Chapter 8

Packaging Machinery, Filling, and Plant Operations

Machinery Types

There is an endless variety of packaging and food processing machinery that are available or that can be manufactured to the users' specification, and many of them are remarkably similar. One of the great problems in choosing machinery is distinguishing which, if any, offer any particular advantage over the other. Similarly, the degree of versatility must be considered; it is pointless to buy a do-everything machine when there is only a single task at hand, and similarly a machine with too little adaptability may be a bottleneck in a variable production process.

The assembly sequence of the particular product and package will dictate the type and position of the machines and personnel tasks, but the sequence of operations will follow the general pattern shown in Figure 8.1.

Intermittent and Continuous Machinery

Machinery can operate on an intermittent or continuous (*straight line*) basis depending on the needs of the production facility and the amount of capitalization available. Typically, intermittent machinery will take a single package or small number of packages, perform an operation on them all at once (often after stopping their motion), and then pass them along to the next process step. A continuous-operation machine accepts a stream of packages "on the fly" and performs the operation without stopping or slowing the motion of the overall flow of material. Whereas a four-station manual-feed filling machine might be suitable for a small winery, that machine would be pointless for a soft-drink bottler who requires several thousand fillings per minute to remain economically competitive. Conversely, while continuous machinery is more economical at high throughput rates, it might make little sense to have a high-capacity operation that is active only for several hours a week because of low demand, although for the smallest of markets this may happen because of the employment of used machinery and the lack of appropriately scaled equipment.

Machinery for Specialty Products

Whereas the specialized machinery for creating and filling aseptic and hot-fill products is discussed in Chapter 6, other similarly stringent requirements exist for many types of common products. Hair products may contain quantities of volatile peroxides and other aggressive chemicals that must be handled properly. Pharmaceutical products may have to be both produced and packaged under sterile conditions, some products contain fine powders that may contaminate

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Food and Package Engineering, First Edition. Scott A. Morris.

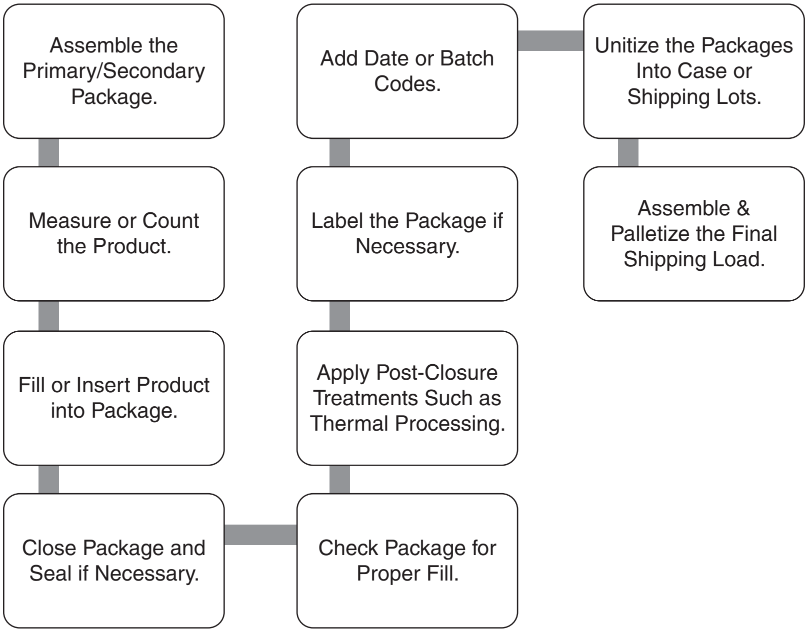


Figure 8.1. Package Assembly Sequence

other parts of the operation, and nearly all types of food processing equipment must be thoroughly cleaned regularly and then returned to service on a timely basis. Some of these machines must have glass-lined product-contact surfaces, or entire machines that are made of stainless steel to avoid corrosion or reaction with the product or cleaning solutions.

Other process considerations must be taken into effect; controlled-atmosphere packaging will require a gas supply system, as does sparging equipment for the previously mentioned wine filler, and for some products, the actual product manufacturing and handling system may be run under a gas layer to reduce the amount of oxygen present during formulation.

Package Erection and Assembly

Taking prefabricated packages from their collapsed or jumble-packed state to readiness on the production line requires machinery that is a specialization unto itself. Bottles must be unscrambled and oriented for proper filling, as must their closures. Flat cartons must be dispensed from magazines or otherwise loaded into machinery, then pushed open and the end flaps made ready for closing, bags may need to be grasped and opened, film may need to be preformed or heat sealed and trays thermoformed from stock. Each process will have its own unique list of operations.

Each of these operations is both specialized and necessarily meticulous – poorly formed packages will jam, misfill, or spring open farther down the production line. This is particularly problematic in food processing plants that often have live steam exhaust or a high humidity level during operation that can affect paper products and processes such as the handling of films and the setting of adhesives.

Fillers, Feeders, Metering, and Measuring

The essential job of fillers and feeders is to take product in a predetermined number or amount to fill the assembled package. There is a broad spectrum of different types of equipment to achieve this, many of which can handle difficult materials such as thick pastes and creams, or very fine objects.

The simplest of machines will fill and dump baskets, cups, or trays of material, are well suited to loose and granular products such as cereal and animal food, and can be used for single objects if the objects are properly oriented in feed chutes going to the packaging machine. These may be fitted with weighing sensors to allow a net-weight fill to be directly applied to the product, and may use a combination of smaller fill trays to approximate the net weight more accurately. It is also possible to use auger metering where the product is dispensed by either timing or counting the rotations of an auger that delivers product into the package.

Many types of powders, particulates, and granular products are subject to *bridging* or *arching* phenomena, where the powder or material will jam feed chutes if they are not properly designed for the product. Fine powders form cohesive arches using interparticulate bonding whereas larger particles will form interlocking arches where the mechanical locking of irregularly shaped particles provides the cohesiveness to form arches. Both of these phenomena rely on the same principles that traditional arch structures in bridges and buildings use – transferring radial compression into vertical and lateral force to maintain the arch structure. Additionally, *ratholing* may occur where product is only removed from the center portion of the hopper while leaving the material near the wall intact. Worse, the flow may alternate between ratholing and arching, creating erratic flow conditions, as shown in Figure 8.2. Proper design of the hoppers for the product as well as adaptive equipment such as agitators or *bridge breakers* may be necessary to keep the device operating properly.

The converse side of the bridging phenomena is that it can be used to stop product from flowing in certain types of measuring devices, such as screw-auger fillers. These are designed

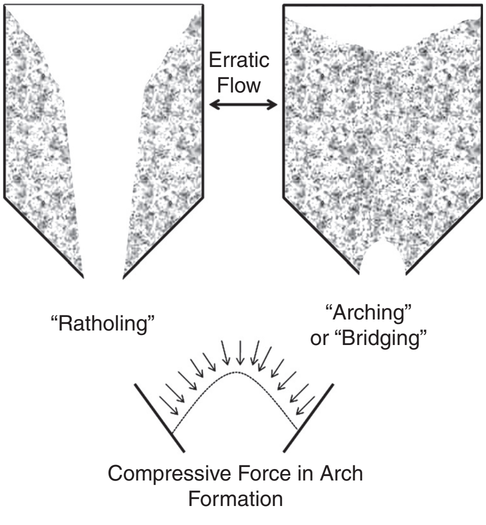


Figure 8.2. Particulate Bridging and Ratholing

with a small disk at the end of the auger that creates blockages when the auger is not rotating and rely on bridging to stop the flow between package fillings.

Direct counting machines can use trays, simple photocells, or complex vision-system pick-and-place manipulators to acquire the exact number of products required in a package. Similarly, it is possible to use the package or an inner tray as a measuring device, filling it with the proper number of product units, and then enclosing it in a larger secondary package. Liquid and semi-liquid materials are usually either filled with displacement or metering pumps or fed into a package by vacuum displacement, and often the product may be heated to reduce viscosity and to speed up the fill rate. Products that can change substantially when heated may have to be carefully handled with this type of system. For example, peanut butter, which is too viscous to handle efficiently at room temperature, is heated so that it may be pumped into packages, but protracted overheating will cause destabilization of the saturated fats added to prevent separation, leading to severe separation of the oil components and degradation of the product texture and quality.

Metering of liquid and semi-liquid materials can be achieved by timed flow, fixed-volume displacement pumps, piston systems, fill-level shutoffs, or drains in the filling head, and are roughly divided into constant-level fillers and constant-volume fillers. Constant-level fillers are most often used where the product can be seen through the container and a variable-fill level will make a package or shelf-full of product look as though some have been underfilled. This is most often used with glass containers because of their variable internal dimensions. This is the reason for many bottles' label-wrapped necks, which hides the fill line and allows a constant volume fill. Liquid fillers may have to include bottom-up filling capability, where a filling tube dispenses a thick liquid from the bottom of the container and withdraws as the fill level increases, or a pressurized seal to allow carbonated beverages to be filled under pressure.

Form-Fill-Seal Systems

Form-Fill-Seal (FFS) machinery is a preferred method for many food items, and as the name implies, it forms packages from roll stock around a central mandrel that incorporates a product fill tube and allows the forming, filling, and sealing of packages of nearly all types of products from hardware kits to liquid condiments. Many types of these may be multiple-head machines to produce small packets of sauces for fast-food restaurant use. With many types of food products, the product handling must be done accurately as the filled pouches are filled to avoid contaminating the seal surfaces. Additional types of machinery peculiar to the food industry will insert slices of meat products into folded or vacuum-formed film and seal it, or will even extrude a cylinder of cheese food product into a tube of plastic film and then flatten and seal the product to create the familiar wrapped processed cheese food slices.

Specialty machinery may be necessary for particularly sensitive materials such as fruit juices and meats that may discolor with the slightest acquisition of dissolved metal [1]. In the most extreme cases such as processing some types of juices and many types of pharmaceutical and cosmetic products, special surfaces must be constructed for contact with the product using materials such as borosilicate glass, Teflon, or other materials, as appropriate.

Robotic Operations

Robotic operations are most effective in jobs that are repetitive and predictable but require either handling heavy goods, as with palletizers that are discussed further on in this chapter, or

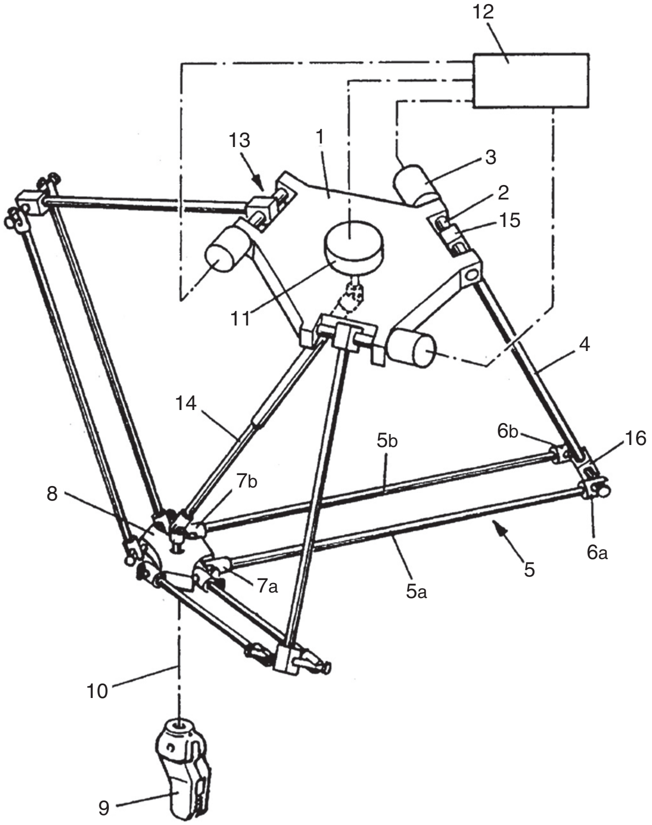


Figure 8.3. Delta Robot Detail
Source: U.S. Pat # 4,976,582

with fast, accurate pick-and-place operations that demand consistent, accurate results at speeds that human operators would have difficulty maintaining. The latter application is common in some types of food packaging operations, and one of the first and most complete integration of robotics in the food packaging industry was in the high-speed filling of boxes of assorted chocolates where dozens of different products had to be accurately placed in a moving container.

While many robotic installations mimic the human arm, or involve an articulated manipulator set on a rotating base, so-called *delta robots* (Figure 8.3) have been successfully integrated into many packaging operations. Originally developed by Raymond Clavel at École Polytechnique Fédérale de Lausanne, these can be built with high-speed actuators and lightweight carbon fiber elements to provide extremely accurate high-speed operation for the handling and placement of small, light objects. They have been implemented in many applications ranging from machine parts to bakeries and confectionary manufacturing.

Pre-closure Treatment and Closure Application

Closures and seals may be applied as discussed in Chapter 5, but increasingly a pre-closure treatment such as a headspace gas flush may be applied. This may require an extraordinarily complex system of nozzles and diffusers to avoid blowing the product out of the package or contaminating the seal. Vacuum application may be required, either alone or as a part of the gas-flush process as in a draw-redraw flushing where air is withdrawn, replaced with gas, and the process is repeated to ensure saturation of the flush gas. This procedure is common in products with high interstitial volume, such as bagged salads.

Accumulators and Conveyors

Accumulators are used as a means of aggregating the output of one stage of production in order to smooth the flow into the next step. Paradoxically, they are also used as dispersers, allowing a huge surge of input such as the unloading of a case of components, or the output of a batch of thermally processed product to be slowly metered out into other steps in the production process. Most often, these are simply a flat table or conveyor that allows the physical aggregation of material in a single plane, though it is possible to create multidimensional stacking or spiral accumulators. Because accumulators are used as buffers, they can be used to keep production synchronized among machinery operating at different speeds, to disperse high-output results into multiple slower machines (and vice versa), and frequently to correct poor line-integration practices. They also can be used as a *time delay* buffer, allowing machinery to be maintained or otherwise manipulated without bringing upstream production to a halt.

Conveyors carry material from one operation to the next and can be as simple as a smooth surface that lets material slide downhill or as complex as an air jet conveyor that floats containers along above its surface. Often, they provide powered rollers, discs, or belts that move product along. Conveyors also may act, in a limited sense, as accumulators, because they provide a wide area for product to aggregate between process steps, and large, spiral conveyors are often used in processing such as the cooling of product from ovens, chilling of products in freezers, or the *proofing* (final dough rising) of bread products in large bakeries because of their ability to provide more exposure time in less space.

Checkweighing, Inspection, and Measurement

Many packaging operations, particularly those involving food, require some kind of checkweighing or fill level inspection step to ensure that the package meets its label claim. The use of checkweighers demands a balance between the risk of under-filled packages (curve “C” in Figure 8.4) and therefore not meeting the label claim as required, and the cost of giving away extra product (curve “A” in Figure 8.4). Because of this, accuracy both in metering product and in measuring it after filling is at a premium. A tight grouping of fill weights or volumes as shown with curve “B” in Figure 8.4 as a result of both accurate metering and of inspection speaks well for the integration and adjustment of the filling line, as well as providing the most profitable setting for under-fill versus giveaway.

Although the weighing or measuring of the fill in a package may seem a simple matter, the implementation may be complex. Weighing a product on a moving conveyor belt may involve specialized machinery that samples the weight of packages at a precise time and place on a weighing belt, whereas fill levels, particularly in opaque containers, may require any number of steps including X-ray imaging. Checkweighers are also used for less intuitive applications such as checking consumer appliances to ensure that components have not been omitted from the final assembly.

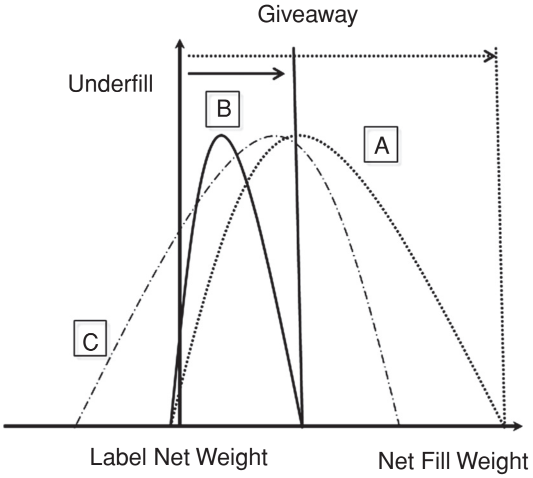


Figure 8.4. Fill Weight Distributions

Product Inspection

Inspection of the finished package is often a part of the manufacturing process. This can range from the occasional glance at the production line to sophisticated automatic inspection devices to ensure complete seals on shelf-stable foods and pharmaceuticals. It is tempting to think that human inspectors can be freed entirely from the tedious task of package inspection, but there are some caveats that must be considered when considering any type of inspection device, including checkweighers.

An inspection or measurement device (or person) must have several characteristics to provide reliable measurement or rejection of defective or out of tolerance products or components:

Sensitivity – the minimum magnitude of stimulus required to produce a specified output in a measuring device.

Resolution – the minimum amount of change in the measured quantity that can be detected by the measuring device.

Accuracy – the closeness to a "true" value, often a standard item or standardized measurement value.

Precision – the narrowness of distribution of measured points about a mean value.

A good inspection system should incorporate all of these characteristics, but cost and design considerations impose limits. The development of more complex inspection systems is hampered by the trade-offs inherent in creating devices or systems that will work well in high-speed production lines. Whereas some industries, such as glass production, have a sufficiently homogeneous product to have implemented automated visual inspection decades ago, this kind of automation has evaded much of the packaging and particularly the food packaging industry. For example, acoustic resonance testing on filled metal cans can provide a quick and reliable test of the can's integrity, but a stream of retort pouches coming from a filling line has both so much inherent variability in product and such subtlety in dangerous defects that manual inspection remains in place for all but the grossest seal defects, which are usually tested by low-resolution pressure differential machines.

The Base Rate Fallacy and Inspection System Failure

Inherent in any inspection system, whether automatic or manual, is the probability of *false positives*. Essentially this means that for a number of products being inspected, inspections will provide an indication of defect when there is none. In a population of manufactured goods that have a high quality level, this can result in a lot of product being needlessly rejected. The most common example of this is in medical diagnoses:

> *In a population where the known incidence of a particular disease is one case in 1,000 members of the general population, and the false positive rate for the medical diagnosis – the rate at which the diagnosis will tell you that you have the disease when you are healthy – is 1%, a positive test among 1,000 people will return 1 true positive test and 10 false positive tests – 11 positive tests in all. Thus, a patient getting a positive test would only have a 1 in 11 chance (about 9%) of actually having the disease.*

Although the previous example underscores the sensibility of “getting a second opinion” and has significantly changed many diagnostic procedures, it also highlights how quickly the number of false positives can grow in a large population with a low incidence rate and an apparently accurate test method [2,3]. It also indicates that the results can be quite counterintuitive and has lead patients who do not understand the concept to have unnecessary surgery based on a single diagnosis or even to commit suicide thinking they have a low-incidence fatal disease based on a single test with a relatively high rate of false positives.

In manufacturing environments, where the “population” may number hundreds or even thousands of units per minute, a very low actual defect rate coupled with even a modest rate of false positives can very quickly create an enormous absolute number of false positives, and a distrust of the detection system. For example, the production of canned goods at a rate of three hundred cans per minute, with an actual defect rate of one can in ten thousand, a test accuracy of 99.9% and a false positive rate of only .1% – all excellent figures – gives performance levels shown in Equation 8.1:

$$
\begin{aligned}
&\text{Defective Product :}\\
&\text{Production Level :} \quad 300/\text{minute} = 432{,}000/\text{day}\\
&\text{Actual Defects :} \quad (432{,}000/\text{day}) \cdot (0.0001) = 43.2 \text{ defective cans/day}\\
&\text{False Detections} = 0.1\% \; (432{,}000/\text{day}) = 0.001\,(432{,}000/\text{day}) = 423 \text{ false detections/day}\\
&\text{True Detections} = 43.2 \text{ defective cans/day} \cdot 0.999 = 43.157 \text{ true detections/day}\\
&\text{Total Detections} = 466.157 \text{ detections per day}
\end{aligned}
$$

Thus, the probability of a detection being accurate is

$$
\begin{aligned}
&\frac{\text{True Detections}}{\text{Total Detections}} = \frac{43.157}{466.157} \cong 0.0926 \cong 9.26\%\\
&(\text{Missed Detections} = 43.2 \text{ defective cans/day } - 43.157 \text{ true detections/day}\\
&\qquad = 0.043 \text{ defective cans/day, or about one every 23 1/4 days)}
\end{aligned}
\tag{8.1}
$$

With such a low probability of accurate detection, due to the low incidence of real defects being swamped by false alarms, if the cost or annoyance of a single false-alarm event becomes significant, the overall cost of operating the detection system can make it unworkable. Much like a smoke detector that goes off with random household events, it will eventually be disconnected despite the inherent hazards involved. Anecdotal information from production engineers has indicated this to be the case for several of the automated detection systems that have been marketed and test-run in actual production systems. Therefore, for design and specification purposes, it may be necessary to develop a minimum acceptable false-positive level for a testing device or protocol.

For safety-related concerns such as seal integrity in food and medical packaging, the costs of failure detection can be significant if the implication of detection is that system parameters must be altered or the item must be exhaustively inspected based solely on the detection system's "flagging" the item. Of course, the costs of missing a defective item can be extraordinarily high in such cases when liability and safety concerns are factored into the situation. Multiple-level inspections or a more involved testing procedure may be necessary in this instance.

Case Packers

Although case packers are thought of as a distinct type of machinery, it is not unusual to have case packers that drive home at the end of their shift. Many operations still depend on manual labor for some level of case aggregation, filling, and packing. Although tedious, this can be assisted by accumulator tables where product can be lifted in case quantities or inverted cases turned over for the final grouping. Larger operations may automate many of the tasks, with machines lifting case quantities into shipping containers and sealing them. At this point, particularly for small consumer items and food, the handling of the filled case deserves some attention to the ergonomics of the material movement, discussed later in this chapter, because the filled case may be heavy enough to cause health or safety problems for the personnel involved.

Palletizers

Manual palletization may be used much as with case packing, but because of the risk of repetitive-motion injuries and the likelihood of dropped cases, there is often mechanical assistance used in the high-speed accumulation of pallet loads of finished goods. Palletization is one of the first areas where large-scale automation and robotics were integrated into packaging operations because of the combination of load weight, precision placement, and speed of operation. As heavy-lift robot arms become more capable, they may be preferred for ease of setup and flexibility of mixed product loads and interlocking stacking patterns.

If mechanical assistance is used in palletizing or handling, the case itself must be designed with the material handling system in mind. For example, vacuum-lifting structures in an automatic palletizer may put unexpected tensile stress on box flaps that will pull them open if the box-closing adhesive or tape is inadequate.

Machinery Acquisition

Machinery acquisition is a function of whether the line is expected to run continuously or intermittently, the production level and lead time available, the relative cost of other alternatives (including leasing, used equipment, and contract packaging), the payback period, and capital and installation costs. Because many machinery acquisitions are made to supplement existing lines, the equipment must be specified to interface properly with the existing operation. This may require retrofitting controls on the older machinery or the alteration of the physical characteristics of the components. One perplexing difficulty that may be encountered is the reluctance of a few machinery suppliers to adapt their machinery to the product design being considered, which argues strongly for involving machinery considerations throughout the package design process.

Machinery suppliers should be carefully investigated to ensure that parts and service are available, if necessary, and if delivery, setup, and installation schedules can be met because delivery times for custom machinery can be extensive. Additionally, operator training may be necessary and may have to be done as a jointly scheduled arrangement between suppliers and the production facility personnel.

As the global economy expands to include many types of industrial machinery that may have to be built to order or extensively modified, the current domains of equipment manufacturers will be subject to the inevitable sorts of changes and consolidations that other industry sector have seen. There is no reason to believe that the current broad range of small packaging machinery manufacturers in the United States can continue dividing domestic markets without substantial changes, some of which are already underway. Many small firms are being brought into consolidated operations either through purchase or by cooperative agreement. With that in mind, the range of suppliers is growing to include more flexible, lower-cost manufacturers from all over the world, and domestic manufacturers may become retailers of equipment sourced from many countries. As with many of these changes, the great concern is over the initial quality of machine fabrication as well as a continuing supply of service parts and upgrades.

Many machinery suppliers who are intent on remaining competitive in this increasingly diverse and competitive marketplace have turned to system integration as a value-added service to their machinery manufacturing operation, helping packaging lines with integration of new machinery into more optimal systems so that the customers can remain competitive as well.

Machinery Layout

When installing machinery, careful planning for current and future production requirements is essential. The best layouts have a great deal of time invested in planning and modeling before anything is installed or moved. It is critical to adapt the machinery layout to the space available, the equipment required, the materials movement demanded by the process, and the personnel that will be involved in the ongoing operation. Horror stories abound about structure and walls that have to be removed to get large equipment into a building, equipment specified for utilities that are not present in the building, inaccessible service panels, uncleanable process machinery, product that cannot effectively be moved out of the production facilities, and similar mishaps.

Unfortunately, many operations grow in piecemeal fashion, starting with manual, labor-intensive operations and expanding into greater levels of automation and complexity as the business grows. Even though it is usually not possible to start with a completely blank slate in terms of facilities and machinery, it may be possible to utilize expansion or redesign as an opportunity for improving control and integration systems. If at all possible, both the current and future manufacturing capabilities must be considered when specifying production layouts – will there be room to expand if production increases, or will temporary increases have to be contracted?

When laying out a production line, it is also important to consider the number and placement of operators, as well as the necessity of getting workers into machinery for cleaning, loading and unloading, repairs, and routine maintenance. Operator effectiveness and safety must be considered for economic effectiveness, regulatory, and ergonomic reasons.

Machinery Controls and Displays

Machinery controls have moved from simple indicator lights, analog gauges, switches, and mechanical counters to complex, touch-sensitive video displays that may interface with the rest of the production plant's network and may contain substantial computing capacity. Many of these can be networked so that the production status can be checked from any point in the network or from outside the manufacturing operations. If networked, the potential for remote operation either as standard operating procedure or for emergency purposes may be incorporated, but some attention should also be given to the integrity of the networks' security. Graphic display panels offer the advantages of language-independent icon-based operation, as well as changeable multilingual displays, adaptable displays with layers of operation detail, and graphic representation of data such as checkweigher values and production run charts.

Graphic and computer displays have advantages, yet it is worth looking into the design of controls for most efficient indication of particular operations – a simple red and green light can effectively and decisively communicate whether something is operating or not, with other simple status lights to indicate jams or a "hold" status. Similarly, a simple mechanical counter can be added to machinery at minimal cost as a backup device or confirmation of production levels.

Controls and display units must be mounted in accessible and visible locations, with adequate control systems to provide a fast line or machine shut-down capability in order to cope with a manufacturing or safety problem, and sufficient "lock out" capability to allow safe changeovers when necessary.

Plant Operations

Scheduling plant operations and logistics, particularly in a combined processing and packaging plant, is an entire business specialty unto itself. Much of the work has been supplemented by accurate computer analysis, but the efficient management of an operation still has to consider a large number of variables.

Production Run Schedules

For continuous-run products, the overall production level per time period must be determined for purposes of shift scheduling and materials ordering. For changeable, multiple product runs changeover time, supply of different materials and ingredients and shipping schedules must be accommodated.

Raw Material and Component Ordering, Acceptance, and Tracking

Ingredients, package components, and the like must be ordered, subjected to quality control procedures, and tracked so that they arrive where they are needed on a timely basis without shortages or excessive inventory.

Storage Levels of Materials and Components

Are a lot of small orders required or several large ones for any time period? Which is the most economical and practical alternative?

Is there sufficient storage if the products are being held for Just In Time requests from customers or other parts of the operation? If so, what is the optimal level of production?

Product Line Scheduling

Which products should be run at particular times in order to meet seasonal demand, spikes in product popularity, and opportunities for downtime?

Personnel Management

Which operators will be required to work during which shifts in order to meet production schedules?

Is it more economical to have a smaller number of shifts working harder or a three-shift operation running at reduced levels?

Facilities Management

Can the facility handle round-the-clock production or does it need to be stopped for cleaning, maintenance, or changeover for several hours each day or during a particular shift?

Is there sufficient transportation access to transfer materials in and product out of the facility?

Are the utilities (electricity, steam, fuel, wastewater, etc.) adequate to handle the projected production level?

Larger-Scale Concerns

If the production is scheduled over several facilities, how should it be arranged so that the market demand is met both in terms of delivery schedule and delivery of the required quantities to their markets in the most efficient mix?

If production is to be outsourced over several countries or even globally, how are the product levels to be most acceptably managed to provide for a continuity of product quality, supply, and brand identity?

Machinery Modification and Upgrades

Whereas much of the world's software upgrades are done automatically, the modification and upgrade of manufacturing machinery is much more complex and has both benefits and pitfalls. It may be beneficial to improve the operation of existing machinery with more capable control systems or a higher speed drive system, but the concept of diminishing returns (less and less reward for greater and greater investment) will begin to take over at some point, and it may be more effective to start with a new (or substantially reworked) production system, although justifying the capitalization of this is often a pitched battle.

Before any upgrade or modification is undertaken, it should be determined whether the final result can justify the engineering, software, downtime, and retraining costs involved. One should also consider unforeseen benefits, particularly with large installations that may require building or facility rework if they are to be replaced rather than refurbished. In some cases, the benefits are bureaucratic rather than physical, because machinery refitting or rebuilding may fit in a budget that otherwise does not have a capital expenditure allowance for new machinery – the equivalent of having a car's engine replaced when one cannot justify buying a whole new car.

There are also many older machinery installations with refitted controls, replacing older hydraulic, pneumatic, and mechanical controls with faster and more accurate electronic ones. In the best of cases, the combination of sturdy machinery infrastructure and fast, accurate controls can produce a good performance level, but the retrofitting must be carefully engineered and tested before installation, particularly on a high-throughput line that cannot afford much downtime.

Line Changeover and Flexible Manufacturing

Line change historically has connotations of production losses as an industry shuts down its production process and retools for a new model year. This has changed radically as demands for more productivity and flexibility have caused changeover methods to trickle down from large-scale manufacturing plants to smaller and more entrenched operations such as food manufacturing and packaging.

Taking lessons from Toyota's "Single Minute Exchange of Die" and "Single Touch Exchange of Die" methods, used to add rapid flexibility to manufacturing plants, as well as several other fast-change operations (such as stock-car racing pit crews), food manufacturers have begun to demonstrate extremely rapid changeover times. Tools and fasteners are optimized for changeover, racks of change parts and the necessary tools are modularized, and changeovers may be videotaped and reviewed by the teams doing the production line changes.

Generally, changeover time may be accelerated by several improvements:

- Finding and eliminating unnecessary tasks complexity that slows down changeovers.
- Externalizing the changeover tasks to off-line operations as much as possible. For example, gathering and staging the needed supplies and tooling in dedicated kits before the changeover occurs.
- Simplification by reducing the number of specialized tools needed, and labeling and color-coding tools, fixtures, and parts bins wherever possible to allow fast changeover and highlight any mis-installed components [4].

These improvements can reduce changeover times from hours to minutes and have added the capability of expanding production capacity without capital investment. This provides, as it did for Toyota, the capacity for rapid deployment of a variety of products by increasing the capacity for flexible manufacturing.

Flexible manufacturing (as distinguished from flexible packaging) is often seen as a goal for many linear and single-product production facilities of non-food items, and has been a facet of the food processing and packaging industry for many years. In the simplest of manufacturing environments – small crafts shops and food establishments – nearly all work is customized as is the packaging that is used depending on the order serviced. On a slightly larger scale, small food (and particularly dairy) production operations are required to make optimum use of common ingredients to make a variety of different products, often using many rearrangements of similar equipment profiles. In many instances, there will be common ingredients used (such as raw milk for dairies and vegetable oils and corn syrup for salad dressing lines, for example), but the pumps, vats, cooking operations, packaging, and labeling can vary from product to product. In contract packaging operations, these can be even more varied as both the nature and the name of the product changes.

Truly Flexible Manufacturing Systems (FMS), often termed *Mass Customization Manufacture* (MCM), where many different, made-to-order products travel down a single assembly line, has begun to occur for non-food items, but it requires that both manufacturing and packaging not only be adaptable but have the capacity to communicate the assembly and packaging requirements "on the fly." Fortunately, with visual coding of products and the potential use of RFID, Computer Integrated Manufacturing (CIM), and other data systems to carry the information needed, this is becoming a simpler operation. Unfortunately, the level of automation required is high enough that many packaging operations will shy away from the investment necessary to achieve it, preferring to run continuous batches, warehouse production runs, and then remix them into mixed-product point of sale displays.

The advantages of FMS systems are fast changeover, higher precision and quality, and lower costs due to labor savings. Disadvantages include a limitation on the breadth of scope of manufacturing possible (for example, a line that is machining pump assemblies may not be able to be adapted to the production of volume air blowers), and a substantial investment in equipment, software, and planning capability. Additionally, product designs may need to be reviewed to ensure their ability to integrate into the existing manufacturing system.

Paradoxically, Design for Mass Customization (DFMC) eventually represents a complete decoupling of the traditional product design and manufacturing systems in that the manufacturing system (in an ideal sense) is dynamically adaptable to the immediate market demands for many different products rather than strategic planning for perceived future demands. Additionally, truly flexible manufacturing systems may work against lean manufacturing systems in that the volatility of market demand for particular items may feed back into the system and require enlarged inventories of components to remain responsive. Thus, there is a conflict among the flexibility of the production run size, variability of the product, and delivery schedules [5]. This is most often addressed by the large-scale integration of modular elements in the production system, which allows the production facility to integrate different production modules, where each module may be made of one or several machines or processes, to create different "recipes" of production capacity, as shown in Figure 8.5. In a high-volume, low per-unit-profit industry such as packaging, and particularly food packaging, this may or may not be seen as a worthwhile investment, but as data, control, and computation costs plummet and visualization and task integration software becomes more usable, it may trickle down into the food packaging industry.

Coordinated Packaging Lines

A well-coordinated packaging operation traditionally required machinery that was built with common mechanical timing linkages, and may have required the simplification of the packaging design and other changes that can affect the competitive nature of the product after production. Changes in the controllers used in industrial equipment have allowed the implementation of data- and sensor-driven machine coordination based on industry standards that allow machinery from different manufacturers to communicate and operate efficiently.

New IEC-61131-3 standards for programmable logic controllers (PLC) represent a tremendous opportunity because they allow a uniform set of communication and operation protocols to be operated both internally and using software and XML protocols [6]. This allows machinery from different manufacturers to have a basis for passing information about operation and timing both to other machinery and to centralized control that can be used for both scheduling and optimizing production systems to operate as efficiently as possible. This also places demands on

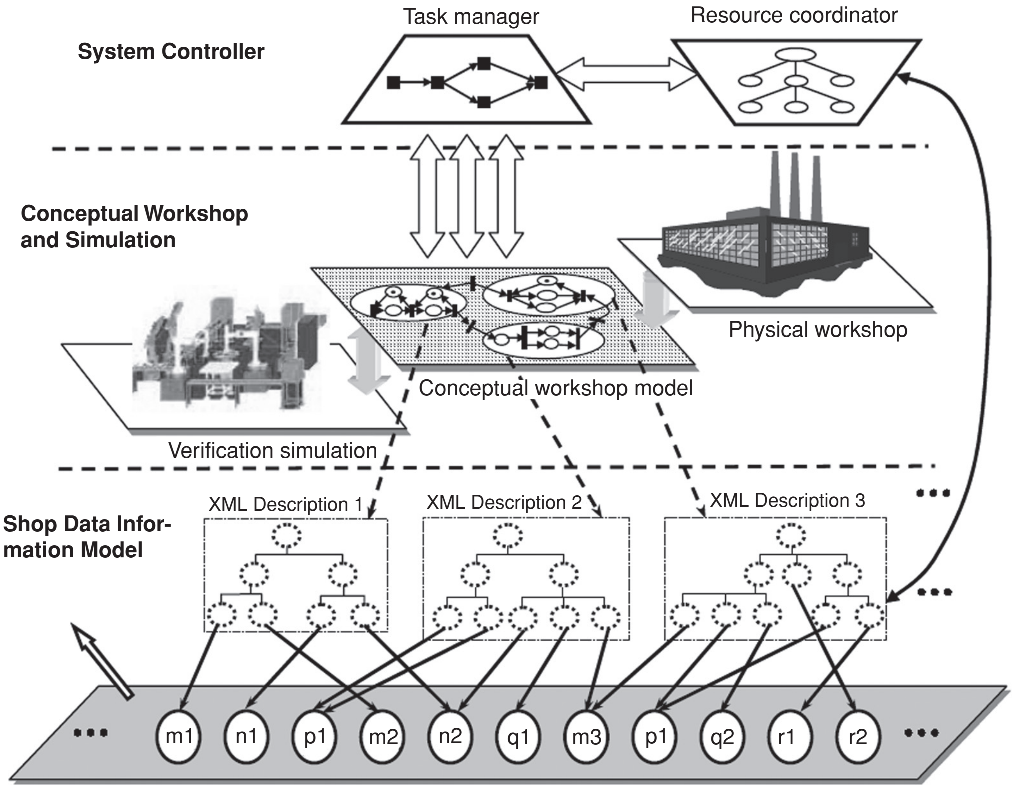


Figure 8.5. Flexible Manufacturing System Detail
Source: NIST

the machinery manufacturers to utilize the data transmissions efficiently and system integrators to use data to optimize systemic efficiencies.

Production Optimization

Optimization of production processes is an involved topic, and a complete discussion of the subject is well beyond the scope of this text, but it is possible to extend some of the basic concepts involved in order to provide a starting point for further reference. Generally speaking, the engineering concept of optimization is the manipulation of particular parameters in a system until a desired output (usually measured as a maximum or minimum value for a particular value) is achieved.

In its simplest form, the maximum speed of operation in any particular linear-sequential process is the speed of the slowest sub-process contained in it. This "weakest link" reasoning provides a good idea of the maximum speed for many flow-type processes that do not depend on timing, machine stoppages, or accumulation. Unfortunately, it is often applied to all types of more complex situations, often leading to inaccurate analytical results where the maximum speed of a process is actually well below that of the slowest sub-process it contains. The most extreme example of this would be a machine that requires an accurately timed product transfer running completely out of phase with the next machine in line, with the end result being two machines running furiously with no net production at all. There are many reasons for this occurrence, but the most common one is synchronization. A linear sequential process may have a device that is only capable of accepting items from a previous sub-process at particular times. If the previous sub-process is not timed correctly, the product will stall – be out of one process yet not accepted by the next. Other variables of timing include batch processes that disgorge items in large surges that have to feed into continuous processes that accept items in smaller quantities, and variable processes that may only accept items at a fixed range of rates.

These problems are often dealt with by adding accumulator capacity or by trial-and-error solutions, but with the declining cost of producing intercommunicating machine controls as well as networked central information systems, the effectiveness of optimization processes in high-speed manufacturing is only limited by the willingness to make initial investments in the analysis and production changes. The further benefits of production modeling and analysis is the ability to entertain "what if" scenarios, allowing trial changes to be modeled without disrupting ongoing operations, and minimizing changeover downtime.

The benefits of these analyses can be a remarkable increase in the operating throughput with little or no capital investment. In some scenarios, pre-construction modeling have saved huge amounts of capital expenditure on unessential building features and have pre-tested machinery and operations improvements in order to optimize their efficiency or to indicate that they may not be effective [7].

Basic Types of Production Optimization

Production optimization methods have grown from the observation that the basic principles of mass production tended to produce large quantities of both work in progress (WIP) and accumulated inventories of both components and finished goods, all of which may represent a great deal of capital that is not earning any sort of return. In an ideal sense, the best manufacturing operation would only have enough materials on hand at any point to finish the particular job at hand. The economics of purchasing and transportation dictate that the more economical alternative might be a very small supply of components on hand, purchased at an economic balance point of optimal ordering costs and brought in on a timely basis, which is discussed in the subsequent section on supply chain management.

Advanced Methods of Production Optimization

Complete production optimization is much more complex and must take into account the throughput capacities of machines, buffering, downtime, breakdown, and changeover factors, among others. Needless to say, this can be an extraordinarily complex task and one that many operations may avoid due to the lack of the personnel, time, or investment necessary to complete it. In many operations, particularly those that have grown from a small startup operation, this kind of analysis can have great benefits in the "tuning" of components that may have been added as the production facility's needs and capacities grew.

The usual procedure for optimizing production systems is a multistep process that requires a substantial amount of initial data, as well as the construction and validation of a mathematical model of the production system that will allow the incorporation of actual data to provide meaningful results. In the past, this often required a great deal of personnel time to accumulate, but with more automated controls and data collection, this has become somewhat easier, though this is balanced by the necessity of deciding which data are meaningful.

Model Types

The simplest of model types is a sketch made on anything from a whiteboard to a cocktail napkin. While these lack elegance, they are often the starting point for further and more accurate analyses. Beyond the iterative "sketch-and-toss" method, however, a quantitative result is necessary, and there are several commonly used methods.

For a simple production line, the types of operation are generally separated into several different types [8]:

Homogeneous: All of the operations have the same cycle time.

Non-homogenous: Cycle times may differ and may be affected by variations such as acceleration, deceleration, or distribution.

Synchronous: All of the production units operate at the same time.

Asynchronous: The production units all operate at different times.

Similarly, as the number of production lines increases in a facility, the concept of symmetric lines, all of which have the same characteristics and capacities, versus asymmetric lines which all differ, comes into play.

In order to create an analytical solution, the traditional method has been to create a series of simultaneous equations that describe the operational characteristic (cycle time, failure rate, etc.) that is of interest at each step in the process, and then solve the equations to create a generalized model that will provide an analytical approximation for the desired solution. Unfortunately, these methods required both a substantial background in linear algebra and a good working knowledge of computer programming to provide a solution.

Optimization Software Tools

More recently, tools to accelerate these solutions, both in the form of spreadsheets and numerical analysis software, have become not only available but convenient to use. Better still, several companies offer graphically-based software that simplifies the nature of the modeling and makes the process more intuitive. The availability of these tools does not eliminate the need for a working understanding of the mathematics involved, but it does reduce the arcane nature of the task and helps the industrial engineer solve production problems more efficiently. Graphically-based programs can also accelerate the rate of design changes and "what-if" thinking for production layout, as with the soy processing simulation shown in Figure 8.6.

Examples of advanced simulations using physics-engine-based software to produce real-time, quantitative simulation of both production processes and the response of control systems are shown in Figures 8.7 and 8.8, whereas examples of a software package that will provide design tools ranging from the product and secondary package through to truck and container load patterns are shown in Figures 8.9 and 8.10.

Real-Time Optimization

Given a sufficiently sophisticated and timely optimization model, the production optimization model can be incorporated into real-time control systems to continuously update and "tune" the

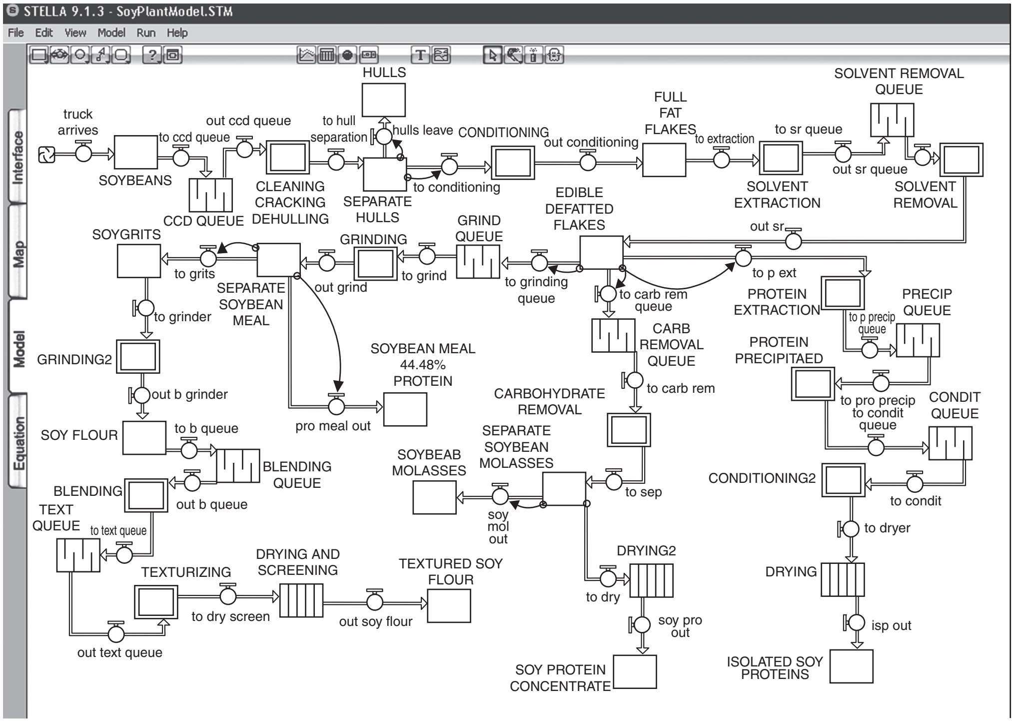


Figure 8.6. Soy Processing Plant Simulation
Source: C. Weeks and S. Morris, 2007.

manufacturing system to achieve a previously defined goal by anticipating and correcting the operating conditions in real time. Although this seems like a daunting process, nearly every new automobile currently manufactured has this type of system built into its drivetrain, responding to throttle and environmental inputs by continuously optimizing power, gear selection, fuel economy, and emissions to follow a pre-programmed model.

Integration of Manufacturing Processes

In a larger sense, the optimization of manufacturing processes should fit in with a larger-scale integration of Manufacturing Execution Systems (MES) information systems. This allows the manufacturing facility to exchange data with the larger manufacturing operation, and can provide a method to connect with the larger information cycle described in Chapter 1. Whereas the integration of orders and operations might be as simple as the efficient use of an order whiteboard, the advantage to a larger, more integrated manufacturing system can be to shorten and economize production cycles and production operations themselves, as well as integrating operations such as quality control, supply chain management, sales levels (and forecasts), and others into a more cohesive picture of the real-time operation of the organization.

While there is a separate industry built around large-scale software installations for these purposes, the smaller operation may benefit from taking the same principles forward on a smaller, more local scale, because the basic principle at work is timely cross-communication

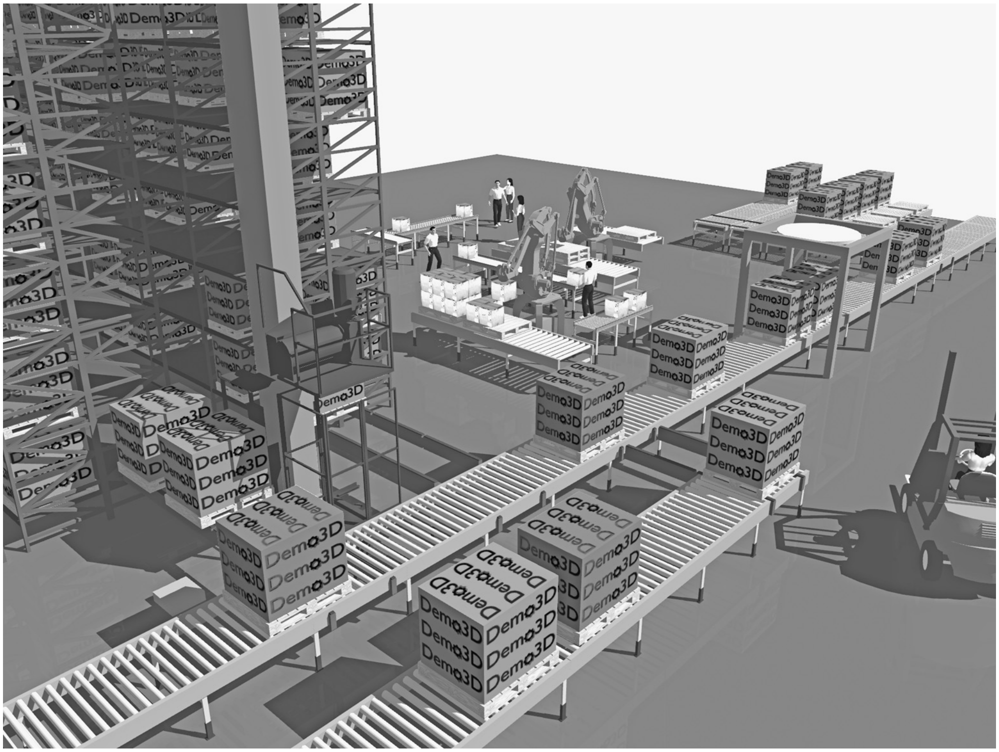


Figure 8.7. Real-Time Simulation of Operating Packaging Line
Source: Courtesy of Demo3D (www.Demo3D.Com), used with permission

of information about orders, work status, and completion information during production. Even fast-food franchises have adopted a reduced version of this to track food orders in real time and assure accurate delivery of the customer's order.

Supply Chain Management

Supply chain management concerns itself with the flow of materials, in-process goods, and finished goods from the point of origin to the point of consumption. It is a much larger field than can be addressed in this book, and is an entire industry unto itself, but a basic understanding of the goals and processes are necessary to understand the role of packaging and information flow into the supply chain. Further, supply chain concepts apply both to the packaged goods manufacturer who is seeking to reduce inventory costs while minimizing risk as well as to the products' retailers who are continually trying to minimize inventory without running out of it.

The rapid globalization and migration to the Internet of world commerce has placed supply chain management squarely in the spotlight as companies struggle to create and maintain flexible, resilient, and efficient manufacturing, distribution, delivery, and retail systems to match customer demand. Packaging extends this in somewhat unique ways in that the information carried in some coding systems is also used in automated recycling systems and carries the materials back to the point of origin or to a recycling facility.

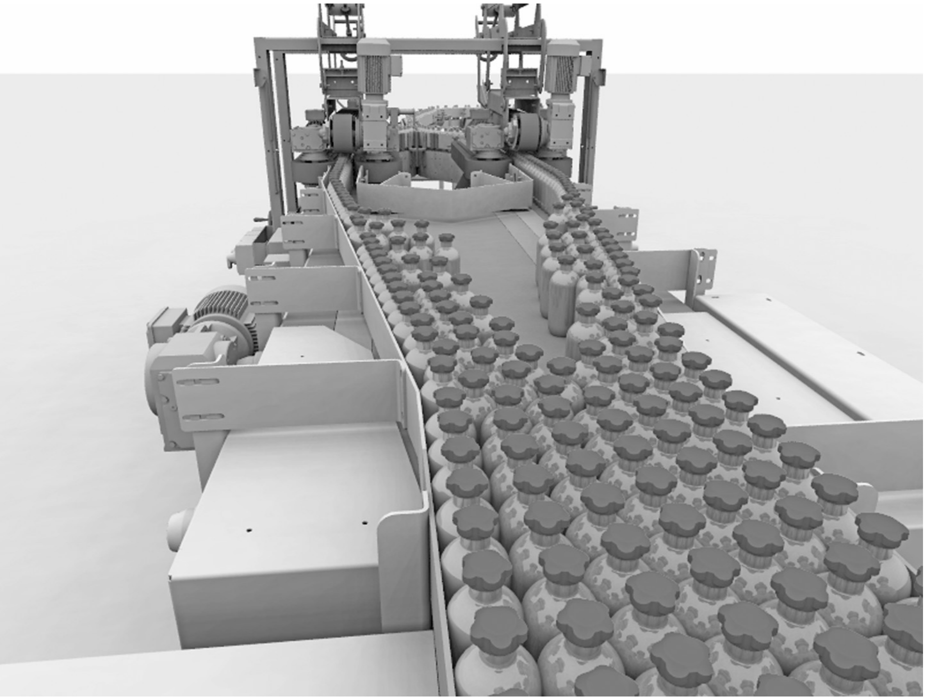
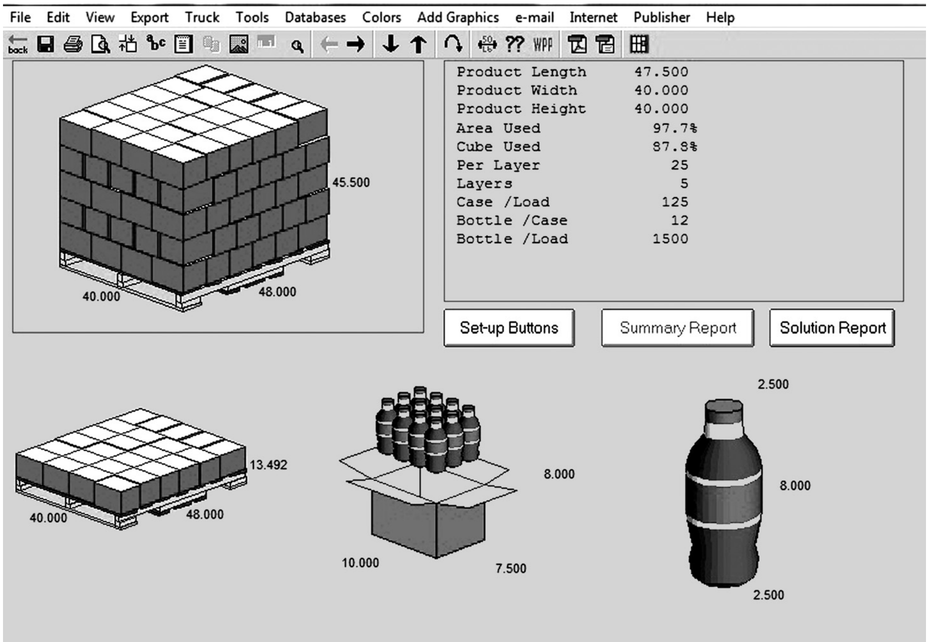
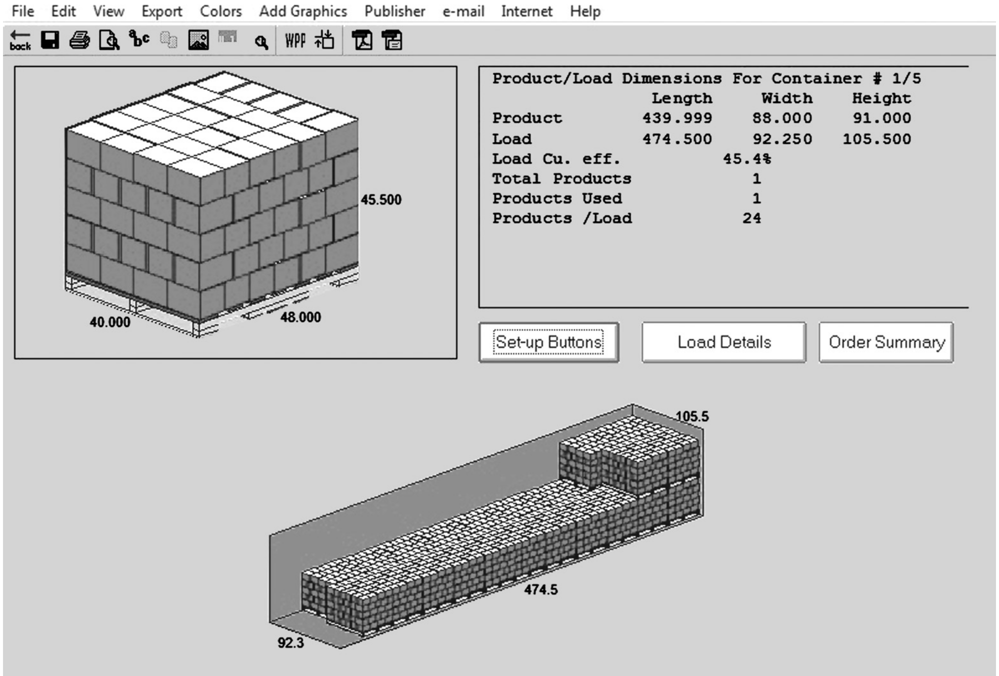


Figure 8.8. Real-Time Simulation of Bottle Handling and Control System
Source: Courtesy of Demo3D (www.Demo3D.Com) and Can Line Engineering, used with permission



```
Product Length     47.500
Product Width      40.000
Product Height     40.000
Area Used            97.7%
Cube Used            87.8%
Per Layer              25
Layers                  5
Case /Load            125
Bottle /Case           12
Bottle /Load         1500
```

Figure 8.9. Package, Shipper, and Palletload Design Using Software-Based Design
Source: Courtesy of Cape Systems Inc. Used with permission



```
Product/Load Dimensions For Container # 1/5
                 Length     Width    Height
Product         439.999    88.000    91.000
Load            474.500    92.250   105.500
Load Cu. eff.           45.4%
Total Products            1
Products Used             1
Products /Load           24
```

Figure 8.10. Vehicle Lading Using Software Analysis
Source: Courtesy of Cape Systems Inc. Used with permission

Supply chain management also concerns itself with strategic goals such as distribution site location, transportation sourcing, new product line integration, and economic optimization. The latter concern often manifests itself in the ongoing goal of reducing materials flow and waste to the absolute minimum possible. Considering that packaging is often seen as a cost item rather than the value-added system allowing products to be used, there is always an economic incentive to reduce the amount of packaging both in use and in inventory. There is a similar tendency to reduce resources for development efforts and new technologies, although emphasizing the added value provided by packaging may alter these perceptions.

Value Chain Analysis

Value chain analysis is a managerial tool used to track the value (rather than cost) added to products at each stage of their primary activities in conversion of materials into finished products throughout the supply chain (Figure 8.11). The value chain originates from the post-consumer environment and ends at the raw-material stage in a direction that is reverse of the supply chain. Addressing value in this direction allows each step of the conversion process to be evaluated based on the value of the conversion. Further, suppliers and support activities are aligned to deliver value that is meaningful at each step of the process. The final goal of value chain analysis is to provide analysis and optimization leading to a product whose value to the supply chain and to the customer exceeds the cost of the activities required to produce it.

Given that many products, and particularly food products, are inherently dependent on their packaging to add value to a somewhat generic product, and are certainly dependent on it to get

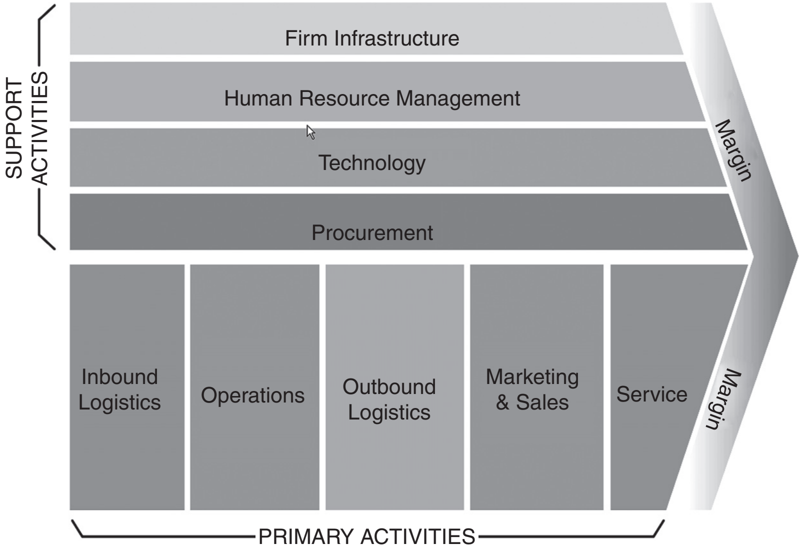


Figure 8.11. Value Chain Components
Source: Dinesh Pratap Singh. Used with permission

it to the customer in good shape, value chain analysis may be a means of increasing the focus on improved packaging technologies and systems that are meaningful to the final consumer and also customers within the value chain. Gains can be derived when value chain analysis and systems integration are employed to focus on specific goals such as increasing agility, shortening time to market, offsetting market fluctuations, and building customer confidence. Additionally, focusing on adding value with packaging may provide a competitive advantage both internally as support activities shift to maximize this, and externally as a specific product positioning is achieved to increase market share [9, 10].

Inventory Reduction Methods

Inventory reduction is one of the primary means of simple cost reduction in many manufacturing operations, and several basic methods for managing this will be discussed in this chapter. The simplest ways of reducing inventory costs are to manage materials inventories, work in progress, and finished product on hand to maximize economic returns. Although there are industries founded on managing and implementing these methods, several simple inventory management concepts will be discussed. All of these have the underlying idea of reducing the costs of production that also include costs of production space and equipment, capital costs, or opportunity costs. The last two of these terms are linked, in the sense that they represent the difference in the rate of return of using capital for the current purpose rather than applying it to another investment with similar risk.

A simple, conceptual example of this would be for someone to take their entire annual food budget and apply it in one of three different ways:

1. Buying a year’s worth of food at one time and storing it for use during the year.
2. Buying a week’s worth of food once a week.

3. Buying just enough food for the day or a particular meal in a single trip and have no inventory carried over.

While casual inspection of these three alternatives might highlight at least one that seems ludicrous, the "sensible" choice will vary from culture to culture and is almost always between one of them. For example, a year's worth of food may seem like a silly decision, but remote research stations may only resupply once or twice a year, and in some cultures, the only time available for shopping for those who work during the week may be on a Friday or Saturday. Conversely, daily shopping is not uncommon in many cultures, particularly those in which people depend on very fresh ingredients and may have a more traditional culture with regard to domestic tasks.

For purposes of this example, we can consider a few simple retail cost factors in each choice.

Ordering Costs

This is the cost associated with actually placing an order for goods or materials, and is independent of the order size. In the grocery shopping example, this would be the total cost of making up a list and then going to the store or ordering supplies online.

Storage Costs

These include the costs of the building to store materials, as well as refrigeration and other ancillary costs related to maintaining the stockpile of food.

Transportation Costs

These are transportation, handling, and inventorying costs and are assumed to depend on the order size, and therefore are large in total for the full-year purchase. It is also reasonable to assume that a large purchase will take advantage of the economy of scale and will result in a smaller per-unit cost, whereas a series of very small purchases transported individually over time will result in higher per-unit costs. In reality, this may be modified somewhat because a year's supply would require the use of a much larger vehicle than a usual automobile, whereas daily shopping can be carried by hand, but the general principle still holds true.

Out-of-Stock Costs

The technical definition of this is the cost of lost product sales when a particular item is not available for use in a manufacturing operation for retail sale. In the simpler example of buying groceries for personal use, this is the all too familiar scenario of running out of a particular item and having to run to a pricey all-night store to purchase it at the last minute. In both cases, these costs tend to be quite high on a per-unit basis.

Opportunity Costs

This is a term that accounts for costs for alternative uses of the capital in a particular investment or business strategy. This would be highest when tying capital up in a year's worth of grocery purchases and thereby making those funds unavailable for investment or emergency use.

Table 8.1. Grocery Purchase Example

Inventory Example – Total Annual Cost			
Cost Type	Yearly	Weekly	Daily
Storage	Highest	Moderate	Lowest
Ordering	Lowest	Moderate	Highest
Transportation	Fewest trips, Large Vehicle	Moderate	Most trips
Out of Stock	None	Moderate	High
Opportunity	High	Moderate	Low
TOTAL COSTS	High	Moderate	High

By inspection, one can construct a relatively simple qualitative chart of the total costs of each alternative (Table 8.1).

So, whereas most consumers achieve some sort of balance for their grocery shopping on an intuitive or traditional basis, it is possible to create analytically based systems that reduce the amount of capital tied up inventory to a practical minimum. Extensions of these concepts to the economic optimization of work in progress and finished goods are the goals of so-called *lean manufacturing* systems as well as modern distribution systems that seek to minimize the quantity of finished retail goods in storage and transit by large-scale transportation, logistics, and information integration.

Inventory Management Techniques

Inventory management techniques can be as simple as having a look in the freezer in the back room of a pizza parlor or as complex as a globally linked dynamic logistics management system. Some of the simpler examples given in this chapter will illustrate the basic concepts that are used, though extremely complex models can be adopted and are in current use in some operations, particularly in real-time distribution network restructuring and global sourcing of inventory.

Economic Order Quantity (EOQ)

This is a generations-old basic calculation for the generation of the optimal balance between the overall costs of ordering items for production as shown in Figure 8.12, and the costs of carrying an excess inventory (Equation 8.2) [11].

$$\text{EOQ} = \sqrt{\frac{2(\text{Periodic Useage of Units})(\text{Ordering Cost})}{(\text{Periodic Carrying Cost per unit})}} \tag{8.2}$$

Ordering Cost: Time to place and process order.
Carrying Cost: Cost associated with keeping inventory on hand

It does not incorporate any consideration of the costs of being out of stock (costs of lost production), nor does it account for rate of use or fluctuations in the rate of use of materials. This induces a risk of cost being accrued from an out-of-stock condition, which is not considered in the calculation but must be balanced against too much inventory, as shown in Figure 8.13.

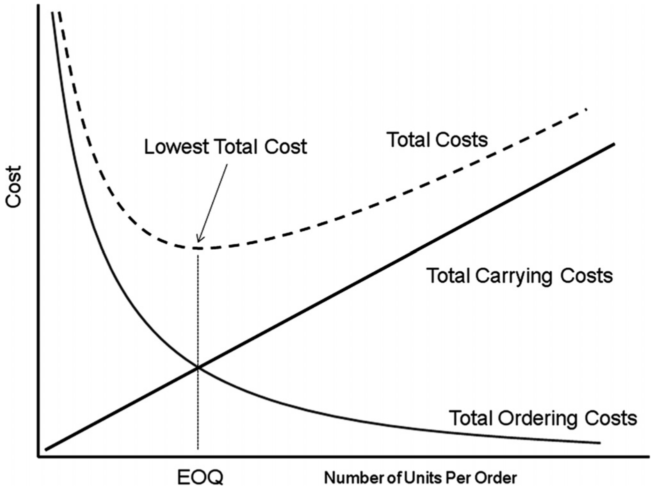


Figure 8.12. Economic Order Quantity

Note that actually getting accurate data for ordering costs and carrying costs can be quite difficult without a rigid method for analysis because it is subject to a great deal of estimation by the people involved. The ordering cost is also considered to be constant and the formula presumes that many things such as lead time, rate of demand, purchase price, and delivery and stocking happen in very predictable, constant ways.

Just In Time (JIT)

Just-in-time scheduling works on the principle that only the immediately necessary amount of material should be kept on hand, with the correct incremental replacement amounts delivered on a timely basis. This is a commonsense step that has been in place since the large-scale implementation of mass production, but was refined and publicized in large part by Taichi Ohno of Toyota in the 1950s and 1960s, who used it to provide flexible manufacturing capabilities

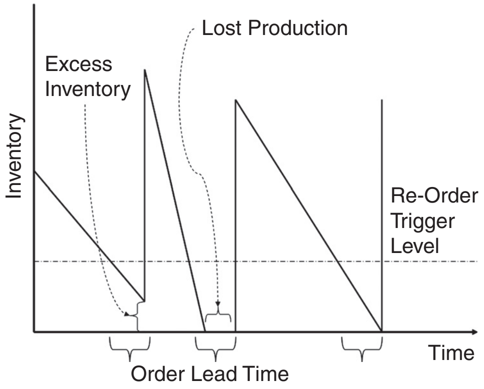


Figure 8.13. EOQ Ordering Showing Effect of Variable Lead Times and Useage Rates

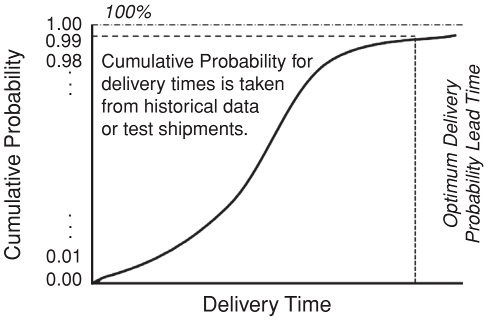


Figure 8.14. Delivery Time Cumulative Probability

with severely limited factory space. JIT methods incorporate statistical data about delivery times and can make approximate adjustments for the rate of material use. For JIT systems to work, the production facility must collect data about, and work with suppliers in order to accurately determine, what the cumulative probability of delivery times and conditions might be in order to minimize the risk of out-of-stock conditions as well as avoid accumulating excess inventories (Figures 8.14 and 8.15).

In a manufacturing operation, the absence of a single item of inventory can cause the manufacturing operation to stop entirely, and it may be economically advantageous to have it sent by any means, no matter how expensive. Supply chain disruptions can be enormously destructive, depressing stock prices, causing long-term financial problems and, in over-lean organizations, causing the failure of whole product lines [12].

Kanban Systems

Kanban (literally, "signboard") systems use internal indicators to trigger orders for new materials, often within a particular manufacturing process, and are an extension of the JIT system. The name is reputed to stem from the practice of putting a re-order tag or indicator near the bottom of a large bin of components, triggering a new order when the tag was uncovered. Current practical implementation usually has an order triggered when a bin of parts starts being used,

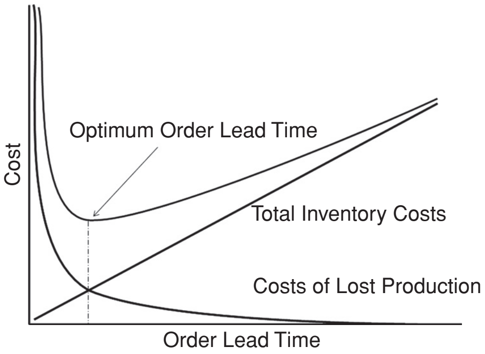


Figure 8.15. Order Lead Time Factors

with the rate of consumption tracked as a function of production. Overall, it is very simple and quite robust, and has rapidly replaced many Materials Requirement Planning (MRP) systems that were complex and cumbersome. More modern assembly processes use means of flagging parts, trays of components, and ingredient bins combined with barcode- or RFID-assisted re-ordering. The kanban system can be chained with many components and processes (and the initial manually handled paper tags can be replaced with networked data systems), making it ideal for large-scale manufacturing industries such as automobiles. The concept can be extended into JIT manufacturing and distribution that incorporates the basic concept of depletion-driven orders into other hybridized systems.

Kanban may be cascaded to trigger larger orders from a factory inventory or to trigger orders directly from a supplier. Optimum order sizes and rates of consumption as well as order lead times must be determined to keep inventory as low as possible. A net effect of the kanban system is to push inventory-carrying costs back onto suppliers, as well as to demand a tight supply delivery schedule, possibly causing orders to be in unusual quantities, all of which may carry economic consequences that should be considered. Simple kanban systems do not account for variations in part quality or type, nor do they consider delivery schedules. Additionally, kanban and similar systems represent a transition from “push” production that relies on an accurate estimation of market demand to a “pull” system, where production facilities respond to sales levels more directly and efficiently. As might be expected, many larger operations have moved away from literally putting cards into bins of parts and toward more sophisticated electronic methods that track part location and consumption, and which are integrated into larger supply chain management systems. Simple JIT and kanban systems attempt to compensate for variations in demand by back-chaining demand into the supply system, but often do not account for inventory delays and delivery times from external sources, nor do they do a very capable job of juggling several suppliers for a single item. Considering that this is easily included in other advanced inventory management models, the accumulation of external supplier data then becomes an important part of the overall economic picture. It becomes necessary to balance the costs of rapid or dependable delivery against the costs of being out of stock on a particular item – something that has been of great benefit to the rapid and overnight delivery industry. In the retail food distribution system, there are so many overlapping products that it often seems unlikely that the lack of a single item would close an entire store, so there is a wide range of alternatives depending on the product and its market niche, but having the product available for the consumer is a fundamental component for the success of a particular product line.

Thus, a more flexible and efficient management model relies on statistical information about delivery times and delays, as well as forward-looking predictive models about both supply disruption due to weather or other factors and demand to provide ordering and distribution that puts the product on the shelf just in time to be purchased without the accumulation of excess inventory or extensive outages of products, as shown in Figure 8.16.

The demand for fast, flexible, and efficient delivery in order to provide low inventory levels and high response to changing market conditions have pushed distribution logistics into complex modeling and simulation, and the plunging cost of data acquisition and transfer has allowed an ever-increasing degree of partnering and cross-integration both within and among companies.

Manufacturing Quality Assurance and Quality Control

Quality is an elusive concept when taken beyond a simple degree of satisfaction with a product. In most cases, there are two components of quality – quality of design and quality of

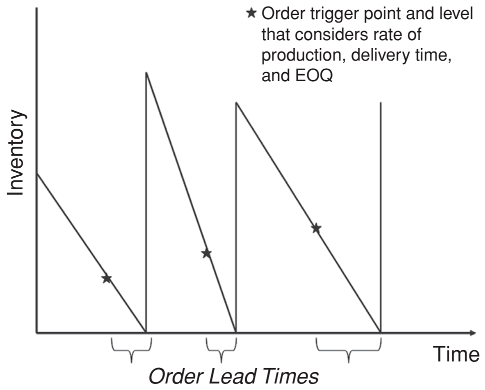


Figure 8.16. Demand and Delivery Time Optimized Ordering

conformance – that combine to produce *product quality*. Quality of design addresses how well the particular product design meets the needs of the situation for which it was designed and how well it can be manufactured under ideal circumstances. Quality of conformance follows this and addresses the issue of how well the product conforms to the specifications and tolerances demanded by the design.

Most day-to-day quality control (QC) work is aimed at addressing issues of conformance, while the more effective effort is in the creation of Design For Quality (DFQ) as well as Quality Assurance (QA). A good component design will have features that facilitate accurate and complete integration into the larger production system, and a workable quality assurance program can help ensure that quality and productivity will increase together with the reduction of rework and rejects.

The difference between quality assurance and quality control is often blurred, but a useful distinction is that the first is the set of processes and procedures that provide a manufacturing environment that promotes the production of a high-quality product, and the second is a set of processes and procedures that assures that the product is of acceptable quality when it is actually produced.

Before any work is done on either topic, the definition of what defines quality for a particular item is important. One of the more common problems in quality control and quality improvement is the lack of agreement on a clear, objective, and measurable definition of what a high-quality product or outcome is, how much variation is acceptable, and how these attributes are to be measured. Many disputes over quality arise from the difference in the perception of quality of a particular product between the producer and the consumer, and can be avoided by establishing, understanding, and communicating these criteria before production begins.

Typical quality-control attributes include dimensional tolerances, mechanical properties, color, specific composition, and more difficult-to-assess attributes such as taste and odor. Sampling plans are often taken from established ASTM/ISO and ANSI protocols, MIL-STD (military standard) testing systems, and others. The actual test methods used may be developed in-house, may be taken from a third-party standard such as a TAPPI test method, or be a combination of the two. It is important that an understanding is reached between the supplier and customer regarding test methods, sampling protocols, and other factors before delivery to avoid misunderstandings.

Sampling, Testing, and Remediation

Constructing a broad sampling plan is a difficult task, even for those with a deep love of statistics. Because of this, there are several quality-attribute sampling plans that have been used as the basis for product quality testing for some time. The MIL-STD 105 series (now superseded by the ANSI/ASQC Z1.4 sampling plan) and others provide a useful starting point for quality attribute testing. These can be obtained at minimal cost, and there are currently online calculators that incorporate the standards to simplify the task further [13].

Sampling can be broken down into sampling by attributes or by variable, single or multiple sampling plans, and rectifying versus non-rectifying sampling plans. The distinction between sampling by attributes or by variable is whether the inspection leads to a conforming/non-conforming (*Go/No-Go*) decision or an accounting of the number of non-conformities versus a continuous measurement of a particular variable. Single and multiple sampling plans are constructed to provide the most statistically useful acceptance decision at the least sampling cost. Often, because of the high cost of testing items versus a similarly high cost of inaccurately accepting or rejecting products, a multiple sampling plan will require an initial small sample test that can provide a clear accept/reject decision or may lead to additional testing before a final decision criteria is reached. Rectifying plans will also account for the disposition of items that have been found to be non-conforming. This may range from disposal costs for a small batch of ingredients to the costs of return and rework for a large order of sub-assemblies.

Increasingly, product testing and certification has been pushed back on the suppliers of ingredients and components. This has the advantage of reducing costs to the purchaser of these items, but puts quality control in the hands of those most likely to have an interest in misrepresenting the quality of the particular item. Because of this, quality audits and specific contractual obligations must be considered carefully, as should the remediation procedures such as defective item return, reworking, or disposal.

To implement a pre-calculated sampling plan, an acceptable quality level (AQL) must be established, and a lot size is usually determined. Lot sizes may be self-evident (a single container of components, shipment of product, or production shift) or may have to be designated in a continuous production operation. Additionally, a determination about which type of sampling to use must be made incorporating costs of testing and factors that are usually incorporated into the test protocol.

For example, for the normal, single-sampling plan shown in Figure 8.17, the lot size is between 3,200 and 10,000 units, and for a 1% AQL, the number of items to be sampled is 200, and the lot can be accepted if the number of defective items is five or less.

Quality Assurance and Quality Improvement

Quality assurance seeks to provide a system under which the quality of a finished product will continuously improve. This is particularly critical in food processing operations where the economics of the processing operation will dictate both speed and low cost, but quality failure can have catastrophic consequences.

History of Manufacturing Quality

As the world moved from small-scale crafts and manufacturing to large-scale mass production, the specialization of tasks and manufacturing of large quantities of interchangeable parts

Single Sampling Plan for Normal Inspection*

Lot size†	Sample size‡	Acceptable quality level§								
		0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5
Over 2	2	0	0	0	0	0	0	0	0	0
8	3	0	0	0	0	0	0	0	0	0
15	5	0	0	0	0	0	0	0	0	1
25	8	0	0	0	0	0	0	0	1	1
50	13	0	0	0	0	0	0	1	1	2
90	20	0	0	0	0	0	1	1	2	3
150	32	0	0	0	0	1	1	2	3	5
280	50	0	0	0	1	1	2	3	5	7
500	80	0	0	1	1	2	3	5	7	10
1,200	125	0	1	1	2	3	5	7	10	14
3,200	200	1	1	2	3	5	7	10	14	21
10,000	315	1	2	3	5	7	10	14	21	21
35,000	500	2	3	5	7	10	14	21	21	21
150,000	800	3	5	7	10	14	21	21	21	21
500,000	1,250	5	7	10	14	21	21	21	21	21

*Inspection by attributes (go or no-go) at level II (normal) for acceptance or rejection on the basis of a single sampling.

†Number of units in a batch or shipment.

‡Number of units to be inspected that are selected at random from each lot.

§Acceptable if the number of defective units in the sample are this amount or less, rejectable if above.

Figure 8.17. Example Using Mil-Std-105D

demanded that the operation be supervised to ensure good results. Unfortunately, the pressure to increase production volumes to meet a quota (and the rewards for doing so) often led to a “get the iron out the door” mentality, which resulted in a very high rate of rejected parts and defective assemblies caused by high part variability and poor workmanship. This required that the individual parts be inspected at some point in the manufacturing and assembly process, as well as further inspections to ensure that the complete assemblies functioned properly, and these methods often suffered from various lapses in attention or outright neglect because the reward system was often still tied to simple production levels.

The first response to this was to provide inspectors to “inspect in” quality as a separate oversight function in many manufacturing operations, providing a secondary and somewhat objective evaluation function in the manufacturing process. With the huge burst of industrial production required during World War II, the costs and delays of reworking defective goods and assemblies became critical, and various data-driven quality control methods began to be implemented, the most famous of which were outgrowths of Walter Shewhart’s work at Bell Laboratories during the 1930s that brought careful use of statistics and economics into the picture [14]. This work became the foundation for what is currently termed *Statistical Quality Control* or SQC, which made inspections more efficient and provided statistical tools for the inspectors to use, and which became vitally important in the production of war materials.

During the reconstruction of Japan after World War II, Japanese industry became known time for producing shoddy imitations of goods from elsewhere. To assist in the redevelopment of Japanese industry, W. Edward Deming, who was prominent in statistical methods of quality control, and Joseph Juran, who strongly advocated collaborative quality management principles, began working with Japanese industries using ideas of quality control and quality management that had been rejected in the entrenched markets of the United States. These proved to be vital mathematical tools for quality control, and these revolutionary managerial methods were instrumental in bringing Japan to the forefront of efficient manufacturing of high-quality products by the 1970s, while the United States lagged behind. Competition drove many companies to reexamine their approach to quality control and most of them to depart from inspection-based quality assurance systems to company-wide, collaborative quality assurance models.

Diagnostic Tools for Quality Management

While an entire culture of quality management tools, software, and philosophy have developed over the last half-century or so, there are several tools that are simple to use and can prove useful in the determination of causes of quality problems at the production level.

To determine the cause of a quality problem, a thorough understanding of the process is necessary, as well as a grasp of the cause-and-effect relationships that verifiable data provide. Additionally, the difficult distinction between important and urgent problems (Juran's "The vital few and the useful many") must be made, and cause-and-effect relationships that contribute to these problems must be determined.

Process Flow and Contributory Factors

Useful tools in the visualization of process flow include flow charts that give a picture of movement of materials, energy, and labor through the production system's processes and activities, as shown in Figure 8.18. These may become quite complex but will provide a useful mental picture to help isolate not only problem areas in production design, but potential critical control points for use in safety management such as the HACCP programs discussed in Chapter 10.

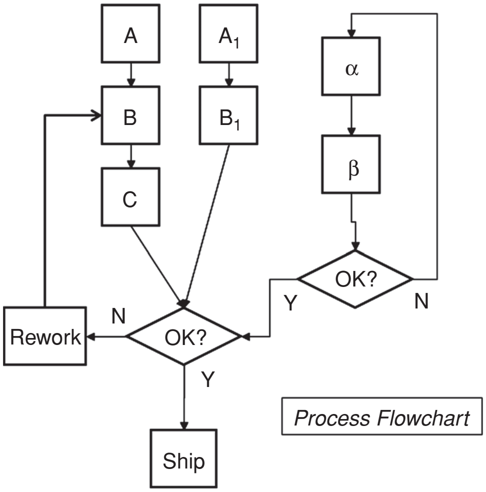


Figure 8.18. Production Flowchart

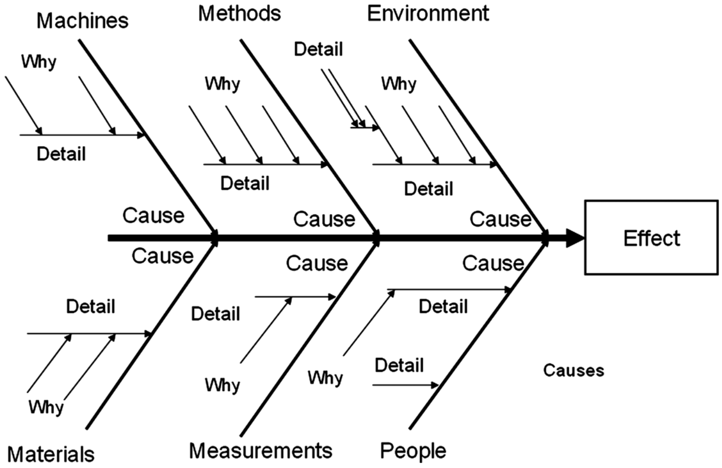


Figure 8.19. Fishbone ("Ishekawa") Diagram

Ishikawa ("Fishbone") Diagrams

While at the University of Tokyo, Kaoru Ishikawa (who also developed the concept of quality circles, among many other contributions) developed a distinctive type of cause-and-effect diagram that shows contributory factors in a process and, when dissected into sufficiently fine detail, can highlight unnoticed factors that contribute to quality problems. The "fishbone diagram" term comes from the distinctive fish-skeleton shape of the chart shown in Figure 8.19, each "rib" of which is a broad category of factors, listed in Table 8.2, which are dependent on the particular type of industry. Secondary and subsequent causes branch from the main "ribs" to give a useful picture of causes that might be usefully addressed.

Determining Importance, Magnitude, and Correlation

Pareto charts, histograms, run and correlation charts, and other statistical methods are used to determine not only which problems are important, but which causative factors can be shown to

Table 8.2. Ishekawa ("Fishbone") Diagram Cause Chart

Ishekawa Diagram Main Cause Chart	Type of Application		
	Manufacturing	Administration	Service
Causal Factor	Machine Method Materials Maintenance Personnel Environment	Price Promotion People Processes Location/Facility Policies Procedure Product	Surroundings Suppliers Systems Skills

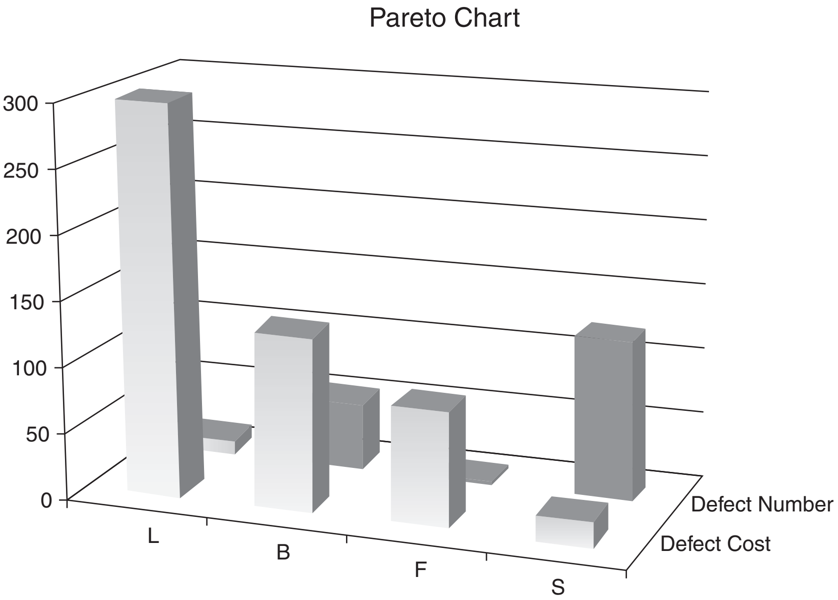


Figure 8.20. Pareto Chart of Occurrences versus Total Cost

have an effect in the creation of the problem and therefore point to the most urgent component to achieving a solution.

Importance and Magnitude: Pareto Charts

Pareto charts are initially used to chart the type and frequency of problems, and often are best used when the results of the problem (such as cost, product returns, or customer complaints) are used rather than the simple number of occurrences, as shown in Figure 8.20. A simple tally of a small number of problems will not stand out, but if they create a great deal of negative impact or expense, they will often create an obvious prioritization.

Frequency Histograms and Correlation

Correlation of cause and effect may be measured using any number of statistical tools; indeed, this is the bulk of the field of statistics, but several simple, useful visual tools are histograms (Figure 8.21), which will give an idea of the distribution of actual data measurements and process capability, and are often expanded to include time, work shift, or material supplier.

Correlation charts will give a visual representation of the likelihood of causal linkages between different manufacturing inputs. Figure 8.22 represents a closely correlated data set (high $\rho_{a,b}$ value) between variables A and B, and therefore an increased likelihood of a causal link, while Figure 8.23 shows a very low correlation because the data is broadly distributed in a nearly random fashion between the two variables.

Many of these tools are easily accessed with spreadsheets or even simple handheld calculators. Additionally, users who shy away from deep statistical analysis will gain a great deal of insight from the visual representation of data.

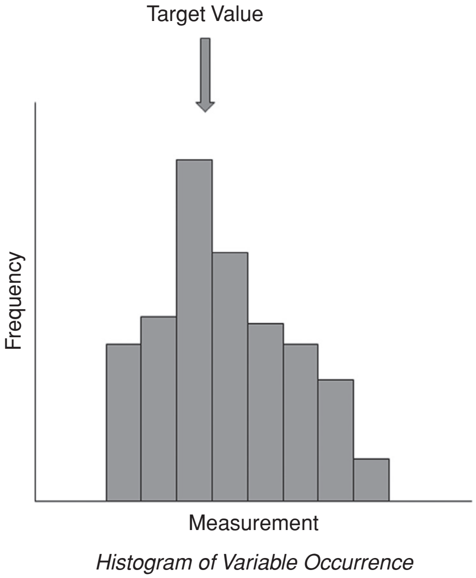


Figure 8.21. Histogram of Intervals of Measured Values during Production

Run Charts, Control Charts, and Time-Based Data

Information taken from ongoing production operations will often highlight time-dependent problems that may, in turn, showcase unusual causes that might not come to light otherwise. These *run charts* (Figure 8.24) highlight slow trends that may not be obvious from simple fixed-time examination of data, and the cumulative statistical data will also provide a basis for evaluation of ongoing control chart measurements during production.

Control Charts (Figure 8.25) represent a means of plotting an ongoing series of measurements taken from the production operation. These measurements, along with their standard distribution

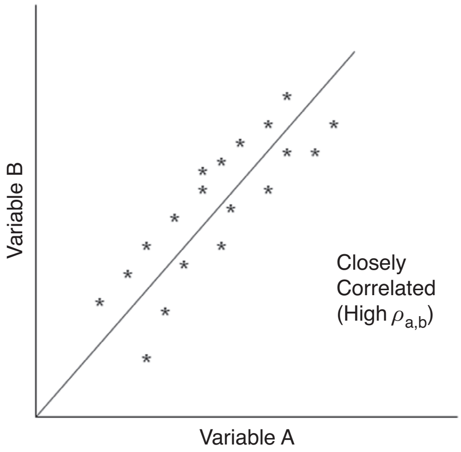


Figure 8.22. Good Correlation between Variable A and Variable B

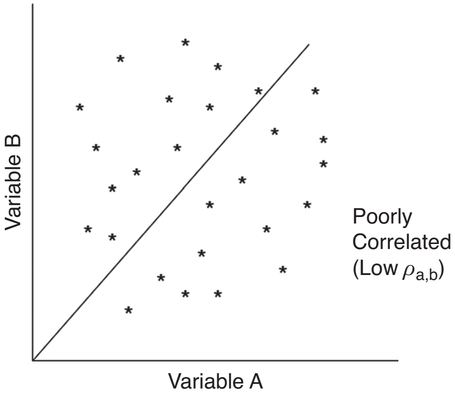


Figure 8.23. Poor Correlation between Variable A and Variable B

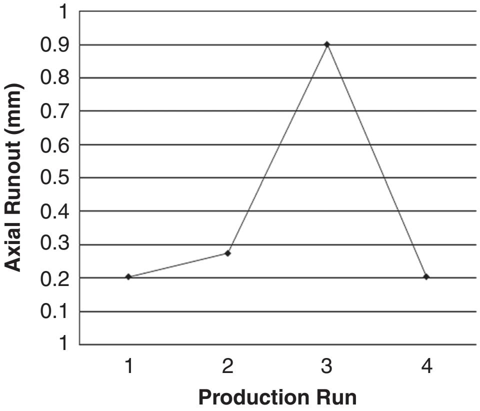


Figure 8.24. Run Chart of Measured Attribute (Axial Runout)

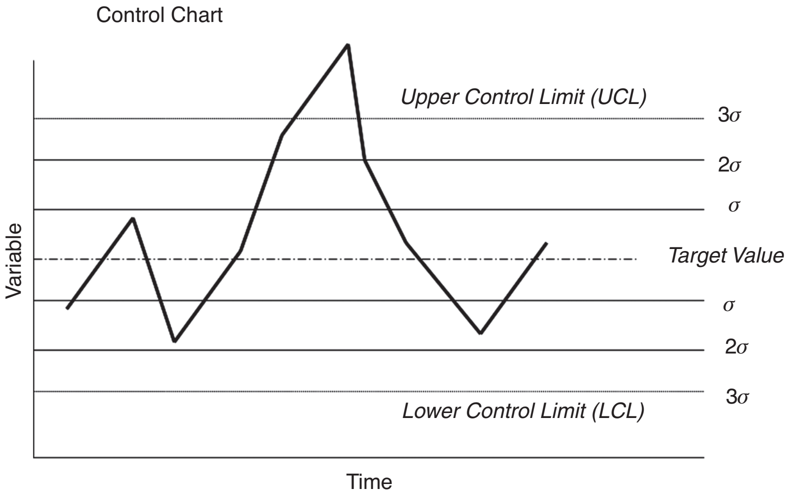


Figure 8.25. Control Chart Showing Measurements

Table 8.3. WECO Process Control Rules

WECO Rules state that a process is out of control if:

- A single point falls beyond $\pm 3\sigma$*
- Two out of three successive points fall beyond $\pm 2\sigma$
- Four out of five successive points fall beyond $\pm 1\sigma$
- Eight successive points fall within the same side of $\pm 1\sigma$
- A process variable is trending if 6 points in a row trend consistently up or down or 14 points in a row trend alternately up and down, indicating an oscillating trend.

Where σ is one standard deviation taken from historical data.

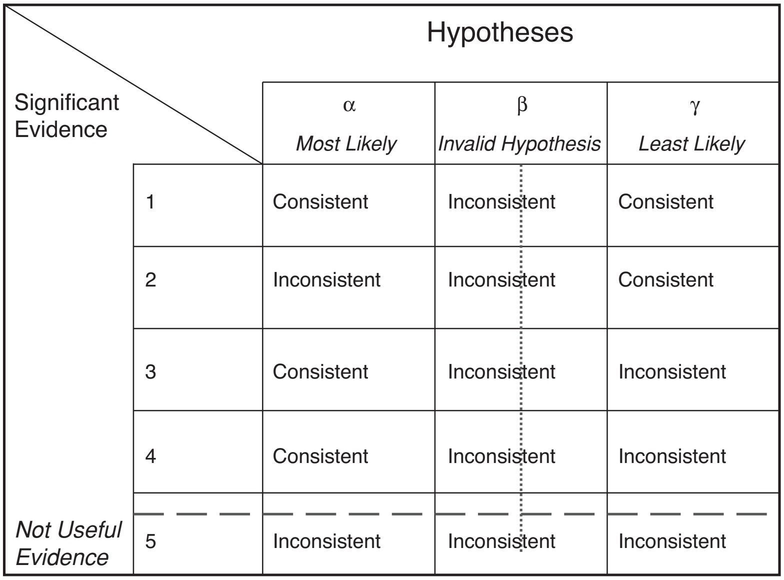
values, may be tabulated manually or taken automatically and displayed on an ongoing screen. The results can both show the stability of the operation and demonstrate the effect of changing speed to increase (or decrease) throughput.

Traditional *WECO* ("Western Electric Company") rules given in Table 8.3 are often used as a starting point for analysis of the results of run charts, although they may increase the number of false alarms [15].

Hypothesis Testing as a Problem-Solving Tool

Hypothesis testing is a useful tool for determining the cause of a problem that may be obscured by a large amount of information or mixed opinions about the source of the trouble. The steps of hypothesis testing as shown in Figure 8.26 consist of the following [16]:

1. A clear decision must be made about the problem or effect to be addressed.
2. List the hypothetical factors that are apparently applicable to the problem or effect.



		Hypotheses		
Significant Evidence		α *Most Likely*	β *Invalid Hypothesis*	γ *Least Likely*
	1	Consistent	Inconsistent	Consistent
	2	Inconsistent	Inconsistent	Consistent
	3	Consistent	Inconsistent	Inconsistent
	4	Consistent	Inconsistent	Inconsistent
Not Useful Evidence	5	Inconsistent	Inconsistent	Inconsistent

Figure 8.26. Hypothesis Testing Grid
Source: Morgan D. Jones, "Thinkers Toolkit." www.thinkerstoolkit.com, used with permission of the author

3. Construct a matrix with hypotheses as headers to the columns and available evidence as labels for the rows.
4. List the significant evidence that impacts the problem in the row headers.
    a. Include factors that are missing that should be present.
5. Working row-wise across the matrix, test the evidence for consistency with each hypothesis, one item of evidence at a time, labeling each square as being either consistent or inconsistent with the evidence at hand.
6. Refine the matrix.
    a. Are there other hypotheses that might need to be considered that were not put forth previously?
    b. Is there other significant evidence that might be needed?
7. Eliminate unnecessary evidence.
    a. Delete evidence that is consistent with all of the hypotheses because it has no diagnostic value.
    b. Similarly delete all hypotheses that are inconsistent with all of the evidence because they do not have relevance to the problem or effect.
8. Rank the remaining hypotheses by the weakness of inconsistency of the evidence.
    a. The hypothesis with the largest number of consistent hypothesis-evidence (or smallest number of inconsistent) pairs is the most likely hypothesis, in this case hypothesis α.
    b. It may be that there is no clear ranking, which may highlight the need for more data or different evidence regarding the problem.
9. Perform a "reality check" to be sure that the analysis is yielding real-world results.

While this may seem an ornate method of analysis, it is used in the investigation of aircraft accidents and crime scenes (and figures heavily in the base plots of a great deal of crime fiction). It has the advantage of being able to sift through a situation where a large number of conflicting opinions exist, and where hard decisions must be made with incomplete data.

ISO 9000 Series Standards, ISO 22000, and Six-Sigma Processes

The ongoing continuation of the *culture of quality* has brought forth several enduring process types that are incorporated widely in many types of operations. As with many well-publicized trends in management and corporate culture, the results have varied from astonishing improvements in product quality systems to bewildering paper exercises that wind up costing a great deal and returning little effect.

ISO 9000 series quality management standards began in 1987 as several distinct categories of standards, the ISO9001, 9002, and 9003 (and the European equivalent, EN 29000 series) standards, which covered several overlapping sets of activities, were created from the British BS 5750 quality system that was developed for the munitions industry during World War II [17]. These three distinct ISO standards were created for complete design through installation and service operations, manufacturing-only operations, and final inspection and test operations respectively. The confusion that this array of standards caused has been reduced somewhat after all of the standards were rewritten into the ISO 9001:2000 document, which was further revised in 2008. Additionally, ISO 22000 is an implementation of the ISO 9001 concept specifically adapted for food safety management systems.

The elements that make up ISO 9000 certification include:

- An effective quality system.
- Valid measurements and properly calibrated test equipment.

- Appropriate statistical techniques.
- A method for identifying and tracking products, including adequate record-keeping.
- An adequate process for handling, storing, packaging, and delivering products.
- Adequate processes for inspecting and testing as well as for dealing with non-conforming items.
- An internal audit system, including concrete evidence of compliance.
- Adequate training and experience among employees.

Although there is a wealth of information about the ISO 9000 systems, the essence of it is that the culture of quality must not only be created, but must be documented and improved on an ongoing basis. All processes, whether managerial, design, production, or service-oriented, are subject to examination and documentation as are processes for dealing with non-conforming goods and services. ISO 9000 certification is not done by the ISO organization but by private agencies, many of which work on a sliding scale based on company size.

Six Sigma

Six Sigma quality management practices are a formalization of the work of basic quality management advocated by Juran and others, and has been the subject of a significant amount of criticism for creating a huge infrastructures and bureaucracies that inhibit creativity and speed of implementation. In its initial form, Six Sigma was a tool developed by the Motorola Corporation in 1981 to improve the quality of its electronics parts and assemblies to create a defect rate of less than 3.4 defects per million opportunities (DPMO) where "opportunities" may represent physical products, consumer contacts, or procedural operations [18]. Motorola credits the process for more than $17 billion in savings, but the process has been subject to some criticism, not the least by Joseph Juran who considered it a ". . . basic version of quality improvement" [19]. Whether the quality improvement effort fits neatly into one of the pre-existing frameworks or is invented for an ad hoc process, the basic steps should go back to Shewhart's cycle of "Plan, Do, Check, Act" – a continuous cycle of measurement, evaluation, implementation, and reassessment that leads to a continuous improvement of the products and processes in any particular operation and does not require an overburden of bureaucracy or jargon.

Ergonomics

While some segments of the packaging and food production industry, such as high-volume beer production systems, have come to epitomize automated manufacturing systems, food production and packaging is still quite often a labor-intensive process that requires an understanding of the effects of the manufacturing environment on the employees.

Ergonomics – properly the study of human motion that is usually applied to the design of objects and devices – has also been used to define the area of industrial design that accommodates the human worker. Many of the common changes that people may be familiar with, such as monitor stands and ergonomic keyboards, have been developed as a result of studies done by the National Institute of Occupational Health and Safety (NIOSH). As data processing became a more commonplace mode of work, and particularly in the 1970s and 1980s, when a large amount of data entry was still being done by hand, there was a rise in the number of workplace injuries and chronic conditions – most often, eyestrain and carpal tunnel syndrome – related to simple factors such as the placement of monitor height and keyboard design.

Taken further, industries such as the meat processing industry that relies on a great deal of hand-work in unfavorable conditions (carcass processing in refrigerated facilities) have benefitted from changes in workflow brought on by NIOSH studies. Several other case studies will be considered here to illustrate both the approach that was undertaken to diagnose and make changes, and how those changes were presented in a financially favorable light.

Methods of Ergonomic Analysis

Most often, ergonomic analysis and changes are thought to be an involved process that requires a great deal of mechanical analysis, when often a bit of commonsense – or a few conversations with people doing the actual work – will suffice. Simple calculators are available to understand the potential for repetitive-motion injury as a function of simple parameters that can readily be measured, and to recommend Recommended Weight Limits (RWL) for particular operation, as shown in Figures 8.27 and 8.28 using the NIOSH Lifting Equation shown in Table 8.4 [20, 21].

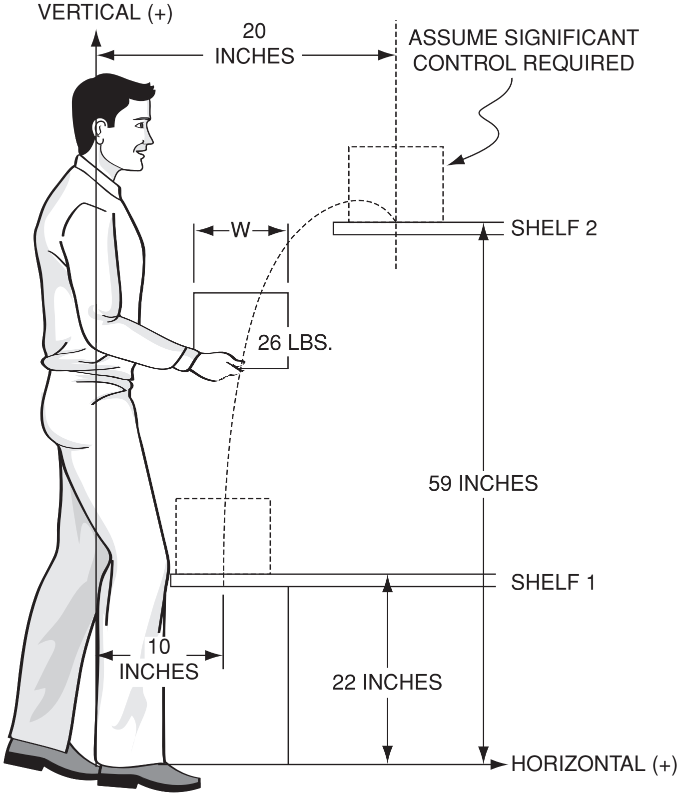


Figure 8.27. NIOSH Lifting Calculation for Package Instpection
Source: Centers for Disease Control and Prevention, National Institutes for Occupational Safety and Health

JOB ANALYSIS WORKSHEET

DEPARTMENT Quality Control
JOB TITLE Packing Inspector
ANALYSES NAME
DATE

JOB DESCRIPTION
Inspect packages

Example 4

STEP 1. Measure and record task variables

Object weight (bs)		Hana Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate	Duration	Object Coupling
		Origin		Dest.			Origin	Destination	ms/min	(HRB)	
L (AVG.)	L (Max)	H	V	H	V	D	A	A	F		C
26	26	10	22	20	59	37	0	0	3	.75	Fair

STEP 2. Determine the multipilers and compute the RWL's

RWL = LC × HM × VM × DM × AM × FM × CM

ORIGIN **RWL** = 51 × 1.0 × .94 × .87 × 1.0 × .88 × .95 = 34.9 **Lb**

DESTINATION **RWL** = 51 × .50 × .78 × .87 × 1.0 × .88 × 1.0 = 15.2 **Lb**

STEP 3. Compute the LIFTING INDEX

ORIGIN LIFTING INDEX = $\frac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \frac{26}{34.9} = .8$

DESTINATION LIFTING INDEX = $\frac{\text{OBJECT WEIGHT (L)}}{\text{RWL}} = \frac{26}{15.9} = 1.7$

Figure 8.28. NIOSH Lifting Calculation Worksheet
Source: Centers for Disease Control and Prevention, National Institutes for Occupational Safety and Health

For more involved processes, more observation and analysis may be necessary to remediate the problem, but the cost reduction and potential process improvement are often a large multiple of the initial investment. As previously discussed, the analysis of problems occurring in complete production systems can be a multistep process, requiring an understanding of all contributors to the processes' operation. Once the problems have been highlighted, one can concentrate on the most urgent hazards in order of severity. Fairly often, the changes involved may be the sort that requires small changes or modifications that seem all too obvious once discovered, and it may be more effective to spend development time to reduce noise levels and provide proper lighting

Table 8.4. NIOSH Lifting Equation Calculation

RWL = LC x HM x VM x DM x AM x FM x CM

LC: Load Constant = 51 lb (23 kg)
HM: Horizontal Multiplier
VM: Vertical Multiplier
DM: Distance Multiplier
AM: Asymmetric Multiplier
FM: Frequency Multiplier
CM: Coupling Multiplier

than to require workers to wear hearing protection and to deal with operator errors, cleaning, and maintenance problems that are exacerbated by the lack of lighting and the difficulty of accessing equipment.

Because a great deal of the packaging industry relies to some extent on hand labor, if only to move materials into and out of processing operation, or to access machine changes or clear jams, and the food industry often relies on manual labor to assemble dinners or fill large containers, ergonomics is both an item of concern and a potential benefit for production facilities. For food processing operations that may be substantially altered from product to product, ergonomic improvements can be somewhat more difficult, but it is often possible to couple ergonomic standards to particular sub-operations that then can be reassembled as needed, paying attention to the intermediate links (table heights, for instance) that occur between them.

Example: Frozen-Food Distributor

A frozen-food distributor was incurring large injury rates from WMSD and other injuries in its facilities; through analysis of its operations, it discovered that many workers were suffering back injuries resulting from the repeated lifting of heavy institutional packages of frozen foods. Additionally, there was a high rate of back and shoulder injury associated with moving materials on pallet jacks (manual forklifts that lift a palletload of product just off the floor and can be moved manually), and other injuries associated with slipping in the cold environment.

After analyzing all shifts in the operation, both for types of injury occurrence and location and operation that produced them, several important items were discovered and inexpensively remedied:

- Institutional package sizes were reduced. This allowed workers to load smaller increments per lift, increasing loading time slightly but substantially reducing back strain during the process.
- Non-skid shoes were provided for the employees. This simple change reduced the number of slip-and-fall accidents remarkably at little cost.
- Pallet jacks with brakes replaced the existing ones that had to be stopped by brute force. The brake assemblies are a relatively inexpensive option and are usually operated by raising the pallet jack handle to the upright position. This change allowed pallets of material in motion to be stopped without additional force being applied by the operator.

Some of the secondary effects of ergonomic improvements are less likely to be immediately reflected in production quotas or quality valuations. Short-term health claims may be shown to be much less prevalent, but the longer-term effect on employee turnover or marginal customer satisfaction will be much more difficult to correlate with changes made in workflow layout.

Generally, the process flow for ergonomic evaluation in production facilities can be assisted by workplace claims, but a thorough evaluation should be made of the workflow and the ergonomics of particular tasks, as well as soliciting the cooperation of the people who actually do the work because they will know the task most intimately.

Remedies for most workplace ergonomic changes include simple steps that can often be fabricated in-house, or can be purchased. These include steps such as:

Movement Assistance

When moving materials from one place to another, the inertia or weight of the items can cause repetitive-motion injuries during handling. Mass movement assistance can range from something as simple as a low-friction tabletop to more complex lifting and movement fixtures or automated moving devices.

In many cases, such as the reduced package sizes mentioned in the example, the movement can be assisted by minor changes in items such as the way materials are delivered into the system. The best examples of this come from industries such as the automobile assembly where engine/transmission units are fitted with attachments that allow them to be moved into car bodies with the use of lifting and movement fixtures. This method can be used by specifying the form factor of the materials to be delivered into the packaging line, whether fitted with a lifting tab, provided with a slip sheet that allows easier feeding into a magazine, or other changes.

Positional Fixtures and Work Height Adjustment

If the task requires that workers reach into machinery, or need to extend significantly into the work task, simple supports such as elbow rests may allow a great deal of task improvement with little investment. Obviously, these should not circumvent safety fixtures. Employee seating or standing workstations should similarly be constructed to allow ease of movement and optimal access to the workpieces.

Very often, when materials or workpieces have to be moved from one station to another, the workers must lift them and place them at a different height. Adjustable height tables and work fixtures can assist in proper positioning. Similarly, the height of many workplaces is simply determined by the construction of the machinery or devices that must be used, with an adjustable chair added to accommodate individual worker dimensions. Adjustable tables, jigs, and fixtures can reduce worker fatigue and increase the accuracy of work.

Proper Lighting

Inspection tasks in particular require a good lighting source for most operations. Very often, inspection stations simply assume that a good bright light source will be sufficient for accurate vision of particular defect types, when in fact it may take a specific type of light (diffuse, specular, or even coherent) for ease of visualization of the defects that might be present.

Even non-inspection tasks can require lighting adjustments – newer spot-lighting systems using bright, low-power LED systems can assist in providing an unobtrusive visual aid to material flow or product assembly.

Environmental Adjustment

Working frozen-food facilities, around ovens, and high-temperature processing operations all require protective gear, but small changes in some environmental protection can have a profound effect on production. For example, improving insulating gloves' dexterity may reduce the number of dropped products in a frozen-food handling operation.

Task Rotation

Particularly strenuous (or tedious) tasks can be rotated within a workday so that no single worker will be exposed to high levels of a particular workplace. This typically has the added benefit of reducing boredom with a particular task and may be used to cross-train employees.

Table 8.5. Estimation of Costs and Sales Equivalent of Workplace Injuries

Estimation of Occupational Injuries and Related Costs as Sales (5% margin)					
Injury Type	National Average Direct Cost[1]* (US$)	OSHA Multiplier	Indirect Costs[2] (US$)	Total Cost Per Incident (US$)	Additional Sales Needed to Cover Incident[3] (US$)
Carpal Tunnel	24,000	1.1	26,400	50,400	**1,008,000**
Tendonitis	15,000	1.1	16,500	31,500	**6,300,000**
All Sprains/Strains	23,000	1.1	25,300	48,300	**966,000**

[1] Workers Compensation = medical treatment and wage indemnification.
[2] Indirect Costs = Administrative costs, lost time, overtime to cover missing employee, and related expenses.
[3] Additional Sales Needed to Cover Incident = Total Cost Per Incident/5% Profit Margin.
*Approximate

Sales Multiplier Method

The advantage of considering the worker in this instance has been shown to have several effects, the most profound of which is to generate the equivalent of a large jump in sales volume. When the economic effects of the internal savings resulting from ergonomic accommodations are translated through sales margins, the result can be the equivalent of an enormous increase in sales (or the cash-flow equivalent thereof). This type of reasoning has been used to successfully argue for changes that have other desired effects as well such as reduced downtime, reduced worker turnover, increased product quality, and fewer health claims [22].

As shown in Table 8.5, the effective equivalent of savings because of ergonomic changes has a huge multiplier effect, particularly given the extended health care costs of some of the injuries and disabilities involved. This can be a powerful argument to use with many types of process improvements, considering that ergonomic improvements, like many internal changes, are often seen purely as a cost item. The equivalent of increased sales has a deep resonance with management's concern for the bottom line and can make a powerful case for improvements.

Additional Resources

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