Solutions Manual to Accompany

Engineering Design Fifth Edition

George E. Dieter and Linda C. Schmidt

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CHAPTER 1
ENGINEERING DESIGN

1.1. A company making snowmobiles should have the capability to design and build equipment that stands up in an aggressive service environment. Working in the snowmobile business should have resulted in expertise in small gasoline engines. The company probably sells to a network of distributors, so there is no experience in selling directly to the customer.

Snowmobiles are part of the growing business market segment of recreational vehicles. An obvious business opportunity that would extend the sales year around is to develop water sport equipment like jet skis. The market is crowded with suppliers, but an innovative design with an attractive entry price, or novel technology or features, could find acceptance. Another market possibility is off-road vehicles like a small dune buggy or three-wheel motorcycles. The same conditions for a new product would apply as for jet skis.

A related, but separate possibility for a new product would be specialized vehicles for business and industry. Some examples are: a safe vehicle for bicycle messengers in crowded city streets, a small logging vehicle, small construction machinery, and a parts-picking vehicle for large warehouses.

1.2. This is an individualized exercise for each student. In general, to make it a design problem the student would remove specific data, like forces, material properties, and add constraints like safety, reliability, and conformance to standards.

1.3

Needs Analysis

Must be capable of being constructed with local materials and labor. Total cost to be less than $300 (U.S.). Should be easily transportable to different locations. Must be powered with human labor since you cannot count on availability of electricity. Hydraulic components may be invalid solutions because of cost and/or maintenance (sand in seals, etc.).

Musts	Wants
1. Cost less than $300	1. Able to make tiles 2 x 6 x 12 in
2. Weight less than 130 lb.	2. Easily maintained
3. Human powered.	3. Easy and safe operation
4. Made from local materials (mostly wood, plain carbon steel)	4. Adaptable to a variety of soil mixes.
5. Easily manufactured in local garage shop	
6. Produce 4 x6 x 12 in. blocks	
7. Produce 600 blocks per day	
8. Compressive strength at least 300 psi dry	

Problem Statement

The objective of this project is the design and construction of a prototype model of a block making machine. The blocks are to be made of soil with a minimum of cement added, and are 4x6x12 inches. The machine must be human powered, weigh less than 130 lb., cost less than $300 to build, and be capable of producing 600 blocks per day with a 5 person crew. Blocks must have a compressive strength of 150 psi as formed and 300 psi when cured. The machine should be easily constructed of local materials with local labor (assume a third world tropical location). The machine also should be adaptable to a variety of soil cement mixtures, and to making tiles 2 x 6 x 12 in. A crew of five persons should be capable of operating the machine to produce 600 blocks per day.

Information Needed

1. Determination of the processing conditions for making blocks.
   What pressures must be generated? Curing temperature and time? Effect of different soil mixtures on pressure.
2. Mechanisms for generating pressure.
3. Human Factors Engineering
   Magnitude of force that can be produced by a human
   Human fatigue
4. Materials handling
5. Available construction materials and their properties.

1.4. This topic is covered in detail in a paper by M.R. Hanley, et.al, *Trans. ASME, Journal of Engr. Material,* vol. 102, Jan. 1980, pp.26-31.

1.5. Some possible concepts are:

- Vapor deposition, in a vacuum on a continuous (as opposed to batch) basis.
- Ion implantation.
- Slurry coating with nickel powder; sinter and hot roll to form a bond with the base steel metal.
- Electroless nickel plating plus cold rolling.

1.6, This topic is treated in detail in a paper by W.G. Jaffrey and G.M. Boxal, *Journal. Iron and Steel Institute,* May 1963, pp. 401-408.

1.7. This design problem is discussed in a paper by R. Davis and M.L. Hull, *Trans. ASME, Journal. of Mechanical Design*, vol. 103, Oct. 1981, pp. 901-907. The need that an aluminum bicycle frame fulfills is decreased weight. While the section modulus will have to be greater for aluminum than steel because of its lower elastic modulus, 10×10^6 vs. 30×10^6 psi, preliminary finite element analysis shows about a 20% weight reduction. A simple FEA using beam elements can establish the critically stressed joints. A more precise FEA can map out the stresses at these joints, and from this the stress concentration factors can be determined. The selection of the particular aluminum alloy will be based on cost and fatigue properties, using the methods discussed in Chap. 11. To give the problem a more current flavor, have the students find papers on the use of fiber-reinforced composites in bicycle construction. This will introduce the issue of material cost and difficulty in manufacturing the structural members.

1.8.

(a) Societal impacts: supply of coal miners; accident rate of coal miners; long-term impact of respiratory diseases in miners; damage to environment from surface mining, especially in mountainous country; adequacy of railroads to transport coal; traffic interference, noise, dirt, accidents from coal transport; adequacy of engineering design talent to design plants since much of this expertise is now retired. A major deterrent to massive substitution of coal produced gasoline, in addition to the cost of plant construction, is the need to control greenhouse gases

(CO_2) created in coal processing. These costs are very substantial. It should be noted that the country of South Africa provided all of it gasoline from coal using the Sasol process for many years, but this was before the world-wide concern about global warming.

(b). In the past there was a big difference between the way society views the impacts of energy generated from nuclear materials and coal. Nuclear is more difficult to consider on a rational unemotional basis due to fear of nuclear weapons and nuclear radiation leaks. Look how long it is taking to establish a national repository for spent fuel rods in the Nevada desert. On the other hand, some people remember when their homes were heated by coal. There is a romanticism associated with the coal miner. People are generally more comfortable with energy from coal than from nuclear sources. This is changing with the great concern about global warming from greenhouse gases, to which CO_2 resulting from coal combustion is a major contributor. Nuclear energy does not contribute to global warming. The safe disposal of nuclear waste remains the main concern of many people, as is the possibility of terrorist acquisition of nuclear material and using it to make a “dirty” bomb. Alternative energy sources like wind, solar power, and biofuels will grow, but at this time they do not appear capable of reaching the magnitude needed for electric power generation by the nation. Thus, the path remains clear for resumption in building nuclear power plants. The greatest obstacle from this happening is the growing cost of construction of a nuclear generation plant, although the 2011 nuclear accident in Japan due to earthquake and tsunami has produced a cloud over further international growth of nuclear generation of electricity.

1.9. It is interesting how quickly things change in the energy field. When answers to the 4^{th} edition were being prepared in 2008 it was correct to state that increased use of natural gas (NG) for generation of electricity had increased the price of NG such that it was economical to ship NG to the United States or Europe from Algeria, the Middle East, and the Caribbean. Now, in 2012 the situation is reversed. Application of directional drilling methods and the use of high pressure fluids (fracking) to increase the permeability of the shale formations holding the gas, have uncovered massive amounts of NG in shale deposits in the Appalachia states, Texas, and North Dakota. This is more gas than can be utilized in the United States, so the local price of NG is severely depressed below the current price in Europe and Asia. \Therefore, plants built to receive NG from overseas are being refitted to ship NG from U.S. sources overseas.

Natural gas is liquefied with refrigeration techniques to -260 F, which reduces its volume by a factor of 600. In the liquefaction process impurities such as water, hydrogen sulfide, and CO_2 are removed to leave nearly 100 percent methane. The liquefied natural gas (LNG) is transported in special doubled-hulled tankers with insulated tanks to maintain the LNG at proper temperature.

At the tanker terminal the LNG is transferred to double-walled storage tanks with insulation between the walls. The pressure must be regulated to minimize vaporization, for both economic and environmental reasons. The next step in the process is to pump the LNG to the vaporizer units, where it is heated under controlled conditions and introduced into the gas transmission pipeline.

Technical Issues

a. Design of the transfer piping system

b. Design of the storage vessels
c. Design of the vaporizer unit
d. As discussed below, safety is a paramount issue, but so is cost. A LNG transfer terminal can easily cost $5B. There needs to be careful balance between these issues, with safety given top consideration.

Societal Issues

Safety is a major concern in working with LNG. Although LNG is not flammable or explosive, when exposed to 5 to 15 volume percent air it becomes highly flammable. If LNG hits water it vaporizes violently and rapidly, forming a gas cloud that can travel for several miles before dispersing to a safe level. If the gas cloud is ignited the flame can travel through the cloud back to the source of the vapor. Thus, the area covered by the fire can be extensive. A leak of LNG or a spill, if ignited, is called a pool fire. This is more localized than a cloud fire, but of longer duration. If LNG is accidently released from a pressurized containment the leak usually takes the form of a spray of liquid droplets and vapor. This is called a torch fire, and delivers greater radiant heating than a pool fire. If the LNG is confined when ignited, it can result in a violent explosion.

When the transportation of LNG was first developed in the 1960s there were several major explosions and fires. Public concern arose over this new technology and as a result the U.S. government developed safety standards (49-CFR-193) and the National Fire Protection Association issued consensus standards (NFPA-59A) which have been continually updated. Since most LNG transfer terminals have been sited in narrow harbors or waterways, there has been concern that a ship collision or grounding might cause a LNG release. More recently there is been concern that a terrorist attack could cause a fire or explosion. Accordingly, the U.S. Coast Guard has issued regulations dealing with the site selection and design of LNG terminals (33-CFR Part 127). Thus, the design of the LNG plant will be highly constrained by codes, regulations, and standards.

One final societal concern deals with the emission of methane, which is a potent greenhouse gas. Clearly, the design must give high priority to preventing venting or escape of methane to the environment. We started this discussion with the statement that natural gas is a preferred fossil fuel from the standpoint of global warming. However there are some who claim that after all of the energy consuming processes of refrigeration and transportation are taken into account the net benefit of using LNG may not be beneficial to the environment.

1.10.

Outsourcing manufacturing to a foreign country usually is done to take advantage of lower manufacturing wages. A secondary objective can be to increase sales in the country of manufacture.

Most product development depends on fine-tuning the design once it gets into production to improve upon design features that make assembly difficult and some parts more expensive to manufacture than expected. Occasionally, customer usage uncovers functional issues that need correction. These follow-on design activities often involve the modification of tools and fixtures used in production, or even the design of a modified part. Often these design tasks are performed by a small design staff that is in residence at the manufacturing location. There are also issues with maintaining quality standards with a workforce where language and culture are much different from the home country.

Therefore, moving the manufacturing plant offshore greatly increases the communication task of leader of the product development team. Early on he/she must visit the new plant and gain the confidence of the plant manager and the top engineer. It is also important to bring that engineer back to the home office to be trained in company values and procedures. Much communication will be done via the Internet, so effective communication protocols must be established.

1.11

The oil spill from the blow-out of British Petroleum (BP) well Deepwater Horizon is one of the world's greatest environmental disasters. Nearly 5 million barrels of crude oil spewed into the Gulf of Mexico for more than three months. Information for the specific questions, (a) through (d) can be found in the following places.

(a) The technology for drilling in water deeper than 10,000 ft. see HowStuffWorks: How Offshore Drilling Works. For general information on oil well drilling see Wikipedia: Oil well drilling.
(b) For information on the Deepwater Horizon accident see Wikipedia: Deepwater Horizon
(c) Sort-term impact: Damage largely affected people living in the Gulf Coast (Louisiana, Alabama, Mississippi, and the Florida panhandle). Immediate jobs lost in the fisheries industry, fishing for shell fish and processing for sale nationwide. Since the accident happened May through August, which is the height of the tourist season for Gulf Coast beach resorts people lost jobs in hotels, restaurants, gift shops, and entertainment facilities. Most of these businesses depend on the summer months for most of their annual revenues. The Federal moratorium on deep sea drilling in the gulf affected people who work on drilling platforms or supply and service the platforms. All told, 50,000 to 100,000 highly paid jobs.
(d) Long-term impact on the United States: There is a major impact to the U.S. oil supply. The deep waters in the Gulf of Mexico are the largest largely undeveloped but proven source of crude oil in the U.S. Although drilling has been reestablished it is with increased federal regulations that significantly increase costs, which drives out the smaller capitalized independent oil companies. The cost to rent a deep water drilling platform is many hundred thousand dollars per day. With the moratorium in place for many months, these platforms could not afford to wait around unproductive, so many were moved to oil fields in Africa and South America. All of these issues make it more difficult for the U.S. to become self-sufficient in oil production

1.12

Brazil is a country of 200M people with vast mineral resources, chiefly iron ore, large but lightly populated areas in the interior available for agricultural development, and relatively poor surface transportation. Its rapidly growing economy needs greatly increased energy production to sustain this growth. Large amounts of oil are reported to exist about 200 miles of the coast at more than 10 miles deep below the South Atlantic Ocean.

However, Brazil's most important energy resource is its many large and free flowing rivers. Eighty-two percent of the energy generated in Brazil comes from renewable sources, with the preponderance from hydroelectric power, and the balance from biofuel produced from sugar cane. Hydroelectric power (http://ga.water.usgs.gov/edu/hyhowworks.html) would appear to be the ideal power source since it uses a renewable resource (water) and produces no greenhouse gases. However, hydropower requires a large dam to back up the water into a reservoir. This requires a large land area to serve as a reserve against drought years and to provide the hydraulic head to generate the energy to turn the turbine and electric generator. The ecological and social problems created by damming a river are:

- Fish are killed by turbines
- Fish are blocked from swimming up river to spawn. Fish ladders provide some relief
- River navigation is blocked, unless ship locks are provided with the dam
- Silt collects at the dam, removing a source of downstream fertilization
- Depending on location, large numbers of people will need to be relocated and assisted in rebuilding their livelihood.

http://www.ems.psu.edu/~elsworth/courses/cause2003/finalprojects/vikingpaper.pdf

A number of hydroelectric plants were built in Brazil in the 1980s along the tributaries of the Amazon River. These were conventional high-head dams that took hundreds of square miles of jungle for reservoirs. When the dams were built the reservoirs filled up, partially submerging the jungle below. Soon the vegetation died and decayed, releasing high amounts of methane, a greenhouse gas even more potent than CO_2. Rather than being zero emitters, the hydroelectric plants became major emitters of greenhouse gas. Also, major protests by the native peoples displaced from their farms led to a ban on future construction of dams in the Amazon region.

With the growth in population (200M) and the economy Brazil will need to find a way to tap the potential of its rivers in the Amazon region. The answer seems to be the utilization of new hydraulic turbine technology and a much more far sighted policy for dealing with indigenous peoples. The San Antonio Dam (see Wikipedia) will employ run-of-the river hydroelectric technology (Wikipedia: Low head hydro power).The power generated is proportional to the falling head of water x the flow rate of the water. Low head hydro power substitutes advanced turbine design, Kaplan bulb turbine, in which the flow rate is much higher than in a normal hydraulic turbine. The San Antonio turbines will each generate 71.6 MW of electric power, and when the 44 units are installed the plant will have a capability of 3150 MW.

The social issues have been addressed by advanced panning. Over 20,000 locals have been trained to work as construction workers and entire modern communities lights, running water, paved roads have been built to house them. Special fish ladders have been designed by U.S. experts and ship locks have been provided. This opens up new ways for local farmers to get their crops to market. An important aspect is that the dam project is being built, for the first time in Brazil, with private capital. The efficiency brought by a private builder is allowing the project to be completed in record time (see John Lyons, Wall Street Journal, Oct.6, 2010).

Chapter 2
PRODUCT DEVELOPMENT PROCESS

2.1 The following are some reasonable estimates.

	Power screwdriver	**Desktop inkjet printer**	**Electric car**
Annual units sold	100,000	4,000,000	300,000
Sales price	$30	$150	$35,000
Development time	1 year	1.5 years	4.5 years
Peak size of team	3	100	800
Development cost	$250,000	$8 million	$500 million

2.2.

A toothpick, paperclip, a wooden baseball bat, a crowbar, a water glass, a tent peg are some examples of a product consisting of a single component.

2.3

In general terms, the need for advanced education decreases from research to technical sales in the spectrum of engineering functions. Many would say that research, development and design provide more intellectual satisfaction, but high job satisfaction can be found in any of the engineering functions depending on the individual and their circumstances. While R&D provides a high initial salary, the long-term financial rewards may be higher in production, sales, or management unless the researcher proves to be highly innovative.

Opportunity for career advancement depends greatly on the individual situation. Strong professional recognition can be provided by a lifetime in R&D. Career advancement within the corporation usually requires a broad exposure to most of the functions listed in Fig. 2.7. In general, the people-orientation increases in going from research to management.

2.4

- Show strong organizational skills: abilities to work with people, meet deadlines, coordinate work, and administer paperwork.
- Show leadership: capacity for organizing and directing people.
- Strong communication skills: ability to write clearly and sell your ideas.
- Attitude: willing to spend time on administrative details for the good of the group; willing to delegate to and trust others; commitment to organizational goals.

2.5

The combination of an engineering degree plus a MBA provides the tools for broad corporate management. This will likely result in a career path that leaves technical work for marketing, finance, etc. MS in engineering is needed for higher level design work and is the minimum educational requirement for a career in R&D.

2.6

Project Mgr.	Functional Mgr.
Takes lead in scoping project.	Participates in development of project plans.
Takes responsibility for developing project needs for cost, schedule, and performance.	Participates in development of project resource needs for one specific specialty area.
Leads project team.	Makes detailed estimate of specialty area workloads.
Integrates and communicates project information.	Assigns personnel to project.
Tracks and assesses progress against plan.	Maintains technical excellence of specialty area.
Resolves conflicts.	Recruits, trains, and manages people in specialty area.
Communicates.	Communicates.

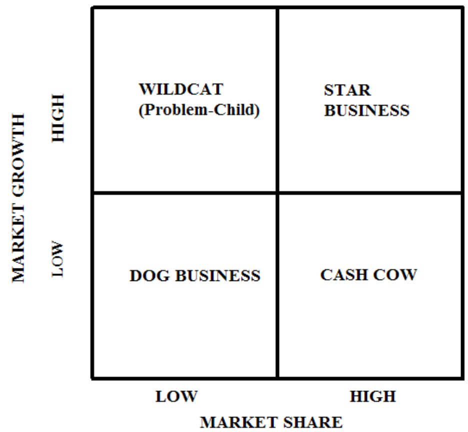
2.7

If the following questions can be answered affirmatively then the success of a new product would be likely.

a. Is there an assured market for the product?
   Does the product satisfy a well-documented societal need?
   Can the product be readily differentiated from its competition?
   Is the product free from governmental regulation?
b. Do you have a proprietary position with the product?
c. Do you have the technical expertise to design, produce, and service the product?
d. Do you have sufficient financial controls in place to sell the product at a profit?

2.8

The word description of business portfolio strategy the Boston Consulting Group, discussed briefly in Sec.2.6.2 is shown pictorially on the next page.



This is shown chiefly because the words cash cow, star, and dog businesses are commonly used in the business literature. However, these strategies should not be taken too literally. In a mature technology area it may not make sense to just milk the cash cow and kill the dog because mature technology businesses tend to result in very large sales volume. Therefore, it may make sense to do enough R&D to keep the cow healthy so that it can continue to provide the cash to start additional promising new tech businesses. Moreover, a moderate shift in a large market may turn a dog business into a cash cow.

2.9

Steps in technology transfer:

a. Information must be prepared in a form suitable for transmittal.
b. An appropriate audience to receive the information must be identified.
c. Information must be transmitted to individuals who can act on it most quickly. These people must be able to understand the new information and have a position in the organization to allow them to act on it.

Factors which make technology transfer a difficult process are:

a. The quantity of scientific/technical information available.
b. The need for feedback between user and originator.
c. The need for multiplicity of communication channels.
d. The need to provide for security of proprietary information. This is often difficult to achieve when outsourcing design and/or manufacturing functions.

Information can be transmitted in the following forms:

a. Technical reports and papers
b. Newsletters
c. Data sheets
d. Workshops and seminars
e. Internet
f. Employees changing jobs
g. Telephone “hot-line”.
h. Service representatives, technical sales people, extension agents.

2.10

It is clear that John Jones is essential for the success of the team, so by both Jones and the team must compromise. Much work of the team is done outside of team meetings, so that Jones’ unusual working hours will not be a hindrance to team progress provided some arrangement can be made for communicating with him. In a sense, this will be similar to the situation when part of a development project is off-shored to India which is separated from the U.S. by about 12 time zones.

However, it is important for Jones to be at team meetings where the group expertise is used in making critical decisions. Here is where compromise is required. For example, it might be decided that every third meeting will be held from 4 to 6 pm, accommodating Jones' schedule and requiring flexibility from the rest of the team. The team leader, and sponsor if needed, must obtain a firm pledge from Jones that he will faithfully honor this schedule. With realization of the accommodations the team members are making to utilize his special expertise, it is even possible that he will agree to come in early so that team meetings can be held in the early afternoon.

2.11

For any product development project there is a window of opportunity, or market window, in which customers are receptive to the product and no obvious competition exists. An experienced product development manager always lives in fear of the window being closed by the competition. Yet in the absence of any known competition it is often difficult to instill the needed urgency in the development team. When the market window closes the team must play "fast follower" and lose the advantages of being first to market.

Another type of window of opportunity is found in the development of large technical systems, such as a military airplane. For strategic reasons the system must be developed over multiple years, and performance improvement achieved with new technology, has a high priority. As suggested by Fig.2.6b, there is a gap between what is currently achievable in some critical technology, and R&D currently underway. This gives promise of improving performance. But, the program can only keep the technology window open for a limited number of months. If the new technology is not proven capable in the time window the program must go with the next best alternative. The new, better technology might not get its chance until the next aircraft of its type is developed 20 years in the future. To better manage this problem many agencies or industries have developed technology roadmaps that attempt to give a time line for the advancement of a critical technology.

2.12

Prior to the adoption of the shipping container, consumer and industrial goods were shipped in crates, boxes, and barrels in the hold of a cargo ship (the break-bulk system). This freight was loaded and later hauled out of the bowels of the ship with cargo nets and winches and the hard labor of large gangs of stevedores. The process was very labor and time consuming. It often took 3 to 5 days to unload a cargo ship.

The introduction of steel shipping containers in early 1960s resulted in major improvements in port handling effectiveness, significantly lowering shipping costs. This eventually made it cost effective to make products in China and ship them to the U.S. consumer.

Malcom McLean is responsible for the concept and implementation of a complete containerized freight transportation system consisting of:

- standardized steel containers, 20 or 40 ft. long x 10 high x 8 wide.
- specialized container ships that carry stacked containers on deck as well as below in the cargo hold.

- special designed cranes portside to load containers directly on flatbed railcars or tractor-trailer trucks.
- computerized system for quickly identifying containers and their contents

In addition to the technology of the new shipping system, several social and political innovations were necessary before containerized shipping became widely accepted. These were:

- Protracted negotiations with the longshoremen unions before they agreed to accept the early retirement buyout plan that reduced their ranks to the current smaller workforce.
- Major changes in the U.S. Interstate Commerce Commission regulations
- International standardization for container dimensions, capacities, and corner fittings for attachment to the crane.
- Development of special dockside cranes along with specialized computer software for deciding where to locate each container for optimum retrieval.

Today, 90 percent of all non-bulk cargo worldwide moves in containers.

References: Marc Levinson, *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*, Princeton University Press, 2006
Wikipedia: see Containerization

2.13.
A charge-coupled device (CCD) is an electrical device that is used to create images, store information, or transfer an electrical charge as part of a larger electronic system. The CCD is the heart of the digital camera, where it takes an optical input and converts it into an electronic signal which is then processed to produce an image. The CCD is also used in fax machines, photocopiers, bar-code readers and video cameras.

A CCD chip consist of an array of square or rectangular silicon picture elements (pixels) that are created on the surface of the chip by a semiconductor micro fabrication process in a two-dimensional pattern, When the photons in the light beam hit a pixel an electron is released from the valence bonds of the silicon. This produces a free electron and a “hole” in the silicon valance shell where the electron was originally located. An electron has a negative charge and a hole has a positive charge. The number of electrons liberated is proportional to the number of photons striking the pixel.

In an ordinary photographic process the image is produced by the chemical process that occurs when the photons of light strike the coated film. If the CCD pixel array is subjected to light for a specified exposure time the number of electrons released in each pixel must be captured so they can be counted and converted digitally to an image. This is done with a series of tiny electrodes, called gates, which are buried in each pixel during its fabrication. The array of electrodes produces a positive potential to hold the electrons in place, in their “electron-bins” within each pixel, until the exposure is completed. Then the number of electrons in each pixel is read out by controlling the potential, pixel by pixel, so the electrons in each bin travel together and can be counted.

The original charge-coupled devices were pure silicon, but currently CCD sensors are being made from Complementary Metal Oxide Semiconductors (CMOS). Integrated circuits made by the CMOS process represent the bulk of current IC production, so there is a large cost advantage to making CCDs by CMOS. This has resulted in large scale use of charge-coupled devices. There is, however, a tradeoff with image quality from CMOS CCDs, so they are not used in applications where extreme sensitivity is required.

2.14
Other technological developments, beside the shipping container, that have made the global marketplace a possibility are:

- Air freight - to deliver critically needed parts overnight compared with the three week ship travel time from China
- Internet communication – for rapid communication with overseas suppliers, and for transmission of CAD drawings and other product development documents
- Electronic funds transfer – rapid settling of accounts is crucial for international trade.
- Radio-frequency identification (RFID) tags that make it possible to quickly identify what is inside each container.
- Global positioning sensing (GPS) that makes it possible to track location of each container.

2.15

Business Plan

According to the National Marine Fisheries Service, 40 percent of the important species of fish are being taken from the sea at a rate faster than they can be replaced. Estimates by the U.S. Department of Agriculture are that the current fish harvest of 97 million metric tons per year will be far below the projected demand of 175 million metric tons in 2025. Aquaculture enterprises, in which fish are raised in enclosures close to shore or in ponds on land, cannot achieve the economy of scale needed to address this problem.

The solution is fish farming in the open sea- mariculture- combining technology learned from deep sea drilling and aquaculture. Huge concrete and steel cages will radiate from a central column anchored to the floor of the Gulf of Mexico. The cages can be raised and lowered by buoyant tanks and rotated around a core support structure to aid in cleaning the cages. Pelletized food will be transmitted to the cages by pipes.

Initially, high value species like red snapper, striped bass, and mahi mahi will be raised. Depending on the species, one 10,000 sq. ft. unit can produce 3 to 5 million pounds per year of fish. It will take 20 pounds of feed@$0.35 per lb.to grow 10 pounds of fish, that will yield 3 pounds of fillets selling for $6 to $8 per lb. wholesale. Once the bugs are worked out of the technology, the return on investment could approach 100 percent.
Source: W.G. Flanagan, *Forbes*, Oct. 23, 1995, pp.328-329.

2.16

Some examples of trickle-up products:

- GE portable electrocardiograph machine that sells for $2500.
- Tata Nano automobile that sells for around $3500 in India
- Acer Notebook sells for $250

Advantages of the Trickle-Up Approach to Product Development

- The obvious advantage is that it introduces a new product line for sale in the U.S. to a market segment that has not been reachable because of the price of the product.
- Another advantage is that it is a big morale booster to in-country engineers to see the product they developed now being bought in the U.S.

Possible Risks

- The major risk is that the lower price product might cannibalize sales of higher priced products with higher profit margins.
- The second risk is that a low price product line might carry a stigma of shoddy workmanship and jeopardize the brand name of the product. Quality must be maintained over all else. Will the customers really be satisfied with a smaller range of functions in the product?
- How the new product is advertised and marketed will be critical to the protection of the brand.