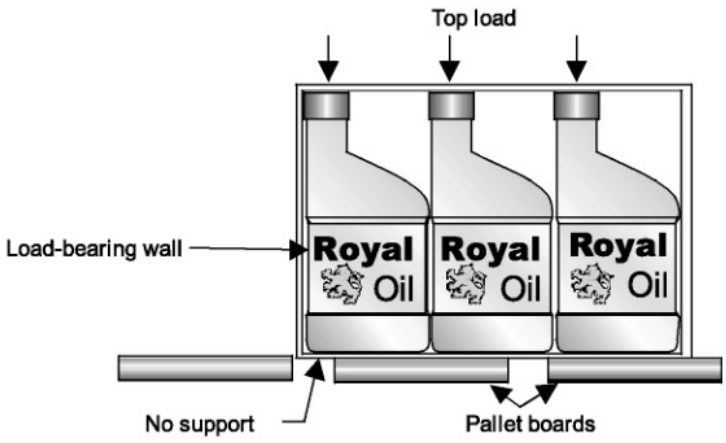


Figure 18.16
Overhanging of asymmetrical supporting contents can have a major impact on a container's calculated ability to hold a load.

Allowing boxes to overhang the edge of the pallet leaves the load-bearing walls of the boxes suspended in midair. Pallet overhang is often deliberate, but is rarely a good idea. Inadvertent overhang can occur internally because of pallet board geometries relative to container size. Typical loss of available compression strength as a result of overhang is shown in Figure 18.15. The asymmetrical nature of the oil bottles, shown in Figure 18.16, can result in overhang of the major load-bearing bottle wall segment. The available bottle compression strength is a fraction of the measured value.

Contents' Effect on Compression Strength

Often times, the shipping container's contents provide some portion of the load-bearing ability. For shrink-wrapped trays, the contents must bear the entire stacking load. Contents sometimes increase apparent compression strength even though they do not apparently support a load. The usual reason is that the contents prevent the container sidewalls from buckling inward, thus delaying the failure point.

Contents also can reduce compression strength. Bag-in-box systems and flexible primary packages containing liquids or semisolids, such as cheese or premixed grouting, exert varying degrees of hydrostatic pressure perpendicular to the vertical container wall. Hydrostatic pressure appears as an outward bulge slightly below the sidewall's midpoint and is greatest at the bottom of the box. Supporting walls become bowed rather than perpendicular, with a corresponding loss of compression strength. (See Figure 18.17)

Where various components contribute to total compression strength, good design calls for the individual components to act collectively. Maximum strength is gained when all components have the same failure point. For example, if a plastic bottle and a partition are expected to contribute to a corrugated container's overall compression strength, the three should be sized so they fail as a single unit. (See Figure 18.18)

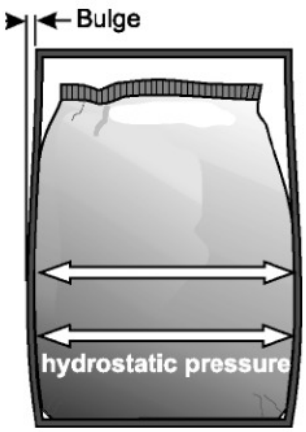


Figure 18.17
Bag-in-box systems reduce compression strength by bowing out the sidewalls.

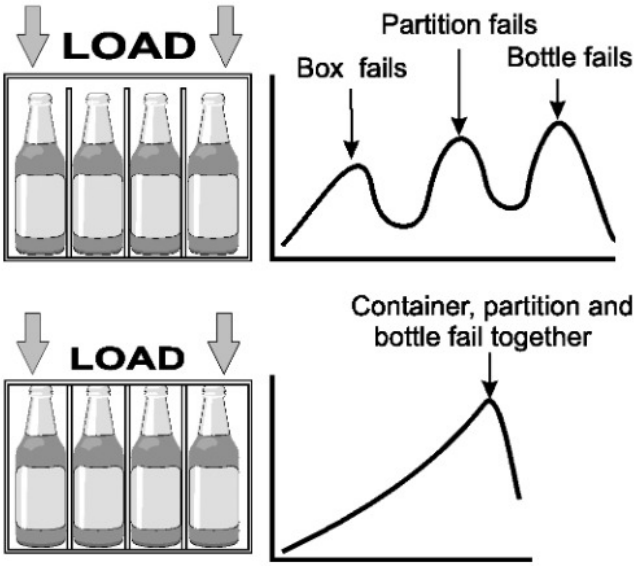


Figure 18.18
The highest compression strength in a multi-component system is achieved when all components act together. Top example shows separate failures, while the bottom example shows simultaneous failure at a higher compression.

Plastic Bottle Stacking Factors

Plastic bottles are expected to contribute compression strength in some shipper designs. This practice is acceptable provided that the plastic's viscoelastic, or "creep," property is taken into account. With plastic, as with corrugated board, the dynamic compression strength must be related to static warehouse conditions.

Stack duration for polyethylene bottles can be estimated using the bottle-to-load ratio. (See Figure 18.19) This ratio consists of the expected load over the compression strength. A bottle with a compression strength of 10 kg and loaded with 3.1 kg would have a load ratio of 0.31. It could be expected to last about 180 days under this loading.

Carefully review the design of any proposed plastic container. Avoid features such a sharp corners, edges or small-radius curves since they act as stress concentrators and promote flex cracking. Containers that are expected to contribute to load bearing usu-

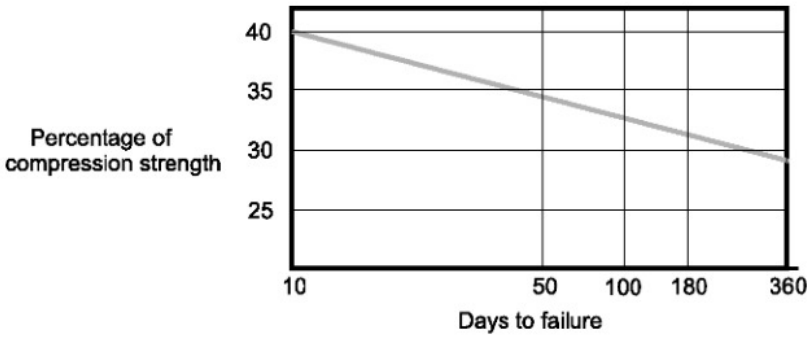


Figure 18.19
Warehouse stacking and load ratios for polyethylene bottles. (Source: Society of the Plastics Industry, now the Plastics Industry Association.)

ally incorporate circular cross-sections and large finish surfaces to spread the load and shallow transitions to distribute the load from the finish to container walls.

ESTIMATING REQUIRED COMPRESSION STRENGTH

Assessing all the factors discussed above and calculating a reasonable stack strength requirement for corrugated shipping units require judgment and experience. Typically, boxes should be designed to have a compression test value of three to seven times greater than the stacking load anticipated during warehousing. This is frequently referred to as the "stacking factor" or the "environmental stacking factor." (See Table 18.2)

The Fibre Box Association has developed a systematic method for determining stacking factor shown in Tables 18.2, 18.3 and 18.4. Environmental multipliers are applied based on the conditions the boxes and contents probably will experience in their distribution. The product of the multipliers is divided into the anticipated maximum load a box will have to hold (the stacking strength) to give the design compression strength.

Example of Calculations

A bottom box will have 76 kg (168 lb.) stacked on it in the warehouse. Boxes will be arranged in an interlocked pattern and required to hold the load for 30 days at 80% R.H. The pallets are in good condition; there will be no overhang. What should the design compression strength of the box be?

The multipliers for this example are:

30 days stack duration	0.60 (Table 18.2)
80% R. H.	0.68 (Table 18.3)
Interlock stack (best case)	0.60 (Table 18.4)
Multiplier product (environmental stacking factor) =	0.245

Table 18.2
Stacking strength multipliers that compensate for storage time.

Days Storage	Compression Loss	Multiplier
Up to 10 days	37% loss	0.63
30 days	40%	0.60
90 days	45%	0.55
180 days	50%	0.50

Source: Fibre Box Association.

Table 18.3
Stacking strength multipliers that compensate for humidity.

Relative Humidity	Loss	Multiplier
≤ 50%	0% loss	1
60%	1–15%	0.85–0.99
70%	11–23%	0.77–0.89
80%	24–37%	0.63–0.76
90%	39–51%	0.49–0.61

Source: Fibre Box Association.

Table 18.4
Stacking strength multipliers that compensate for palletizing conditions.

		Multiplier	
Palletizing Condition	**Loss**	**Best Case**	**Worst Case**
Aligned columns	Negligible	1	0.92
Misaligned columns	10–15%	0.9	0.85
Interlocked columns	40–60%	0.6	0.4
Overhang	20–40%	0.8	0.6
Deck-board gap	10–25%	0.9	0.75
Excessive handling	10–40%	0.9	0.6

Source: Fibre Box Association.

$$\text{Required box compression strength} = \frac{\text{anticipated load}}{\text{stacking factor}} = \frac{76 \text{ kg (168 lb)}}{0.245}$$
$$= 310 \text{ kg (686 lb.) force}$$

REVIEW QUESTIONS

1. Define the terms "shock" and "resonance."
2. What is the typical shunting speed of a rail boxcar?
3. Drops resulting from manual handling are influenced by the nature of the package. Describe five relationships between the package and manual handling drops.
4. A product arrives damaged. Inspection of the shipping container reveals no marks or clues that the package had been dropped or otherwise mishandled. Describe two mechanisms by which the damage could have been caused.
5. What vibration frequency range is of the most troublesome concern to packagers?
6. What are the two basic mechanisms by which vibration can damage goods?
7. Describe how stack resonance occurs.
8. A box falls off a conveyor. What orientation will cause the greatest damage to the container, and what orientation is likely to cause the greatest damage to the contents? Why?
9. What effect does address label location tend to have on the orientation of a package?
10. Vibration is described as a spring/mass relationship. What are the three conditions that can result from a vibrational input?
11. What are two units of measurement most commonly used to describe vibration?
12. What is the difference between compression strength and stacking strength?

Assignment

You have been tasked with designing the distribution packaging for a new product your company is developing. What are the important pieces of information to gather before starting on the package design?

PACKAGING LAW 19

CONTENTS

Complying With Legal Requirements

Packaging is subject to many legal and regulatory requirements, general principles, locating additional information.

Packaging Law as Regulatory Law

Hierarchy of sources, laws and regulations, history of food packaging regulation, food additive petition process, Food Contact Notification Program, Threshold of Regulation, environmental impact.

Packaging Law at the State Level

State versus federal powers, California's Proposition 65, bans of per- and polyfluoroalkyl substances in food packaging, Model Toxics in Packaging Legislation, federal preemption.

Packaging Law and Politics

Bans, bisphenol-A.

Packaging Law as Package Content-Dependent

Beyond FDA, oversight by other federal agencies, child-resistant packaging, meat and poultry products, packaging for alcoholic beverages, packaging for transportation of hazardous material.

Packaging Law and Environmental Issues

Reducing solid waste, post-consumer-recycled content in plastic packaging, letters of no-objection, environmental marketing claims.

Packaging Law as Labeling Law

Intended use, Fair Packaging and Labeling Act, misbranding, agency oversight (FTC, FDA, USDA), pet food.

Packaging Law as Intellectual Property Law

Value of intellectual property, copyright, patent, trademark, trade dress, trade secret.

Packaging Law and Packaging Material Dependency

The importance of determining what laws apply to your product/package.

PACKAGING LAW 19

COMPLYING WITH LEGAL REQUIREMENTS

All, or nearly all, packaging professionals must contend with legal requirements applicable to packaging during their careers. These requirements may be an explicit and obvious part of a packaging professional's job function or, if not part of the job, impact their daily responsibilities.

To bring products to market, packaging manufacturers, particularly suppliers of food packaging and other products that may affect the health and safety of consumers, must comply with a complex array of regulations and requirements administered in the United States by the U.S. Food and Drug Administration (FDA) and other federal and state regulatory bodies. These regulations range from requirements governing packaging composition, component specifications and limitations on use to label information. Similar laws and regulations may be found in jurisdictions throughout the world, including the European Union, South America, China, Japan and many other countries.

This chapter is designed to familiarize readers with the principles and concepts that may apply to their products and processes as they relate to the development and marketing of packaging materials so that professionals involved in this endeavor better understand and guide their company's decisions on FDA (and other regulatory agencies, when applicable) compliance issues.

This chapter does not provide a detailed recitation of all the relevant legal requirements that may confront the packaging professional. Likewise, it cannot provide ready answers to specific situations, products and issues. Rather, the aim of this chapter is to give the reader the tools to understand the different legal and regulatory requirements that may arise, some general principles about how they work and some familiarity about how to seek additional information.

A summary of the information encompassed by the phrase "packaging law" includes seven areas of interest:

1. Packaging law as regulatory law.
2. Packaging law at the state level.

3. Packaging law and politics.
4. Packaging law as package content-dependent.
5. Packaging law and environmental issues.
6. Packaging law as labeling law.
7. Packaging law as intellectual property law.

These concepts will provide a useful framework for familiarizing packaging professionals with this complex and sometimes daunting field.

PACKAGING LAW AS REGULATORY LAW

It is common to refer to the whole field as "law," even though, precisely, "law" refers to statutes passed by the legislature and signed by the President (or counterpart in state governments). Yet, often what is being discussed is not a law but a regulation. When it comes to packaging law, regulations have the most relevance, at least on a day-to-day basis. (See Figure 19.1)

Now, think of packaging law as a hierarchy of sources, higher to lower. The U.S. Constitution is on top, providing an outline for the organization and powers of the U.S. government and declaring the rights of the people. Next are laws, then regulations. Laws passed by Congress often contain instructions for one regulatory agency or another—such as the FDA, the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), the Federal Trade Commission (FTC), the Department of Transportation (DOT) or Consumer Product Safety Commission (CPSC)—to make ("promulgate") regulations to implement the provisions of the law.

Permanent federal rules and regulations are found in the *Code of Federal Regulations (CFR)*. These rules and regulations are first published by the executive departments and agencies of the federal government in the *Federal Register*.

Packaging professionals should become familiar with the process by which regulations are made since that process offers opportunities to provide input and help shape regulations.

Since the majority of laws and regulations governing packaging are administered by the FDA and other agencies often collaborate with FDA on food safety matters, it

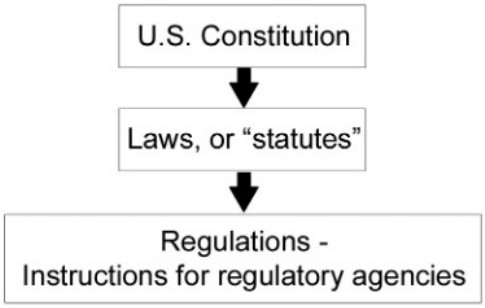


Figure 19.1
"Packaging law" hierarchy of resources

is necessary to provide a brief history of the regulation of food packaging in the United States.

Formal regulation of food packaging in the United States began with the passage of the Food Additives Amendment of 1958. This amendment added, among other things, a new section to the Federal Food, Drug and Cosmetic Act (FFDCA) that defined the term "food additive" as "any substance the intended use of which results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food" unless that substance is Generally Recognized as Safe, or GRAS or subject to one of many exceptions or exclusions listed in the Act (FFDCA Section 201(s)).

This definition is responsible for a distinctive feature of the U.S. food packaging regulatory scheme that is not common to other jurisdictions, namely that all food-contact substances that may reasonably be expected to migrate to food are regulated as food additives, similar to how something added directly to food, such as a sugar substitute or an emulsifier, is regulated. Importantly, under Section 409 of the Act, a food additive that is not the subject of a regulation, or otherwise cleared by the FDA for its intended use, is considered to adulterate food. No showing of the potential for harm is necessary under such circumstances to establish adulteration.

The Food Additives Amendment of 1958 included a process allowing companies and individuals to petition the FDA to allow the use of an additive in food by issuing a "Food Additive Regulation." The food additive petition process involves clearing food additives (including food packaging materials that meet the definition of a food additive) through a notice and comment rulemaking process. A food additive petition requires detailed information about the identity and composition of the substance of interest and a description of how it is made, in addition to information on its intended use—such as food types, temperature conditions and duration of contact with food—and chemistry and toxicology data supporting the safety of the food additive for the intended use. Once a food additive is cleared through this process, the FDA publishes a regulation.

The cleared regulation allows the petitioner to market the cleared additive for use in or with food. As the regulations are of general applicability, they permit the marketing and use of the cleared substance by anyone as long as any limitations and specifications listed in the regulation are met.

A significant development in the regulation of food packaging in the United States took place when the Food Contact Notification (FCN) Program was implemented in 2000 following the enactment of the Food and Drug Administration Modernization Act of 1997. Since its inception, it has become the preferred method for clearing food-contact substances.

A major advantage of the FCN Program over the food additive petition process is expediency. While it could take two to four years or more to obtain FDA permission to use a food additive through the petition process, an FCN automatically becomes effective in 120 days from the time FDA accepts the notification, unless the agency objects in writing. Another major difference between FCNs and food additive regulations is that FCNs are proprietary to the manufacturer of the substance and its customers. The data requirements for an FCN are similar to those for a food additive petition.

There is one other way in which the FDA may act to clear the use of a substance intended to contact food, and that is through a "Threshold of Regulation" (TOR) re-

quest. The FDA amended the food additives regulations in 1995 to establish a process for determining when the migration of a food-contact substance to food is "so trivial as not to require regulation of the substance as a food additive" (60 *Federal Register* 36582-96 (July 17, 1995)). The TOR rule permits the FDA to exempt a food-contact material from regulation based on exposure and toxicology.

Once the FDA receives a request to exempt the use of a food-contact substance from regulation as a food additive based on insignificant migration to food, it will review the data and, if the TOR criteria are met, the agency will issue a TOR exemption letter. These letters are not proprietary and, therefore, anyone can rely on them.

In addition, FCNs, TOR requests and food-additive petitions must include information about the potential environmental impact of their use in order for the FDA to issue a finding of no significant impact, or, if needed, complete an environmental impact statement. This requirement stems from the National Environmental Policy Act (NEPA), which requires federal agencies to assess the potential environmental impact of "major" actions.

PACKAGING LAW AT THE STATE LEVEL

The U.S. Constitution recognizes the states that constitute the United States as sovereign governmental entities that share power alongside the federal government. In fact, the U.S. Constitution specifies the powers of the federal government and explicitly reserves all other powers "not so enumerated" to the states or to the people. This type of arrangement provides unique benefits in decentralizing authority with the objective of allowing decision-making at a level that may be more in tune with the needs and desires of its population. However, it also can be problematic for national and multinational corporations that look to market products throughout the country and find it difficult to know and comply with a myriad of state laws that may be inconsistent with each other, and sometimes even contradictory.

State laws affecting packaging, and often food packaging, some of which are inconsistent with determinations made by the FDA, have been around for some time. Indeed, the number of such laws being enacted during the last few years seems to be growing as state and even local legislators take on what they consider to be "the toxic issue of the day." Most should now have some familiarity with California's Proposition 65 (formally known as The Safe Drinking Water and Toxic Enforcement Act of 1986). Among other things, it requires "a clear and reasonable warning" to be provided to consumers and others before they are exposed to chemical substances deemed by the State of California to be carcinogens or reproductive toxicants.

The substances now listed number more than 800 and expose companies to civil penalties of up to $2,500 per day per violation. Moreover, the law permits private individuals to sue for violations and collect a bounty if successful. The law applies to food products and the packaging materials in which they may be sold and to other consumer products and their packaging materials. While "only" a state law, it has caused manufacturers worldwide to assess their products for compliance and, when necessary, provide warnings or reformulation of products to eliminate or reduce the level of listed chemicals. For a food product, it can be difficult to square the notion of a healthful and nutritious food with a warning that it also contains a carcinogen.

Other examples involve state laws banning per- and polyfluoroalkyl substances (PFAS) in food packaging. Maine and Washington state have been at the forefront of enacting bans on PFAS in food packaging, and several other states have since moved into this realm to require that the use of these substances cease. The state of New York, for example, passed a law in 2021 banning the use of packaging materials treated with such products by the end of 2022.

Significantly, the Toxics in Packaging Clearinghouse, the successor to the Coalition of Northeastern Governors, or CONEG, revised its "Model Toxics in Packaging Legislation" in 2021 to include the marketing of packages or packaging components to which PFAS and ortho-phthalates have been added as regulated chemicals, and also a new process for identifying and regulating additional chemicals of "high concern in packaging." Prior to 2021, the model legislation only prohibited the sale or distribution of packages and packaging components to which lead, cadmium, mercury or hexavalent chromium had been intentionally introduced or is present at more than an incidental level. The Toxics in Packaging Clearinghouse's model legislation is only advisory to state legislators and has no legal effect, but the pre-2021 version has been enacted—in some form—in 19 states.

Sometimes state and local governments are prohibited from imposing legal burdens in certain subject areas if the federal requirement "preempts" or overrides them. Preemption can arise in a variety of ways but sometimes is explicitly provided for within a federal law. On other occasions, courts decide that the subject matter is such that federal requirements must be understood to occupy the field to prevent inconsistencies in the application of the law or contrary determinations. However, recent Supreme Court precedent does not favor the imposition of preemption upon state governments without a clear showing of congressional intent based on the terms of the federal legislation.

PACKAGING LAW AND POLITICS

Packaging professionals use engineering, science and math skills to design and manufacture packaging that contains, protects, preserves, transports, informs and sells products. Likewise, FDA determinations on packaging are based largely on hard scientific results, that is the toxicology and exposure (dietary intake) data available about an additive and safety assessments of the data. Although there may be disagreements about the meaning of the data and the risk management calculus that goes into rendering a final determination, there is little doubt that the final decisions are based on hard data.

However, there is also little doubt that politics sometimes can play a role in the manner in which packaging materials, like any other consumer product, may be treated, regardless of how science-based federal agencies view a substance or its use. These influences can be seen at state and local levels with respect to bans on certain types of products because of purported hazards to human health or the environment.

A good example of this can be seen in the case of bisphenol-A (BPA). Faced with the perfect storm of a well-mounted campaign by an environmental organization, a report from the National Toxicology Program (NTP) and a determination of risk to the health of infants by the Canadian government, bottle manufacturers who used

BPA faced significant media attention, consumer outcry and political indignation. This resulted in the deselection of its products by national retailers and the consideration of legislation that could result in these products being banned permanently. Subsequently, other products in which even trace amounts of BPA may be present faced banishment and worse. All of this took place despite the FDA, the European Food Safety Agency and other governmental bodies (other than NTP), determining that the then-current use levels of BPA in packaging materials did not present undue health or safety issues.

PACKAGING LAW AS PACKAGE CONTENT-DEPENDENT

Although the largest body of regulations affecting packaging materials may be those associated with the FDA, as the agency carries the bulk of regulatory oversight responsibility for food, drugs, medical devices and cosmetics, several other U.S. government agencies can play a role in packaging requirements for these and other products. (See Table 19.1) Some examples of other agency oversight that may arise from time to time are:

- **Child-Resistant (CR) Packaging:** The Poison Prevention Packaging Act of 1970 gives the CPSC authority to require CR packaging for drugs and certain household products. A list of the products requiring CR packaging, such as oral prescription drug products, some over-the-counter drugs, cosmetics that contain certain chemicals and certain household substances, is published in Title 16 *CFR* Part 1700. Requirements for CR packaging for pesticides are under EPA's jurisdiction (40 *CFR* §157(B)).
- **Meat and Poultry Products:** USDA is responsible for the safety of meat and poultry products processed and sold in the United States by way of the Meat Inspection Act and the Poultry Product Inspection Act. Part of that responsibility encompasses the packaging materials used with such products as well as the materials used in equipment to prepare meat and poultry products. The USDA ensures the safety of the materials used by requiring that the packaging and other materials in contact with meat and poultry are cleared by the FDA. Other safety issues are regulated by the USDA through implementation of its HAACP (hazard analysis and critical control point) program standards at the processor level as a way to reduce or eliminate the potential for contamination of food.
- **Packaging for Alcoholic Beverages:** The regulation of packaging for alcoholic beverages is handled by the U.S. Alcohol and Tobacco Tax and Trade Bureau (TTB), an agency within the Department of the Treasury. The Federal Alcohol Administration Act, which provides for the federal regulation of beer, wine and distilled spirits, establishes requirements for packaging used to hold alcohol over and above those imposed by the FDA for foods. The alcohol division of the TTB regulates the production, distribution and labeling of beer, wine and distilled spirits. While production, distribution and labeling are the same types of activities that the FDA regulates for food, the TTB's focus on these activities is on maintaining the proof of the beverage and the tax collected. It typically requires input from the FDA on the safety aspects of the packaging materials used in the final product.

Table 19.1
U.S. agencies with jurisdiction over packaging.

FDA	Food, excluding meat and poultry
	Nonalcoholic beverages
	Dietary supplements
	Animal food and drugs
	Pharmaceuticals (prescription and over-the-counter)
	Medical device packaging (prescription and over-the-counter)
	Cosmetic products
	Tobacco products
USDA	Meat, poultry and egg products
	National Bioengineered Food Disclosure Standard
	Organic Labeling Standards
EPA	Pesticides
CPSC	Consumer products, child-resistant packaging
FTC	Guides for the Use of Environmental Marketing Claims (Green Guides)
	Labeling requirements for certain products
TTB	Regulates types and sizes of containers for alcoholic beverages
	Defers to FDA on safety
DOT	Packaging to transport hazardous material

- **Packaging for Transportation of Hazardous Material:** DOT requirements for packaging to transport hazardous material prohibit the release of the hazardous material into the environment. The effectiveness of the package also must be maintained for minimum and maximum temperatures; changes in humidity and pressure; and when subjected to the shocks, loadings and vibrations normally encountered during transportation (49 *CFR* 173.24).

PACKAGING LAW AND ENVIRONMENTAL ISSUES

As discussed in Chapter 5, Environmental and Sustainability Issues, and elsewhere in this book, environmental stewardship is becoming increasingly important. Companies and government entities are looking for ways to minimize waste and reduce the use of raw materials and energy.

Packaging has been singled out in laws attempting to reduce the amount of material going to solid waste streams. For example, in 2020, California became the first U.S. state to require minimum post-consumer-recycled (PCR) resin in plastic bottles. Shortly thereafter, several other states introduced bills requiring the use of PCR content in certain types of packaging. In addition, packaging professionals are being asked to consider the sorting process when designing new products. This was suggested as a way to increase recycling processing efficiency in the EPA's draft National Recycling Strategy, released in late 2020.

As noted previously, in instances in which the FDA has been asked to clear a product for use in contact with food, one of the required elements in the submission relates to the potential environmental impact of the substance, polymer or article in accordance with the NEPA. There has never been a case in which a petition, notification or TOR submission has been presented by industry in which an environmental assessment did not come back with a so-called "Finding of No Significant Impact." However, the nature of that assessment has changed over the years. Now, in instances where a polymer may be viewed by the agency as a threat to a polymeric article that is heavily recycled (such as polyethylene terephthalate (PET) bottles), the agency is likely to require information to demonstrate that clearance of the new polymer won't negatively affect the established recycling stream.

The FDA, in a more informal process, also has become involved in "approving" the use of recycled materials in food packaging. The FDA does not require independent regulatory review or "premarket clearance" for plastics produced by PCR processes. This is because the FDA's regulatory scheme is based on the composition of the plastic, rather than a specific manufacturing process. In other words, recycled plastic food-contact materials must meet the same regulatory requirements that the FDA sets for virgin plastic materials. Thus, a company is entitled to independently evaluate the status and safety of a polymer produced through a particular recycling process.

However, to support this assessment and provide additional market support, many companies take their determinations to the FDA for review. This process is voluntary and, if the agency agrees with the company's determination, the FDA will issue a no-objection letter on the suitability of a specific process for producing PCR plastic for food-contact uses. In assessing this determination, the FDA generally will focus on whether the plastic from which the recycle will be produced complies with the compositional requirements for the virgin material, whether the adjuvants present in the plastic also conform to FDA regulatory clearances and whether data shows that the source of the recycle can be cleaned so potential contaminants that may be present from post-consumer use or misuse can be removed.

The FTC also operates in the environmental sphere by way of the claims that may be made for products, including those used in contact with food. Its *Guides for the Use of Environmental Marketing Claims* (or *Green Guides* available at 16 *CFR* § 260), while not regulations, per se, attempt to illustrate by way of example, how the FTC evaluates an environmental claim to determine whether it may constitute an unfair or deceptive act and, therefore, prohibited. The examples that are especially pertinent to packaging deal with when and how claims may be made for recyclability, biodegradability and compostability.

In addition, some state laws, notably in California, restrict the use of green claims, such as "compostable" and "biodegradable." Care should be taken to ensure that the claims made for a product can be supported by scientific data and do not overreach.

Needless to say, as political pressure and consumer demand increases for "environmentally-friendly" products, it can be expected that consumer product companies will feel pressure to respond with products, and especially the packaging for those products, that are more sustainable and comply with the myriad requirements being issued by state and local governments.

PACKAGING LAW AS LABELING LAW

While the primary focus of packaging engineers is on materials and processing, they also need to be aware of the laws and regulations governing labeling requirements on packages. Intended use determines a product's regulatory treatment and product labeling is the most common source of information that defines intended use. For example, claims of mitigating or treating a disease are considered "drug claims" and are not permitted on products marketed as dietary supplements (FFDCA, 201(g)(1)). Packagers with responsibility for labeling should determine which government agency has authority over a given product. (See Figure 19.2)

Consumer products generally are regulated under the Fair Packaging and Labeling Act (FPLA), another law largely administered by the FTC. It was enacted in 1966 to prevent unfair and deceptive trade practices and provide consumers with accurate information regarding the quantity and value of products. It requires consumer product labels to include a statement of identity; net contents information; and the identity of the manufacturer, packer or distributor. It specifies requirements regarding placement, form and content of quantity statements for labeling of consumer commodities subject to the Act. The Act also provides that information on the label must be truthful and not misleading.

Figure 19.2
A good first step in approaching labeling requirements for a package is to determine which government agency has authority over the product.

The FDA enforces the FPLA as it relates to food, drugs, devices and cosmetics, while the FTC regulates all other products subject to the statute. A consumer commodity is broadly defined in the FPLA to include any commodity that is customarily produced or distributed for retail sale for consumption by individuals for personal care and for the performance of household services, and that is generally consumed or expended within the course of its use (15 *U.S. Code* (*USC*). 1459(a)). The statute specifically excludes meat and meat products; poultry; tobacco products; commodities subject to the Federal Insecticide, Fungicide and Rodenticide Act; veterinary biological products; prescription drugs; antibiotics; alcoholic beverages; and commodities subject to the Federal Seed Act.

Beyond the FPLA, the FFDCA provides that a food is misbranded if its labeling is false or misleading in any way. The Act also requires labels on food packaging to include the following information: the common or usual name of the food; a list of ingredients; the name and place of business of the manufacturer, packer or distributor; an accurate statement of the quantity of contents; and nutrition information in the format prescribed by FDA regulations under the Nutrition Labeling and Education Act (NLEA).

Meat and poultry products are not subject to the NLEA, however, USDA also issued nutrition labeling, serving size and nutrient content claims regulations that are similar, but not identical, to the FDA's final rules (58 *Federal Register* 631-91). The USDA also has jurisdiction over the labeling of organically produced agricultural products and food containing bioengineered materials.

With respect to pet foods, the Association of American Feed Control Officials has developed model pet food regulations that govern a variety of labeling and advertising issues. These regulations have been adopted by many states. Violations in those states may be subject to penalties under the state's consumer protection acts.

Packagers familiar with the law in this area should avoid the common habit of referring to labeling issues as somehow lesser in importance or centrality than chemical or materials issues. What is claimed on a product's label is just as important as what is in the product in determining whether it is in legal compliance.

PACKAGING LAW AS INTELLECTUAL PROPERTY LAW

The area of law referred to as "intellectual property," encompassing patents, trademarks, copyrights, trade dress and trade secrets can be a source of confusion for many people. Yet, intellectual property often is a company's most valuable asset. Packaging is intimately involved in intellectual property, as package label content and structural designs can be the subject of trademark or trade dress protection or even copyright protection, and patents commonly cover packaging structures, designs or even techniques. These features can be what differentiates a product from the competition or identifies it in the minds of consumers. So, it's important to understand the basic concepts of intellectual property law. (See Table 19.2)

Copyright: A copyright protects the work of an author or artist—more specifically, their expression of an idea—but not the idea itself. Federal law provides for copyright protection, and it is relatively simple to obtain. The U.S. Copyright Office handles

Table 19.2
Types of intellectual property.

Intellectual Property Type	Purpose
Copyright	Protects an author's or artist's original work or expression of an idea, but not the actual idea.
Patent	Excludes others from making, using, selling or importing an item that is the subject of either a utility or design patent for the term of that patent.
Trademark	A word or symbol, or a combination of words and symbols, that distinguishes one competitor from another.
Trade dress	The overall look of a package, including its size, shape, color, texture, materials and label.
Trade secret	Just about any information that gives your company value because it is unknown to others and can qualify for protection.

copyright registration. Registration is not a condition for protection, but it is required before a lawsuit can be filed.

A copyright notice informs the public that someone has ownership over a particular work. It consists of three elements: 1) either the word Copyright or the symbol ©; 2) the year that the work was first published; and 3) the name of the copyright owner. If someone copies (infringes) copyrighted work, the owner of the copyright can sue to obtain a court injunction to stop that person from selling or using that work and for financial damages, including attorney's fees.

Patent: Under U.S. law, a patent allows the holder to exclude others from making, using, selling or importing the patented invention for the term of the patent. Types of patents that could apply to packages are utility and design. Utility patents are issued for any new and useful process, machine or composition or any new and useful improvement to one of those items. A design patent is issued for the ornamental design of an article. Utility patents are for 20 years from issue date, and a design patent is for 14 years from issue date. In exchange for that monopoly, the inventor "teaches the public" about the invention through the published patent itself.

A patent is requested by filing a written application with the U.S. Patent and Trademark Office (PTO) or foreign office. To be patented, an invention must be a genuine advance beyond what has gone before, which is typically referred to as the "prior art." In addition to being new, the invention also must be useful and non-obvious. Copying someone's patented invention, known as "infringement," can be stopped by a court injunction and can subject the infringer to monetary damages. This is true even if the infringement was inadvertent.

Trademark: A trademark is the word or symbol, or a combination of words and symbols, that distinguishes one competitor from another. The Lanham Act, enacted in 1964, provides for national registration of trademarks and protects against infringement. Prior to 1946, only state trademark laws existed in the United States. While trademarks can be registered with the PTO, this is not a requirement for their use. Although, a trademark must qualify as distinctive to be registered with the PTO, simple computer searches can quickly help establish whether a contemplated trademark conflicts with an existing mark.

Trademark holders are advised to take some action to protect it, otherwise, they can be accused of abandoning it. This includes making sure registration is up-to-date and that it is not being infringed upon.

Trade dress: This designation is the overall look of a package, including its size, shape, color, texture, materials and label. Trade dress encompasses a package's shape, color, graphics and overall appearance. It is protected from imitation under trademark and unfair competition laws.

Trade dress may be registered with the PTO, although it does not need to be registered to receive protection under the Lanham Act (Section 43(a)). The registration of package design, a distinctive color used on a package or other trade dress is limited by two basic trademark requirements: functionality and secondary meaning. With respect to color, it cannot be protected immediately upon first use. It is necessary to show secondary meaning—that is, that the color is something that makes consumers identify you with your product. In addition, a color may not be protected as a trademark where it serves some utilitarian functions and will put a competitor at a significant disadvantage because the color is essential to the product or its packaging. An example of a distinctive color is Tiffany Blue, which Tiffany trademarked in 1998.

If someone copies a trade dress too closely, a suit may result for unfair competition, with the remedy available of obtaining an injunction and damages for lost sales.

Trade secret: Just about any information that provides value to a company by virtue of reasonable efforts to keep it secret can qualify for protection as a trade secret. The Uniform Trade Secrets Act (UTSA), which was last amended in 1985, defines trade secrets as: "information, including a formula, pattern, compilation, program, device, method, technique or process, that: (1) derives independent economic value, actual or potential, from not being generally known to, and not being readily ascertainable by proper means by, other persons who can obtain economic value from its disclosure or use, and (2) is the subject of efforts that are reasonable under the circumstances to maintain its secrecy." (UTSA Sec. 1.4). Developed by the Uniform Law Commission, approximately 48 states have adopted the UTSA.

To keep information secret, it must be protected against copying or distribution and access limited only to those who have confirmed in writing that they agree to keep it secret. It is important to note that some information dealing with safety that is provided to a government agency to support an application may lose its entitlement to protection as a trade secret should the agency decide that the information may reasonably be disclosed to the public under the Freedom of Information Act (5 *USC* § 552).

Table 19.3
Harnessing the application of packaging law to a specific package.

Steps
Know what's in the package to determine exactly what legal requirements apply to it.
Ask what the product inside the package is, under the law.
Consider conceptually the identity of the package contents in terms of its place in commerce—is it a retail product or a wholesale product or a component?

PACKAGING LAW AND PACKAGING MATERIAL DEPENDENCY

Often, the packaging professional needs to know what a package is made of to know exactly what legal requirements apply to it. As discussed previously, this knowledge is especially important relating to some specialized areas such as food-contact materials and environmental requirements for packaging materials. Is important that packaging professionals follow several basic steps in determining how packaging law applies to specific packages. (See Table 19.3)

For any type of product, if packaging that violates applicable law is found on the market, the costs and complexities associated with remedying the situation multiply. Therefore, it is wise to assign a high priority to assuring compliance early in the product development process.

REVIEW QUESTIONS

1. What are the key aspects of packaging law?
2. What is the best source of agency news regarding U.S. national laws and regulations?
3. What agency is the driving force behind food packaging?
4. What is an example of a state law that promulgates regulations affecting packaging that are not otherwise enacted and enumerated for U.S. Environmental Protection Agency enforcement of toxic substance restrictions?
5. What is a key packaging content restriction area outlined in the Toxics in Packaging Clearinghouse "Model Toxics in Packaging Legislation"?
6. What area of packaging is driven by the Poison Prevention Packaging Act of 1970 and by what authority is it regulated for drugs, cosmetics or household chemicals?
7. Which U.S. agency operates in the sphere of environmental packaging by monitoring marketing claims and what areas of claims or labeling are affected by their guidelines?
8. What are the two main agencies that enforce the accuracy of product information covered under the Fair Packaging and Labeling Act (FPLA)?
9. What is the best first step in understanding the labeling requirements for any product package?
10. What are three elements of intellectual property?

PACKAGING MACHINERY

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Automated Production

Options for increasing production, factors that dictate the course for increasing production.

Building a New Line

The packaging machine industry, custom nature of packaging machinery, conventional and unconventional machines, industry's global nature, commissioning or debugging, general considerations, single-purpose and multipurpose lines, effective servicing.

Upgrading Existing Equipment

Advantages of upgrading in-house equipment. Advantages and cautions when buying used equipment.

Package Design and Production Operations

Designing for production.

Select Primary Package Type

Rigid, semi-rigid or flexible packaging.

Productivity

Terminology, the speed hierarchy.

Speed

Determining line output requirements, design speed, bringing a line under control, run speed.

Buffers

Isolation of the slowest station, example of using a buffer to increase output.

Changeover

Changeovers and economic order quantity, fast changeover, the ideal changeover.

Machine Configuration

Straight-line or rotary design, intermittent or continuous motion, turrets, timing screws, starwheels

Flexibility

Minimizing the impact of frequent changeovers.

Degree of Automation

Semiautomatic to lights-out operation.

Basic Line Configuration

Typical functions on a packaging line.

Line Loading

Hand-feed, unscramble, uncase, depalletize.

Liquid Filling

Constant-volume and constant-level fillers, piston volumetric fillers, diaphragm volumetric fillers, metering pumps.

Dry-Product Filling

Volumetric-cup (or flask) filling, vacuum-volumetric filling, auger fillers, net weighing, number counts.

Closing Systems

Sealing, seaming, capping, plugging.

Labeling and Coding

Labeling, coding.

Grouping and Packing

Cartoning, multipacking, case packing.

Preparing for Shipment

Palletizing, unitizing.

Ancillary Operations and Conveyors

Quality control systems such as machine vision inspection, checkweighing, metal detection, x-ray inspection; conveyors, the link that ties machines together.

The Role of Robotics

Lower costs, greater reliability, simpler programming for articulated, SCARA, delta-style, cartesian, mobile and collaborative robots.

Machine Control

Optimum settings, control concepts, monobloc lines, human/machine interfaces, augmented reality, virtual reality.

Introduction to Statistical Process Control

Terminology, standard deviation, calculating the standard deviation, standard deviation characteristics, SPC and control charts, X-bar and R charts.

PACKAGING MACHINERY 20

AUTOMATED PRODUCTION

Early packages were preformed paper bags, crude cans and glass bottles of rather doubtful dimensional tolerance. Shipping containers were usually wooden crates or casks. Most factory equipment was operated by belts driven from central line shafts, and it was difficult, if not impossible, to match machine speeds or even maintain a constant speed on a single machine. Early packaging lines were labor-intensive, discrete operational units. In many cases, workers became so dexterous at jobs such as wrapping or gluing labels that there was little to be gained by installing inconsistent machines.

Today, automated production is essential. Neither volume nor product consistency can be achieved any other way. Increasing production in a cost-effective manner is a difficult, complex undertaking. The production engineer must have strong support from management, production, maintenance and vendors. Delays, errors and higher costs will result if this support is not totally integrated, with all concerned playing an active role.

To ensure a full understanding of the technologies and options involved, critical personnel should be exposed to trade shows, vendors, trade literature, seminars and tours of related facilities.

Four options to increase production are:

- Buy new state-of-the-art equipment.
- Retrofit, refurbish or rebuild existing equipment.
- Buy refurbished equipment.
- Hire a contract packager.

Factors that influence this decision include:

- *Availability of in-plant equipment:* Producing a package similar to an existing one conceivably can be done on existing production lines, but an all-new package type must be produced by other means.

- *Market demand for the product:* Temporary surges would best be met by hiring contract packagers. Slow, steady growth initially might be contracted out while a new line is installed. Careful analysis is needed to determine whether the product line will live long enough to provide a return on investment.
- *The time frame in which the product must be produced:* Lead times for product ingredients/components, packaging materials and new packaging machinery can be lengthy. It's important to consider the total supply chain including material availability, inventory and other factors like contingency plans for disruptions due to weather, fires, pandemics or upstream supply constraints. In some situations, it may not be acceptable to wait for the delivery and commissioning of a new line. Upgrading existing lines, purchasing used equipment or hiring contract packagers are possible solutions.
- *Production volume:* A slight increase over existing capacity may best be achieved by upgrading existing machines. Significant increases in volume, however, must be treated in other ways.
- *Quality and safety standards:* Market expectations are continually changing. Dated equipment and technology may not meet these needs.
- *Equipment technology:* Materials and manufacturing technologies are introduced every year. Refurbishing outdated machinery is not a wise investment.

BUILDING A NEW LINE

Packaging machinery manufacturing is a highly specialized business that does not produce large numbers of identical machines. It is, therefore, not possible to visit a few stores, compare prices, buy a unit and plug it in.

Products and packages come in such an infinite variety of materials and forms that even though a machine manufacturer may specialize in a particular machine class—for example, piston fillers—it is likely that almost every order has some small difference to accommodate a product, package or customer need. In this respect, packaging machinery is a custom business, and every packaging machine is built to each customer's specifications. Since construction of a packaging machine usually does not begin until design specifications are prepared and the order placed, long lead times need to be considered for the project schedule. Construction and delivery times vary for different machines and can stretch to 36 weeks or more for some designs. However, it should be noted that many manufacturers are working to reduce lead times and be more responsive to the marketplace by adopting lean manufacturing practices and modular construction techniques.

Even though individual orders are custom, machines are built within a standard frame or configuration that is targeted at a conventional package format. This standard machine is then adapted to the particular dimensions and needs of the conventional package. If you create an unconventional package design, and the machine needs to be designed from the floor up, the resulting financial investment for the package and the packaging line must be considered. For example, cartoning equipment companies provide machines that erect and fill an infinite range of standard tube-style cartons. Stations can be added to date-code, insert leaflets, attach deal la-

bels and so on. Despite these differences, the cartons are still conventional, or standard. Asking for a machine to form and fill a seven-sided carton, however, requires an original (and costly) design.

Years ago, most packaging machinery companies were relatively small, often individually- or family-owned, and tended to be built around the skills of an innovative mechanical specialist. This has changed with industry growth. While many small packaging machinery manufacturers remain and thrive, the largest volume of machinery is supplied by bigger companies that focus on selling to the global manufacturers of consumer packaged goods (CPG). The globalization of the CPG companies has led to their expansion outside of North America in high-growth markets. Many CPG companies now are requesting machines that meet the requirements of the EU machinery directive (CE). Machinery manufacturers meeting the requirements of the ANSI/PMMI B155.1-2016 *Safety Requirements for Packaging and Processing Machinery* will generally also meet the EU machinery directive requirements because the requirements of ANSI/PMMI B155.1-2016 have been harmonized with the requirements of the EU machinery directive. While every industrialized country has some domestic machine production, Italy, Germany and China are the most significant producers on the world market outside of North America.

Given that a complete packaging line consists of multiple functional machines, often from multiple suppliers, sometimes located in different countries, connected by conveyors and buffers made by still another supplier, it is not likely that a new line will run perfectly on startup. New lines have to be debugged and brought up to operating speed or "commissioned." Good production engineers often can coax a bit more speed out of a line given time and experience with the process.

General Considerations

Broad decisions as to machine class need to be made early and are usually obvious. For example:

- *Space constraints:* Use machinery design software to view a three-dimensional model of the proposed line. In addition to the physical space occupied by the equipment itself, ensure that operators have an adequate area to tend the line safely and effectively. This includes ergonomic placement of all controls and adequate access for changeover and maintenance. Allow for the storage and flow of input materials, the removal of input dunnage or packaging and the removal of finished product. Today, augmented reality (AR) and virtual reality (VR) technologies can provide an even more immersive view of these line considerations.
- *Installation requirements:* What services (electrical, water, air, steam, waste disposal) will be needed? What are the required floor loadings? How will the machines be moved to their fixed locations (e.g., do you need to remove walls)? Who will do the installation?
- *Power and control:* What level of automation is appropriate? How will machine movements be actuated and controlled? Using power and control systems similar to existing machinery can reduce training and maintenance times.

- *Special requirements:* Is the product highly flammable? Does the machine have to be explosion-proof? Are particular standards of cleanliness and sterility necessary? Are active chemicals which need special corrosion protection procedures a factor? Should the machine flow be from left to right or right to left?

When examining candidate machines, remember that good packaging lines accomplish their objective with a minimum of vibration and noise. Such forces translate directly into wear and stress on the machine. The machine's mainframe should be heavy enough to hold all the moving machinery adequately and stiff enough not to twist or deform under operational stresses.

The transfer and flow of product and material through the production process should be smooth, with minimal directional changes. Mechanical motions should be rotary rather than reciprocating, wherever practical. Heavy drive trains should be mounted low or on the floor with easy access for maintenance. Motors and gearboxes overhanging the product line should be avoided, as lubricants or debris may drop on the product during routine maintenance.

Before calling on machine suppliers, make a thorough and critical analysis of exactly what needs to be accomplished. Purchasers commonly request broad performance ranges, believing that the machine is thus more versatile and could be adapted to more operations. While it may be possible to design a filling machine that handles 4-milliliter (ml) vials and 4-liter (l) pails, compromises will be necessary, and the machine is not likely to do either job well.

It might be useful to talk with the machinery supplier before settling on a package design or material. They may be able to help optimize the operation and minimize downtime with small modifications to the package and/or material selected.

Be realistic in the range of tasks that the machine will be required to perform, and resist the temptation to compromise the main objective. The more dedicated a machine is, the more efficient it will be. *Versatility should not be purchased at the expense of output efficiency*.

All machines need to be adjustable, and those machines that will be running multiple product types and/or multiple package types will require a changeover capability. A basic tenet to remember is that *the more things that can be adjusted, the more things there are that will go out of adjustment*.

Adjustments are those machine features that accommodate the natural variations inherent in the product and package being run. For example, the viscosity of pancake syrup will vary depending on the ambient temperature. A folding carton will be stiff when the humidity is low, but soft and pliable when it is high. Packages themselves will have a range of tolerances within which a machine must be able to work.

Changeover capability requires that the machine can be significantly reconfigured to run a completely different product, package or both. In general, change parts are preferred for fixed, required changes (e.g., a product that is filled into three different package sizes). If there are a great number of package/product combinations, then a machine must be completely adjustable, within the overall range of possibilities.

Capital outlay for machines can be heavy. Is the proposed product line going to live long enough to repay this investment? Is there a new technology on the horizon that will make your product or package obsolete?

Effective servicing and parts supply is a key vendor issue. Does the proposed machine supplier have a local office and local parts supply, or will you need to wait for parts to be flown in? If you are purchasing equipment from abroad, browse the instruction manuals to make sure instructions are coherent and use appropriate technical terms. If the technology is new, your service people will need to be retrained.

And finally: At what point does the line become "yours?"

UPGRADING EXISTING EQUIPMENT

Refurbishing existing in-house equipment involves some of the same steps as buying new machines, but offers definite benefits

- Proven technology that's already in-house.
- A significantly lower capital investment.
- Shorter lead time.

Although lead time will almost certainly be shorter, upgrading existing equipment probably won't save any time in commissioning and startup because an upgraded machine needs to be commissioned the same way as a new machine. In fact, sometimes refurbished equipment presents more commissioning and start-up hurdles than a new machine/line, especially if the upgrades were done by someone other than the original equipment manufacturer (OEM).

Refurbished equipment may not save any training time either if there have been significant changes to the operation of the machine. In fact, training to run a refurbished machine can require more effort if old habits need to be broken.

Refurbished equipment also can be purchased from a used-machinery broker. Advantages cited are quicker delivery and savings of 30% or more versus new equipment. However, the refurbished machine sold by the used-machinery broker is unlikely to be under warranty with the OEM. In addition, used-machinery brokers are generalists, not specialists, and may not be fully aware of the machine's history. Safety upgrades may be needed to meet current standards. ANSI/PMMI B155.1-2016 *Safety Requirements for Packaging and Processing Machinery* requires the "supplier" (manufacturer, manufacturer's agent, representative or distributor, reseller, installer, modifier, rebuilder or integrator) to perform a risk assessment and build the machine to an acceptable level of risk. The purchaser of used packaging machinery can verify this by asking the "supplier" to share the documented risk assessment.

PACKAGE DESIGN AND PRODUCTION OPERATIONS

The typical package design process tends to focus on marketing, containment and protective values. Machinery's role in bringing product and package together, often at great speeds, is frequently overlooked.

Contribute to trouble-free machining by ensuring that a package shape can be easily conveyed without jamming. Also, keep centers of gravity low and ensure an

appropriate level of package robustness. Common dimensions for products offered in several sizes can substantially reduce changeover time and costs. For example, if a 500-mL and a 1-L bottle of vegetable oil have the same footprint, a changeover between the two sizes will not require adjustment of conveyor guide rails or replacement of infeed timing screws and starwheels. (See Figure 20.1) By keeping the labeling panel in the same geometric location, the labeler will need no adjustment; just a change of labelstock to the size being run.

Good package design makes for efficient production.

SELECT PRIMARY PACKAGE TYPE

All packaging types can be run at the high speeds needed to meet today's production requirements. Rigid glass, metal or heavy plastic containers accept acceleration and deceleration at high rates and withstand significant force applied to the finish during filling or to the sidewalls during conveying. Vacuum or pressure levels during the fill cycle are not critical considerations for rigid containers.

Semi-rigid containers, typically blow-molded plastic bottles, cannot withstand the same stresses. This limits the vacuum or pressure level that can be used during the fill and how the container moves from station to station.

Flexible pouches or bags cannot maintain their dimensions in all axes and must be retained in a fixture while being filled. Since flexible containers cannot be filled to a specified level, fillers must work by time, weight, volume or count.

PRODUCTIVITY

Many factors influence productivity including output, machine speeds, buffering capacity, changeover frequency and time, machine configuration, flexibility and degree of automation. But the lack of specific and consistent terminology often makes discussions of productivity confusing. In this chapter the following definitions (based on the recommendations of Paul Zepf, Zarpac Inc.) are used:

Packaging line A group of integrated special-purpose machines that combine product and package inputs and produce a new product. The in-

Figure 20.1
An example of two bottle sizes with the same footprint and similar label.

dividual machines, each performing a different function, are referred to as stations.

Input Specific product and package items required for package assembly.

Design speed The theoretical capacity under perfect running conditions. The speed of the machine as designed, running empty, is the design cycle rate.

Capacity The upper sustainable limit of quality packages passing a point just before warehousing.

Run speed The instantaneous operating rate at a point in time.

Output The exact quantity of quality product passing a point just before warehousing or shipping in a given time. A machine's or station's output is the exact quantity of quality product leaving that machine in a given time.

Efficiency A ratio of output over input, but in packaging production, this definition has many subtle variations. For this discussion, efficiency is used to describe a station's or a packaging line's actual operating time over the available time. (Other authorities call this "capability.")

The speed hierarchy would be as follows:

1. Design speed
2. Capacity
3. Run speed
4. Output rate

SPEED

The first step in considering a new line is to accurately determine and quantify the desired output. Be specific and realistic in determining the numbers that will serve today's needs and, if necessary, provide a contingency for future sales increases. Bear in mind that a machine that goes twice as fast is sometimes more than twice as expensive. Excess production speed is an expensive luxury.

Vendor literature will quote a "machine design speed" or "cycle rate": the theoretical containers per minute (cpm) at which the machine has been designed to run. One experienced machine integrating specialist reports that, output experienced is 80% of the vendor's quoted speed.

Machine design speed is not "output rate," which is a measure of actual quality product output over time. An empty machine will cycle indefinitely; it is the material passing through it that causes problems. A line capable of 30 cpm may in theory produce 14,400 completed packages in an eight-hour shift. However, the real output might be more like 11,000 units, a 0.76 efficiency based on the theoretical output.

A packaging line is typically composed of several discrete machines that are connected. These individual stations will likely come from different suppliers, and each will need to have an assigned design speed. Evolved practice uses the most critical station in the line, usually the filler, as the benchmark, and all other stations are specified to run at a higher design speed than this unit. Machines upstream from or preceding the filler are specified at a higher design speed than the filler to ensure that the filler is never "starved" for containers. Post-fill or downstream machines also must run faster to pull product away from the filler and prevent backups. The design speed of each machine downline of the filler increases with the distance from the filler. (See Table 20.1) This creates a "pulling" effect on the filler. In this approach, individual machine run speeds are set to balance the flow of product through the entire line.

A more modern approach is to work with dynamic speed settings. Any machine in such a line will vary in speed at any instant in time in relation to upstream and downstream conditions. This may be compared to automobiles traveling down a congested highway—individual cars constantly change speed depending on the conditions ahead of them. At any instant, the cars in any group may all be traveling at different speeds, but as a group, they are making progress. Progress would be interrupted if a single car elected to travel at a fixed speed.

Selection of the design speed required for a new line starts with consideration of final market needs. For example, a proposed filling line needs to produce 57,000 sellable containers per eight-hour shift or 120 cpm. However, the time in which the line is actually available and producing is affected by many factors. While the staff may be in the plant from nine to five, the line does not run nine to five every day. Inci-

Table 20.1
The filler is usually the most critical operational unit in a production line and is frequently used as the benchmark from which all other machine speeds are derived.

Unit	Speed (cpm*)
Bottle supply station	230
Bottle dump station	220
Unscrambler	210
Cleaner/fill station	200 (benchmark speed)
Capper	205
Labeler	210
Inspect/date-code station	215
Six packer	220
Caser/packer/sealer	225
Palletizer	230

**cpm = containers per minute*

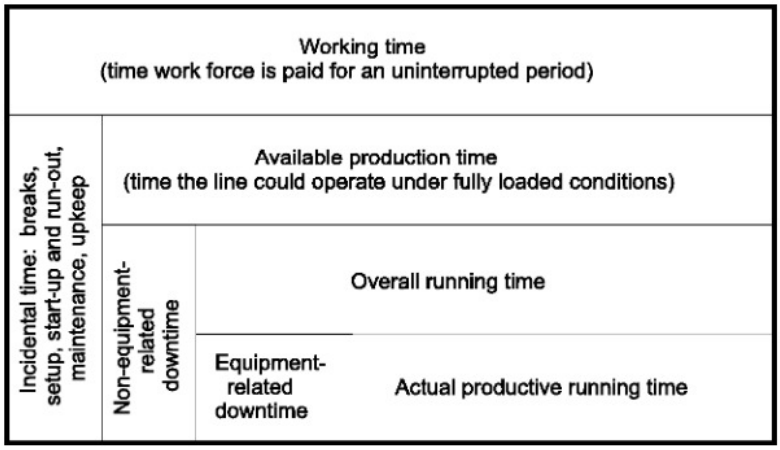


Figure 20.2
Actual production time is working time minus equipment-related downtime, non-equipment-related downtime and incidental time.

dental time reduces the working time. (See Figure 20.2) Non-equipment-related problems, such as product shortage or out-of-specification containers, subtract more minutes from the time the line should be running but isn't, through no fault of its own. Finally, more time will be lost from full run-speed production due to various problems directly associated with the equipment.

Obviously, specifying a filler with a design cycle rate of 120 cpm would be a mistake for many reasons, not the least of which is that the machine may not cycle at 120 cpm once the product and package are introduced. Start-up and shutdown times, changeovers, breaks and routine lubrication and maintenance will eat into the available production time. In other words, the actual running time available during an eight-hour shift might average out to seven hours, in which case, the filler cycle rate would need to be about 136 cpm.

Next, consider what happens when the machine is running for the seven hours remaining for actual production. To start with, the filler will not always be running at its full 136 cpm limit. There will be run-ups and slowdowns. There will be periodic slowdowns or stoppages, because of other stations on the line or irregularities in the product or package. This might bump up the required design speed to 150 cpm.

Finally, will every package produced be a sellable unit? And what about a contingency for growing sales? In the end, a filler capable of 200 cpm or more might be the best choice.

Machine design speed alone should not be a gauge for specifying a purchase. A filler operating at 50 cpm running 98% of the time will outperform a 70 cpm machine running 65% of the time. As a general rule, the faster the machine, the less tolerant it is of input variations. A faster machine usually requires tighter input material tolerances to run at full capacity.

Once new line expectations and the required levels of output and design speed have been determined, a block diagram showing the respective machines and activities can be made. (See Figure 20.3) As the project evolves, the inputs (empty bottles, closures, labels, adhesive drums) and outputs (empty boxes, empty drums) of every station can be entered to provide information on space needed to service the line properly.

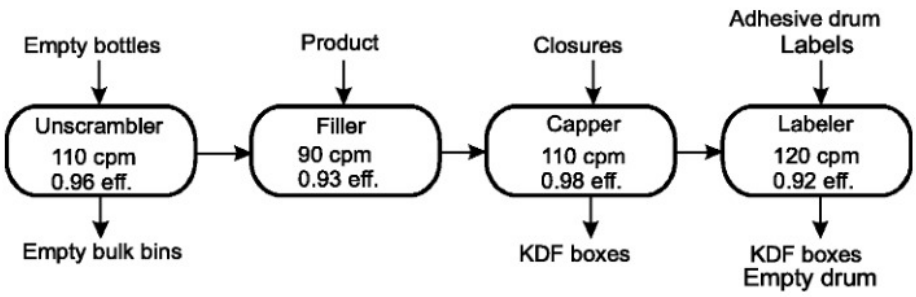


Figure 20.3
The line illustrated in this block diagram cannot be run faster than 90 cpm, the filler's maximum speed. The line's actual output would be the product of each machine's efficiency (eff.): 0.96 x 0.93 x 0.98 x 0.92 x 90 cpm = 72 cpm.

The output of every machine on a line is critical since line output can never be greater than the output of the slowest station. Output inefficiencies are cumulative in lines with directly connected machines, such as the one illustrated in Figure 20.3, since whenever one machine stops, the whole line stops. It is vital that the output capabilities of each station be understood.

A machine/line should be able to run at full efficiency at rated speed. Confirmation that rated speed can be achieved without issues should take place during the design and commissioning phases. Lines should be fully vetted during the commissioning, qualification and verification (CQV) process. At the end of the CQV timeframe (as defined in the contract), the line should be running at rated speed and efficiency. The end-user should not need to continue the troubleshooting phase beyond the conclusion of the CQV timeframe.

Once a line is operational, comprehensive production data and statistical process control data records are valuable sources of information for maintaining and improving efficiency. Operator consistency and skill level also are critical.

BUFFERS

The additive effect of individual station inefficiencies can be reduced by isolating the different stations with product accumulation areas. "Buffers" are conveyor storage devices that hold a calculated amount of product between operational units.

Buffer options include turntable, multi-chain table, bi-directional table, vertical accumulator, horizontal serpentine, and alpine and spiral, according to the *Packaging Machinery Handbook* by John Henry, CPP. Vertical accumulators, alpine and spiral designs take advantage of vertical space.

Buffer capacity should be calculated to provide an accumulation large enough to hold a station's output or continue to feed other stations in line as needed. Buffers are positioned to isolate the least efficient stations on the line or a non-interruptible operation like an oven. Without a post-oven buffer, if the wrapper goes down, product would have to be scrapped. However, it should be noted that too many buffers can negatively impact productivity.

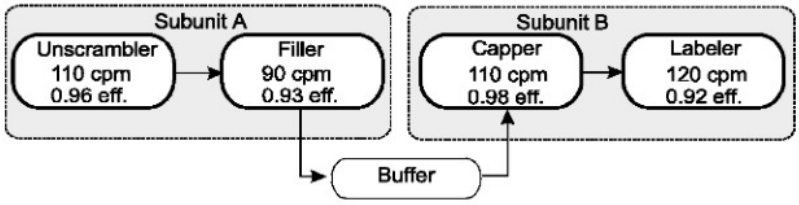


Figure 20.4
Using a buffer to divide a packaging line into two subunits, each of which can run independently of the other for short periods.

Using the line in Figure 20.3 as an example, if the typical problem at the filling station (misaligned bottles, no bottles, bottles that are out of spec) requires one minute to clear, then a buffer located after the filler should be able to hold at least one minute's production at the filling station—in this example, about 90 bottles.

As Figure 20.4 shows, the buffer effectively isolates one part of the line from another, allowing each to run for short periods without the other. An output efficiency can be calculated for each subunit:

$$\text{Efficiency of Subunit A: } 0.96 \times 0.93 = 0.89$$

$$\text{Efficiency of Subunit B: } 0.98 \times 0.92 = 0.90$$

The output of Subunit A is

$$0.89 \times 90 \text{ cpm (the maximum filler speed)} = 80.1 \text{ cpm}$$

But Subunit B can be set to run at a speed of up to 110 cpm, the maximum capper speed. Subunit B at an efficiency of 0.90 and running at 110 cpm could handle up to 99 cpm. If Subunit B is set to run at 89 cpm, then, adjusting for its efficiency factor:

$$0.90 \times 89 \text{ cpm} = 80.1 \text{ cpm}$$

Subunit B will be able to handle 100% of the output from Subunit A. Therefore, line output with the buffer will be the 80.1 cpm output of Subunit A. This is an improvement of 8 cpm or 480 extra sellable units per hour.

In this example, the least efficient machine was the labeler. Looking at the efficiency figures alone, one might be tempted to try to improve the performance of the labeler. However, the calculations in this simple example demonstrate quite clearly that improving the efficiency of the labeler would not have a significant effect.

As a line's run speed increases, the buffer's size must increase proportionately. Well-designed lines should not require extensive buffering areas and should have a capacity run speed approaching 100%. No one would accept a capacity run speed of 85% from a car, and yet a similar run speed from a vital production machine is often considered "normal."

To operate properly, there must always be some product in the buffer. This requires that operations before and after the buffer be capable of short periods of higher speed in order to partly refill the buffer when it has been emptied or to partly empty the buffer when it is filled to capacity.

Buffers can be a great way to increase a production line's output, but it should be kept in mind that the buffer itself is a machine with its own efficiency factor. A good buffer installation will have a 0.99 efficiency. Efficiency below 0.98 can potentially slow the line, as would the installation of too many buffers. For example, three buffers in a production line, each operating at 0.97 would as a group have an efficiency of 0.91.

Do not install buffers to compensate for a defective or improperly operating machine or poorly specified input components. Fix the machine or change the input specifications.

CHANGEOVER

Changeover, as defined by John Henry, CPP, Changeover.com, is the total process of converting a machine or line from running one product to another—not unlike a pit stop in auto racing. Henry defines changeover time as the total time elapsed between the last unit of good production of the previous run, at full line efficiency, to the first unit of good production of the succeeding run, at full line efficiency. Companies rarely measure changeover costs, but Henry estimates them at thousands, or tens of thousands of dollars, per hour. Put another way, 10 minutes of changeover downtime each day equals more than 40 hours—one week—of lost production time per year.

To cut costs, maximize production time and speed product to market, it is desirable to minimize or eliminate any factors that could lead to unnecessary changeover downtime. Both package design and the materials selected for the package can profoundly impact the need for changeover, as well as changeover-associated costs.

Generally, the faster a machine operates, the more complex the changeover. Intermittent-motion machines, for example, need repositioning of the guide rails and timing adjustments. Change parts are minimal. A rotary machine will almost always require change parts, such as additional infeed timing screws, infeed and outfeed starwheels, and sometimes the turret itself.

For applications where several different products will run on the same line, ease of changeover becomes important. The simplest change is when only the product needs to be replaced. Sometimes, the product remains the same, but the volumes required may vary substantially, ranging from unit-of-use to institutional quantities. Systems using cylinders, metering cups or other similar volume fixturing usually have a fairly fixed range within which they can be adjusted. Auger feeds and metering pumps, on the other hand, have broader adjustment ranges because one simply increases fill time.

Changeovers can be an important part of output calculations. Where changeovers are frequent, ease of changeover, rather than actual machine speed, may dictate machine choice. A fast machine requiring excessive changeover time will be a handicap.

Ideally, changeovers should require no tools and should be done from one side of the machine and from one end to the other. It should be possible to make critical or time-consuming adjustments or settings offline. Parts and adjustments should be clearly marked for easy identification and setup by personnel. All settings should be quantified.

Rapid changeovers are important for efficient production. Just-in-time (JIT) manufacturing, in many instances, depends on the ability to make fast changeovers. Packagers need to balance the inventory cost of larger and larger production runs against the per-unit cost of changeovers.

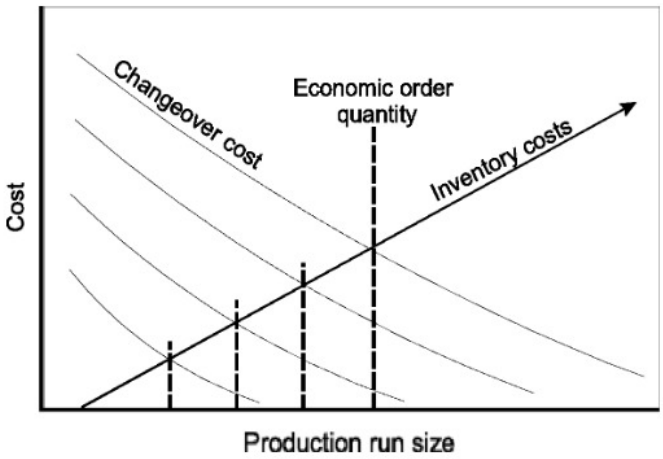


Figure 20.5
As changeover time and cost are reduced, so is the economic order quantity.

Producing smaller lots with more frequent changeovers reduces inventory costs but increases the per-part changeover cost, while long runs decrease manufacturing cost but increase inventory costs. (See Figure 20.5) The most economical point is where the two costs are at a minimum. This point is the "economic order quantity," or EOQ.

Some level of fast changeover is built into most current packaging machinery. Many older, still reliable machines and lines are being rebuilt to increase production by reducing changeover time.

Introducing fast changeover to existing lines starts with listing all the elements in a changeover from "going" to "going," that is, from the last sellable part off the old configuration to the first sellable part made at production speed on the new configuration. It includes both the "hang time" (i.e., the time that the machine is off) and the "run-in time" (i.e., the time required to bring the line up to capacity run speed). Total changeover time can be grouped into four categories:

- Preparation or organization: retrieve parts, gather tools, locate mechanics/operators.
- Changeover: remove and remount change parts.
- Measurement: settings, calibrations, centering.
- Trial run: run-in, final adjustments.

Make a histogram (i.e., a detailed bar chart showing where time has been spent to effect the changeover). Focus on the histogram's longtime elements.

Determine ways to accomplish time reductions:

The ideal changeover takes no time, no tools, no talent, no muscle and you can sell "first off."

- Eliminate the need for tools.
- Externalize or "offline" as much as possible.
- Make all settings to a quantified scale (no "eyeballing").
- Perform the changeover from one side of the machine and in one direction.
- Have a single documented procedure for all operators.

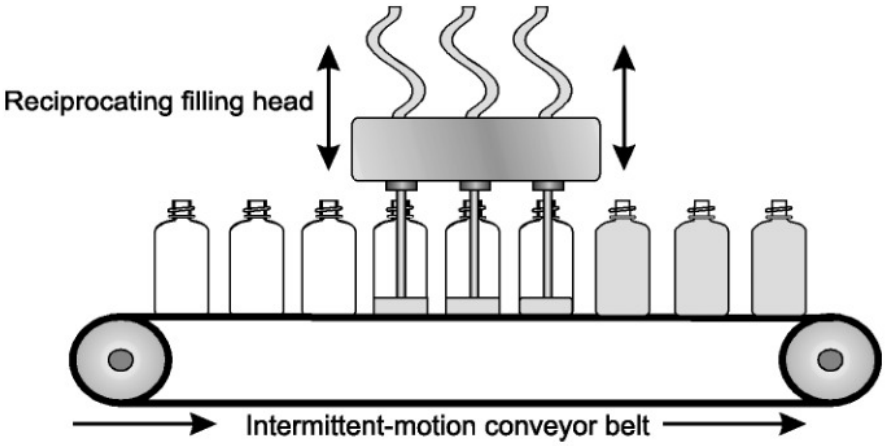


Figure 20.6
Intermittent-motion straight-line filler.

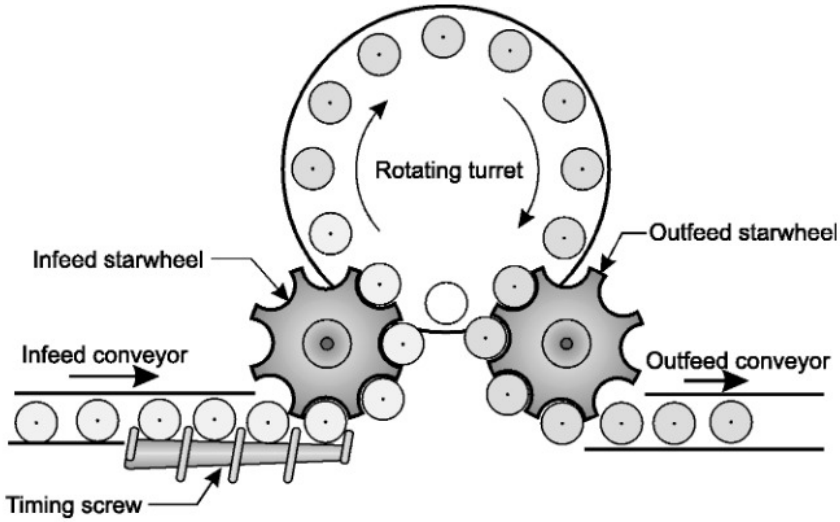


Figure 20.7
Rotary machines are able to operate at higher speeds than intermittent machines.

MACHINE CONFIGURATION

Packaging machines, such as fillers, cappers and labelers, can be designed in straight-line (intermittent) and rotary configurations. Straight-line machines usually index a product into an operational station and then hold it there until the operation is completed.

For example, intermittent-motion straight-line fillers move containers under the filling heads and then stop for the fill cycle. (See Figure 20.6) The machine may have one fill head or several ganged fill heads. Intermittent fillers have operating speeds of up to 150 units per minute. (Some straight-line fillers move the filling heads with the container to achieve a continuous straight-line fill.)

Continuous-motion (rotary) machines feed the container into a rotating turret, where the operational heads work on the moving container. Rotary machines require a timing screw infeed into the starwheel to separate the containers to the correct pitch. (See Figures 20.7 and 20.8) The starwheel changes the direction of the

Figure 20.8
A rotary filling machine showing infeed timing screw (also called a helix), the infeed starwheel and the filling stations.

container flow and inserts the containers into the filling turret or moves them back onto the conveyor as needed.

As the turret diameter increases, more stations can be placed on the circumference. The turret can turn faster and still provide enough time for proper fill.

High-speed rotary turret fillers can be several meters in diameter with more than 100 filling heads. Rotary fillers operating at 80 cpm are common, and machines for the beverage industry can achieve speeds of 2,000 cpm.

FLEXIBILITY

With today's shorter runs and frequent changeovers, flexibility is an essential attribute for packaging lines to minimize downtime, maximize productivity and cut costs and capital investment requirements. Flexible lines simplify changeover for multiple products, package sizes and perhaps even packaging formats. For example, the latest fill/finish equipment for parenteral pharmaceuticals can handle vials, cartridges or syringes. One line takes the place of lines dedicated to each format, reducing space requirements, capital investment and operational costs.

DEGREE OF AUTOMATION

It's surprising the number of manual and semi-automatic operations that take place today on packaging lines. If the output and labor requirements can be met then semi-automatic systems are a good solution, especially for startups and new products where a business case cannot yet be made for a fully automated line.

But labor constraints, ergonomic concerns and output requirements often necessitate higher levels of automation ranging from automated equipment with manual changeovers and cleaning to fully automated lines capable of running in a lights-out environment.

Figure 20.9
Packaging lines typically consist of filling, closing, case packing and palletizing systems, connected by conveyors, as shown in this illustration from Mettler Toledo. Lines often include quality control equipment such as checkweighers and metal detectors.

THE BASIC LINE CONFIGURATION

Packaging equipment is product- and package-specific, so packaging lines may vary widely. Nevertheless, virtually all packaging lines include stations for line loading, filling, closing, case packing and palletizing, as shown in Figure 20.9. Other functions such as inspection, labeling, coding and stretch wrapping also may be included.

LINE LOADING

In a function described as "line loading" in Henry's *Packaging Machinery Handbook*, packaging arrives on the line via hand-feeding, unscrambling, uncasing and/or depalletizing. Hand-feeding, where one or more operators place packaging directly on the line, is the most labor-intensive but may be sufficient on low-speed lines (less than 60 units per minute per operator). However, repetitive motion and handling potentially heavy bulk bins, cases, or shrink-wrapped bundles of containers pose ergonomic concerns. In addition, the line must be configured to provide space for the number of operators needed to hand-feed.

Unscramblers can automate the infeed operation although they may still be hand-loaded. Unscramblers take the form of rotary tables or bowls. The rotary motion helps arrange containers in single file. An additional mechanism might be needed to position the container in the proper orientation for cleaning or filling.

Uncasing separates the case from the container via belts, a pick-and-place mechanism or a robot. On some lines, particularly glass filling lines, the empty cases, known as reshippers, are moved to the end of the line to be loaded with the filled containers.

A depalletizer typically moves containers layer-by-layer from the pallet to the takeaway conveyor for single-filing into the infeed of the washer or filler. Robots also may perform this task with a pick-and-place action.

LIQUID FILLING

"Wet" or liquid products range from low-viscosity free-flowing liquids to viscous "semi-liquids" to extremely viscous products that might better be classed as semi-solids. Liquid-fill characteristics vary widely, depending on such factors as temper-

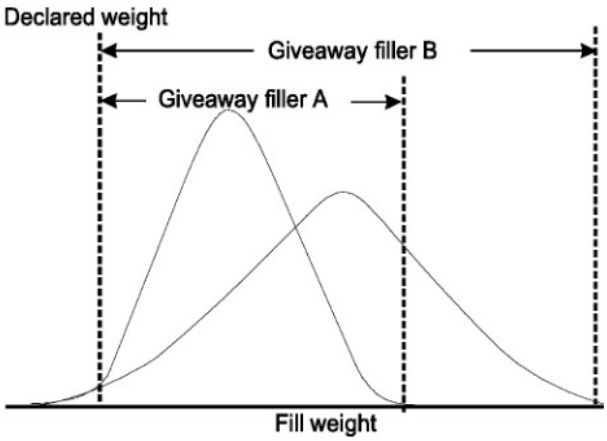


Figure 20.10
The more accurate the filler, the smaller the standard deviation and the closer the filler can be set to the declared fill.

ature, tendency to entrain air, surface tension and frothing or foaming tendencies. Carbonated beverages form a class of their own.

Some products contain a mixture of ingredient types. Instant soups may contain noodles, assorted dried vegetables, dried meat and powdered soup base. It is impossible to premix these and ensure a consistent fill in proper proportions since the ingredients will always separate according to their densities and geometries. Such products need a separate filling station for each ingredient. Mixed solids and liquids, such as canned peas or stew, are similarly filled at two stations: one for the solids and one to top up the fluid portion.

No filler is perfectly accurate, and fillers must be considered in terms of accuracy relative to product value. The challenge is to satisfy legal fill requirements without excessive "giveaway." The more accurate the system, the closer the machine can be set to the declared fill, and the less giveaway there will be. (See Figure 20.10) Accuracy is generally accepted to mean that 99% of all fills meet the declared fill statement. As a practical matter, for quality-assurance purposes, it is the average fill and the standard deviation that often are calculated. The average fill should be at least three standard deviations (sigma) above the declared fill.

Constant-Volume and Constant-Level Fillers

Liquids can be metered into containers so that they reach either a constant level or a constant volume.

"Constant-level filling" is used for most low- or moderate-cost products such as soft drinks, beer and ketchup, where accurate volume is not as important as keeping a visually constant fill level. Containers can have slightly inconsistent volumes due to variations in wall thickness. (See Figure 20.11) Fill height levels will, therefore, vary if the containers are filled to a constant volume. Customer satisfaction demands that all containers be filled to the same level. Constant-level filling achieves this regardless of the actual liquid volume.

Constant-level filling is achieved by using gravity, vacuum, pressure or combinations of pressure and vacuum. The level is controlled by drawing off excess liquid when the required level is reached or by using electronic or pneumatic controls to shut off the filling valve.

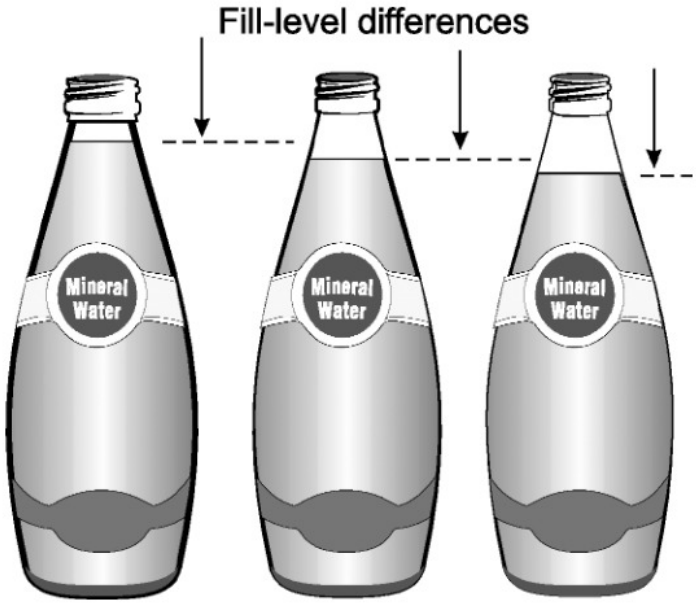


Figure 20.11
Because many containers vary slightly in their actual volumes, filling to a constant volume results in visible fill-level differences.

With "constant-volume filling," a specific product volume is placed into the container, usually with pistons or other accurate metering systems. Uses for constant-volume fills:

- High-cost products.
- Products where net weights must be maintained because the product is sold by weight.
- Products whose end-use demands accurate weight or volume control (such as paint tint bases).
- Pharmaceuticals or chemicals requiring accurate dosage rates.
- Non-free-flowing viscous and paste products.

"Top filling" is done by inserting the filling tube into the container's neck to the fill-height level and allowing the product to drop to the bottom or directing the liquid so that it will run down the container sides with minimum turbulence and air entrapment.

The more common method, "bottom-up filling," inserts the filling tube down to the container bottom and allows it to recede gradually upward as the container fills. Bottom-up filling inhibits frothing, minimizes product aeration, eliminates air pockets in semi-solids and avoids undue vaporization of volatile products. Rigid filling-line connections are used when the containers themselves are raised and lowered. Flexible connections are used when the filling stems are inserted into the containers and gradually moved upward. (See Figure 20.12)

Filling carbonated beverages requires a special approach to eliminate foaming and ensure retention of desired carbonation levels. Product is supplied to the filling heads from a chilled supply bowl that is pressurized with carbon dioxide. (See Figure 20.13) The container is brought up against the filling-head seal, and a multi-

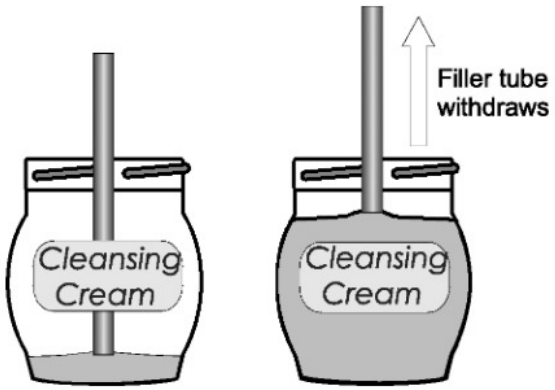


Figure 20.12
Bottom-up filling can be done by lowering the tube into the fixed container and gradually withdrawing it as filling proceeds, as illustrated here, or by putting the container on a stage that can be elevated and then gradually lowered as the container fills.

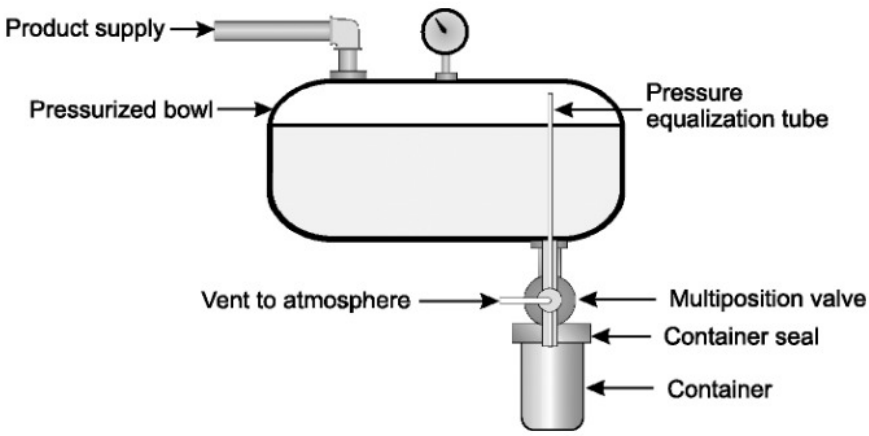


Figure 20.13
Carbonated beverages are filled cold and under pressure to ensure minimum loss of carbonation. Rotary carbonated-beverage fillers can have 100 or more filling heads.

position valve system opens to the supply-bowl headspace. When the pressure inside the container is at about the same elevated pressure as the supply bowl, the valve repositions to allow product to flow from the supply bowl into the container. When the liquid level reaches the bottom of the vent tube, a check valve stops the filling process. A vent then opens to the atmosphere while sealing off the pressure equalization tube. This allows the container pressure to come down to atmospheric levels. The process is virtually foam-free.

"Vacuum fillers" operate by lowering the stem, consisting of the filling tube and a vacuum line, into the container neck and sealing the stem into place with a seal ring. Air is drawn from the container so that air pressure on the product in the supply tank forces product into the container. When the product reaches the vacuum inlet, suction draws it into the overflow tank, preventing it from rising above the fill-height level. Excess product drops to the bottom of the overflow tank, and air is sucked through the tank outlet tube through the vacuum pump.

Vacuum-fill systems are used for free-flowing liquids and products not affected by agitation. Fast, flexible and relatively low in cost, vacuum fillers are limited to rigid containers, e.g., glass, and the constant-level method.

"Gravity fillers" have a filling stem with a spring-loaded outer tube and a rubber seal that fits over the bottle finish. The outer tube is raised by the bottle to open the filling valve. This eliminates drip before and after filling. Gravity filling is slower

than vacuum filling, and for this reason, it is used primarily for some foaming products, since agitation is minimal. Very foamy products demand bottom-up filling. Flow rate is controlled by the height of the product in the supply tank above the filling tubes. Gravity filling cannot be used with slow-flowing products. Few products are filled by gravity alone.

"Pressure filling," which is similar to gravity filling, uses a pump to provide the force to move the product. This makes an elevated supply tank unnecessary and results in a faster product flow. Pressure filling is ideal for viscous products requiring minimum agitation.

Pressure-and-vacuum combinations are used to dispense viscous foaming products into plastic containers. (See Figure 20.14) The pressure gives faster product flow, and the vacuum draws off overflow. The system prevents containers from bulging under the filling seal, which would create an overfill or overflow condition when the seal is removed.

Some of the systems described above require a seal ring on the container finish and an excess-product return line. These may be eliminated by product-level sensing devices. Pneumatic systems use a stream of low-pressure air flowing through an inner tube in the filling stem. The product level exerts a back pressure when the fill height level is achieved. This actuates a high-pressure pneumatic system, which closes the valve and retracts the filling stem from the container. This action provides a drip-free cutoff and eliminates the need for a seal or return line.

Sonic systems bounce high-frequency sound waves off the surface of the rising liquid and cut off the flow valve when the fill-height level is reached.

Piston Volumetric Fillers

Simple "piston fillers" consist of a cylinder fitted with a plunger and a valve. (See Figure 20.15) Product is drawn from the supply tank when the plunger is drawn back and is forced into the container when the plunger is pushed forward. A valve rotates 90 degrees with each cycle. Suction draws the product through the valve duct and into the cylinder during the first part of the cycle. Then the valve rotates,

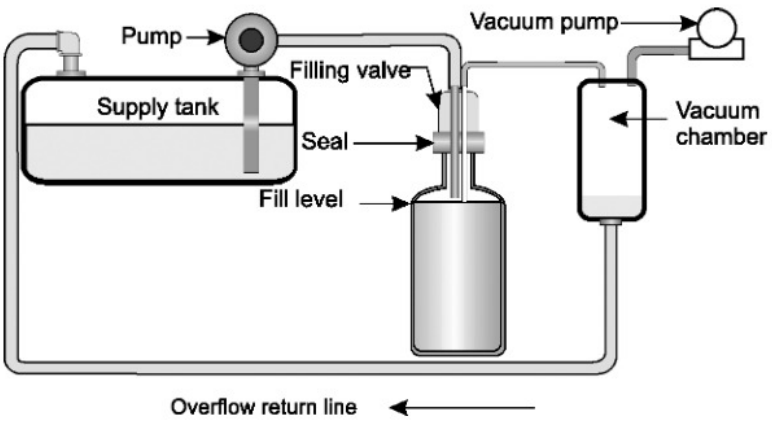


Figure 20.14
Pressure-and-vacuum fill system.

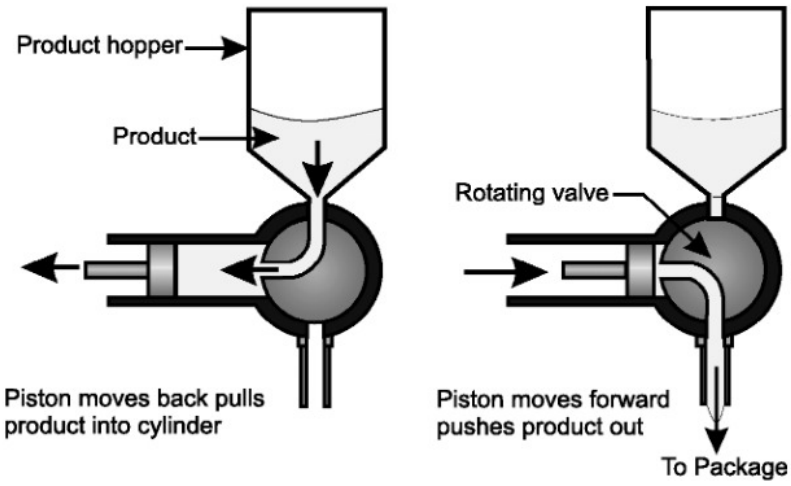


Figure 20.15
A simple piston filler. Piston fillers are able to dispense accurate product volumes.

shutting off the supply tank and allowing product to be forced into the filling spout when the plunger pushes forward.

Piston fillers usually have a control device that prevents the valve from rotating if no container is in the filling station. Product is pushed back into the supply tank without spillage. The amount of product ejected depends on the cylinder's diameter and the piston stroke length. The stroke is adjustable while the machine is in operation.

Piston fillers are available as single, manually actuated pistons or as fully automatic rotary machines with 12 or more pistons. (See Figure 20.16) Many ingenious valve arrangements have been designed for piston fillers. Continuous-motion rotary-head piston fillers are used for high speeds of 500 to 2,000 cpm. They are ideal for viscous or paste products, such as honey, peanut butter, creams and jams, as well as for free-flowing liquids such as fruit juices.

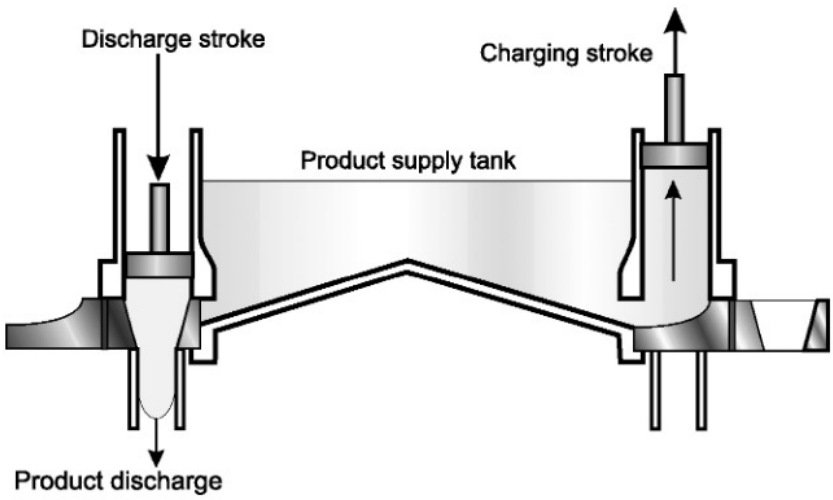


Figure 20.16
Cross-section of a rotary piston filler.

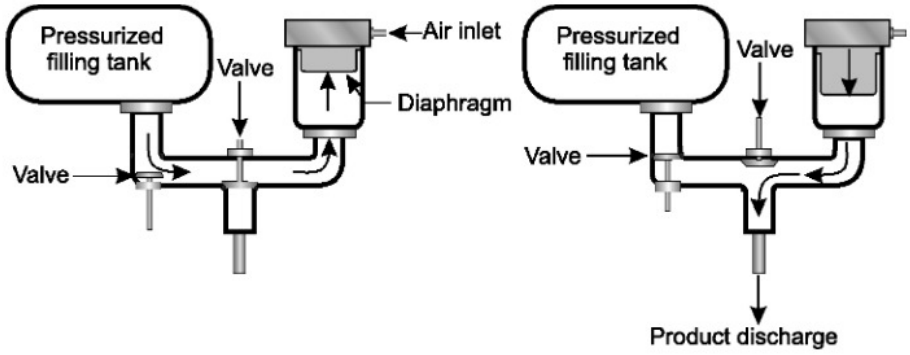


Figure 20.17
Diaphragm fillers dispense accurate volumes of product.

Diaphragm Volumetric Fillers

"Diaphragm fillers" are used to fill a premeasured volume of fluid rather than for filling to a level. (See Figure 20.17) A rolling diaphragm in a cylindrical chamber moves up to charge the cylinder with product. Valves then open to allow discharge into the container when the diaphragm moves down. Precise volumes are attained by adjusting diaphragm movement. The use of a rolling diaphragm eliminates the need for seals between piston and cylinder, as would be needed on a piston filler. Such sliding seals, however, can cause abrasion and particle generation.

Metering Pumps

"Metering pumps" rely on positive displacement pumps or constant output impellers to measure a preset amount of product. To control the amount dispensed, the pump usually operates for a preset number of revolutions and then stops. Timed pumps are also available but are said to be less accurate. Pump fillers are used for aerosol propellants and single portions of ketchup, mustard and other liquids.

DRY-PRODUCT FILLING

"Dry" products include discrete items such as candies, fasteners, pills and nuts. Discrete items often are counted for filling. Free-flowing powders or granules are powders that have a reasonably consistent density and pour readily to form a fairly flat cone when dumped on a plane surface. The flatter the angle of repose, the more readily the material will flow and the more consistent the density. (See Figure 20.18) Because of their free-flowing character and consistent density, they are fairly easy to measure by a variety of methods, including simple free-fall gravity feeders.

Unlike free-flowing powders, other non-free-flowing powdered and granular products do not flow readily and have a steep angle of repose when poured out on a table. This type of material frequently bridges and clogs passages. Some have a tendency to agglomerate, pack or entrain air and, therefore, the density is not consistent. These materials cannot be fed by gravity alone; provision must be made for physically moving them through the filler. Since their densities vary, volumetric fills are inappropriate.

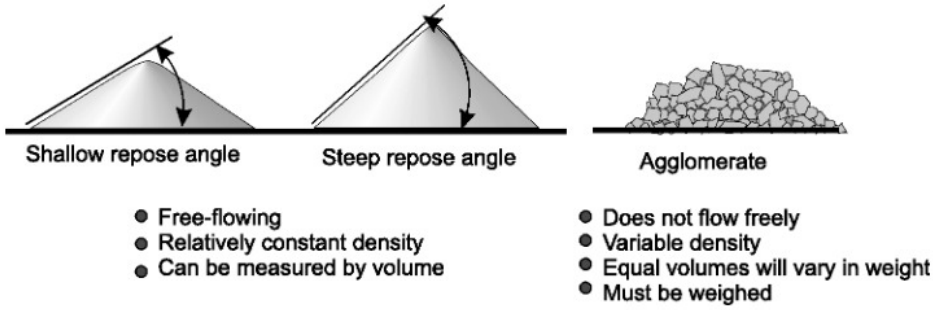


Figure 20.18
Types of dry products include free-flowing, non-free-flowing and agglomerated.

Finally, products such as potato chips, dry cereals and some other granular compositions are fragile and must be handled gently. Vibratory feed systems and net weighing typically are used for these products.

The three principal methods of metering dry fills are by:

- Volume.
- Mass or weight.
- Count.

Volumetric-Cup (or Flask) Filling

In its simplest form, a "volumetric-cup" filling machine consists of a flat, circular plate fitted with open-top cups at regular intervals. As the plate revolves, the cups fill by passing under a product hopper. Scrapers or brushes ensure that the cup is even and level. The cups revolve to a discharge station where the product discharges to the container. (See Figure 20.19)

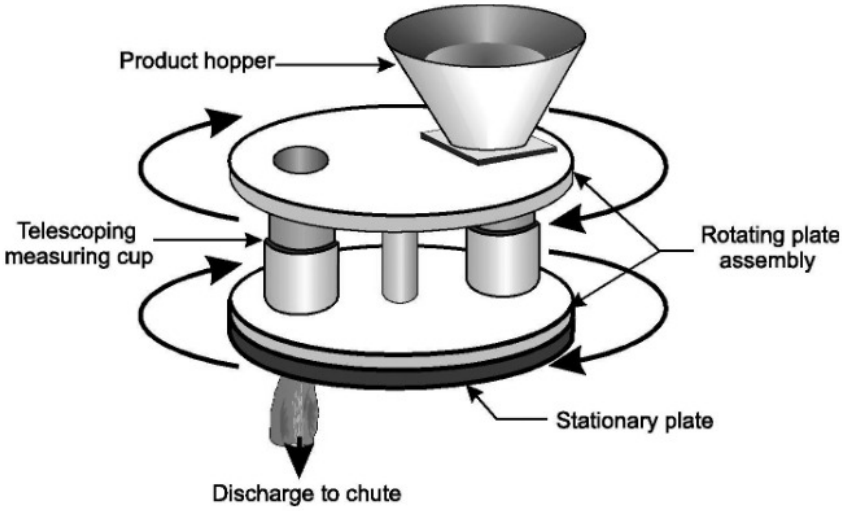


Figure 20.19
Volumetric-cup filling is the simplest form of volumetric filling for dry products. Moreover, it is the least expensive and requires minimum maintenance and changeover.

The simplest discharge system employs a stationary disk under open-bottom cups. This disk has a single opening at the discharge station, and the product is contained in the cups by the disk until the discharge opening is reached. The alternative system employs a trap door under each cup, eliminating the stationary disk. The trap doors open at the container-filling station and close again before the cup-filling station is reached. Volumetric adjustments are made by using telescoping cups, with the bottom half of the cup sliding up over the top half. The maximum adjustment cannot be more than a 2:1 ratio.

Cup- or flask-filling is used for free-flowing solids of consistent density. For consistent density and an even flow of the product into the flasks, it is advisable to maintain a constant level in the feed hopper.

Vacuum-Volumetric Filling

"Vacuum-volumetric filling" is accomplished via a rotating wheel with adjustable volumetric cups. When a cup is in the top position, product is fed from a hopper. As the product flows into a cup, a vacuum is drawn from the center of the wheel, through a very fine filter. The vacuum removes the air from the product, making it more dense and compact.

The wheel rotates to the discharge station, where the vacuum is released. The slug of product is discharged into the container either directly or, when a small-mouthed container is used, through a funnel. This filling method proves accurate with products that are normally light and fluffy and entrain large quantities of air such as talcum or cocoa powders.

Auger Fillers

"Auger filling" is a volumetric form of product measure used for free-flowing and non-free-flowing products. This type of filler consists of a supply hopper and an auger, or "worm," running in an outer sleeve. (See Figure 20.20) The sidewalls of the

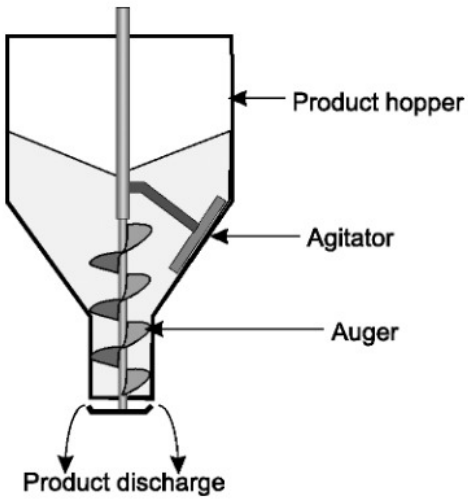


Figure 20.20
An auger filler.

hopper are funneled to form the sleeve in which the auger runs, and the product is discharged from the end of the tube into the container.

When the machine stops, free-flowing product is prevented from falling through by a saucer or disk attached to the lower end of the auger. Free-flowing product uses a straight auger. As the auger spins, the centrifugal force throws product off the disk. The amount measured from an auger filler can be controlled either by a time cycle or by counting its revolutions. Accuracy is largely dependent on the mechanism used to start and stop the auger rotation.

Product characteristics determine auger construction. A straight auger is most suitable for products that do not tend to pack in the hopper. Tapered augers are used with loose products. The larger auger flutes are capable of handling more product than the smaller flutes running in the sleeve. This also ensures that the auger at the discharge point has a continuous supply of product.

Although used primarily for dry products, particularly in the spice industry, auger fillers also can handle many semi-solids such as ointments, thick sauces and patching pastes.

Net Weighing

"Net weighing" employs weigh cells and tared weigh buckets to accurately weigh the product and transfer it to the container. In older systems, product is fed from a hopper, usually by a vibratory feeder, to a scale bucket. An electrical contact stops the feed when the required product weight is in the bucket and trips it to discharge the product into the container. A single-station net-weigh scale cannot work at speeds much higher than 20 or 22 weighings per minute.

An inherent problem of net weighing is the presence of product in midair between the feeder and the scale at the time that the correct weight is reached in the scale bucket. This can be corrected by a "bulk-and-dribble" system that splits the feed into a fast-flowing bulk stream and a slow-flowing dribble. Both lines feed the scale bucket until the required weight is nearly reached. The bulk feed then stops, and the dribble feed continues until the final weight is obtained. This minimizes the amount of product suspended between the feeder and the scale bucket but slows the filling process.

That amount of product above the declared weight, or "giveaway," is an important cost factor. Product cost and legal requirements justify the higher price of accurate scale systems rather than volumetric measure. These considerations have spurred many improvements to the basic net-weighing system.

Bulk-and-dribble filling methods have been replaced by computerized "staged-weighing systems." In these systems, final product weight is based on combining product from several weighing stations to fill the container. Approximate quantities of product are distributed among several holding buckets. The amount dropped in each bucket is usually between 20% and 33% of the required fill. The product in each bucket is weighed by a load cell integral to the bucket. Then, a microprocessor selects the three, four or five buckets that will provide the fill nearest to the declared weight.

In the system illustrated in Figure 20.21, product is brought by vibratory feeders from the main supply hoppers to the filler's circular dispensing cone, and then along individual vibratory feed trays to one of several staging buckets. (Most machines have between nine and 14 buckets. Fillers may be based on a circular-flow dispens-

ing pattern, as shown in this text, or may have a linear-flow pattern.) The vibratory feed trays operate on a demand-timed cycle, only when a staging bucket is empty. The staging buckets empty their contents into their respective weigh buckets whenever one is available. Load cells determine the weight in each bucket and enter these data into the filler's microprocessor memory.

When a package becomes available for filling, the microprocessor searches through the available weights and releases a combination of weigh buckets that is closest to the declared weight but not under. An example of computer-combination weighing is given in Figure 20.22.

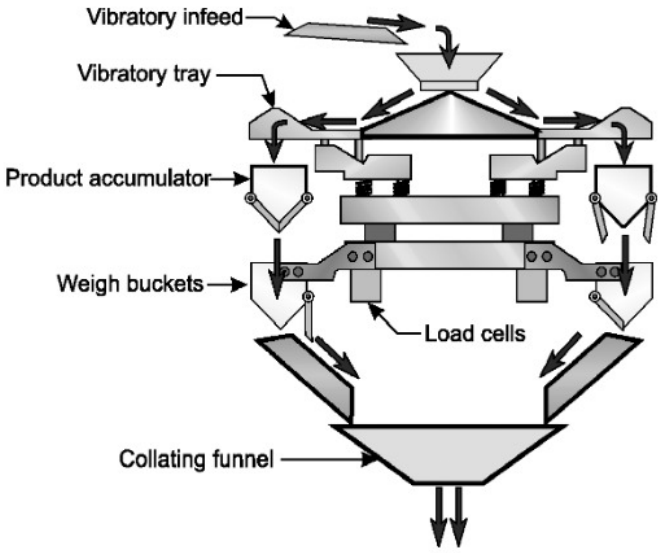
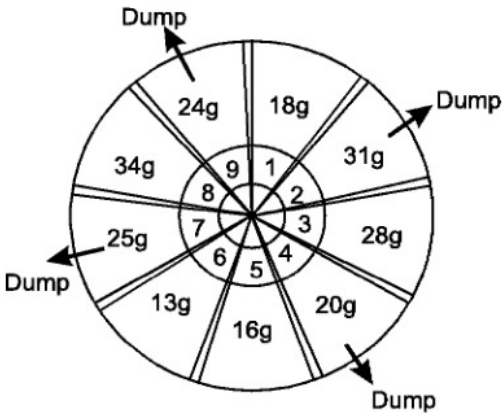


Figure 20.21
Cross-sectional view of a computer-combination or statistical-weighing filling machine. A weigh bucket and a product accumulator bucket are shown in the open position. Some machine variations have another set of holding buckets underneath the weighing buckets. Computer-combination fillers can perform 120 weighings per minute.



BEST COMBINATIONS

Weigh Buckets	Total Grams	Computer Decision
2,4,5,7	92	X
2,4,5,8	101	X
2,4,5,9	91	X
2,4,6,7	89	X
2,4,6,8	96	X
2,4,6,9	88	X
2,4,7,8	110	X
2,4,7,9	100	yes
2,4,8,9	109	X
2,5,6,7	85	X
2,5,6,8	94	X
2,5,6,9	84	X
2,5,7,8	106	X
2,5,7,9	96	X
2,5,8,9	105	X

Figure 20.22
There are 511 possible bucket combinations on a nine-bucket computer-combination weigher. The 15 combinations closest to the 100-gram (g) target weight are shown here. The machine will combine the product in buckets 2, 4, 7 and 9 to dispense exactly 100 g.

For example, an assortment of chocolate-covered confections has pieces weighing from 2 to 8 grams (g). With bulk-and-dribble systems, the average giveaway is about 20 g in a 350-g package (0.7 oz. in a 12-oz. package). Staged-weighing divides the feed stream into 10 holding buckets, each typically holding 70 to 120 g. The computer selects whatever combination of buckets comes closest to but not under the declared fill weight. Giveaway is reduced to 0.5 g (0.02 oz.).

It is possible to use load cells to check container tare weight and automatically adjust the gross weight so that consistent net weights are obtained. This system requires two weigh cells. The first cell weighs the empty container and relays the weight to a receiver and a memory unit, which adjusts the reference voltage so that an accurate net weight is obtained. Sophisticated systems record weights continually; compute averages, deviations and ranges; adjust fillers through feedback; and eliminate off-weight packages.

Number Counts

Electric-eye counting, perforated-disk counters and measurements from chutes or channels are used for packages requiring exact numbers of discrete pieces. "Electric-eye counting" is ideal for hardware and tablets, where versatility and quick changeover are required. A photocell counts the items passing in a single file along a belt or conveyor. Usually, a gate diverts the stream of items from one channel to another as soon as a required count is completed.

"Rotating perforated disks" provide a simple, inexpensive method for counting tablets or capsules. The mechanism consists of a metal or plastic plate that revolves over a fixed plate. The revolving plate has holes that are appropriate to the tablet size and are grouped according to the desired count per container. As the plate revolves through a feed hopper, the holes fill with product. An orifice in the stationary bottom plate allows the items to drop out of the holes into a discharge spout. An inspector checks to ensure that all the holes are full.

"Chutes" and "channels" are the most popular counter device for tablets or pills of consistent size. The product travels single file down the channels and is measured linearly to give the correct number. High-number counts are obtained by releasing the required number of single-row counts into a single container. For instance, a fill of 100 tablets might require five counts of 20 tablets. Continuous-motion rotary-head machines can fill 450 such bottles per minute. These machines use rotating turrets with vertical chutes, and the bottles are automatically indexed.

An adaptation of the "perforated-disk-type counter" involves the use of a series of slats moving on an inclined plane. The openings in the slats are designed to the product shape. The slats move through the hopper area, where they pick up the product, then carry the count to a discharge section, where it is released into a bottle chute.

Orientation devices are needed for irregularly shaped items such as screws, nuts, bolts or other hardware. Usually, bowl-shaped vessels act as hoppers. The unoriented items tumble or vibrate in such a way that they settle into a track leading out of a hopper. Unoriented items are detected and blown back into the hopper. The track leads to a conventional counting station.