Pallets Move The World

The Case for Developing System-Based Designs for Unit Loads

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The largest domestic non-fuel use of wood fiber is the packaging and palletization of consumer and industrial products. Products that because of their form cannot be shipped or stored in bulk are consolidated or unitized for storage and transport. Most consumer and industrial products are formed into unit loads for this purpose. A unit load is a single item, a number of items, or a bulk material, that is arranged and restrained so that the load can be stored, picked up, and moved between two locations as a single mass.

A typical unit load, as shown in Figure 1, consists of corrugated containers stacked on a pallet and stabilized with stretch wrap or other materials. It is estimated that more than 2 billion unit loads are in continual daily use in the United States (Ward 1993).

Figure 1. — A typical unit load for the storage and distribution of consumer and industrial products.

Figure 2. — Wood framing dominates single-family home construction in the United States.

Relative Wood Fiber Consumption for the Shipping and Storing of Unit Loads

Wood fiber in the form of solid wood, paper, and paperboard is the most common packaging material and constituted 44 percent of packaging sales in the United States in 2000. Plastics represented 16.8 percent, metal 15.5 percent, and glass 4 percent of packaging sales (Rausch Associates 2002/2003). More than 93 to 95 percent of unit loads include a pallet and 95 percent of pallets are made of solid wood or wood-based composite materials (Modern Materials Handling 2000). It is clear from these estimates that large volumes of virgin and recycled fiber are required for the storage and distribution of domestically produced consumer and industrial products. The unit load is the largest non-fuel domestic use of virgin and recycled wood fiber. Consider the following comparison with other large-volume product uses of domestic wood fiber.

New Residential Construction (NRC)

There are three main wood-based components of NRC: softwood lumber, hardwood lumber, and structural panels (Fig. 2). For the year 2001, total U.S. consumption of softwood lumber, hardwood lumber, and structural panels was approximately 54 billion board feet (BF), 11 billion BF, and 34.2 billion square feet, respectively (Gibson and Smith 2001, Howard 2001). The National Association of Home Builders reported 1,602,700 housing starts (single-family homes) in 2001, with an average floor area of just over 2,000 square feet (NAHB 2002). They also estimated that the average new home built in the United States consumes roughly 13,000 BF of softwood framing lumber and 2,000 BF to 3,000 BF of hardwood lumber for cabinets, flooring, and millwork. Thus, softwood and hardwood lumber consumption for NRC construction in 2001 was approximately 20.8 billion BF and 4.0 billion BF, respectively. Also, an estimated 19.1 billion square feet of structural panels were used in 2001 (3/8-in. thickness basis) (APA 2001, Hayne 2003).

Using a 10 percent moisture content (MC) basis for all estimates, softwoods weigh 3.0 to 3.5 lb./BF (USDA 1999). The total dry weight of virgin softwood fiber used in NRC was 31.2 to 36.4 million tons (Table 1). The average weight of hardwood lumber at 10 percent MC is 3.5 to 4.0 lb./BF (USDA 1999). The dry weight of hardwood lumber used in NRC in 2001 was an estimated 7.0 to 8.0 million tons. Square footage for structural panels (3/8-in. basis) is converted to BF by multiplying by 0.375. Thus, the equivalent board footage of structural panels used in NRC for 2001 is 7.1 billion BF. Most of these panels are composed of softwoods or low-density hardwoods. If we

Wood fiber use category	Material	Total annual estimated wt. (million dry tons)
New Residential Construction	Hardwood lumber	7.0 to 8.0
	Softwood lumber	31.2 to 36.4
	Structural panels	10.6 to 12.4
	TOTAL	**48.9 to 56.8**
Repair/ Remodeling	Hardwood lumber	4.6 to 5.3
	Softwood lumber	24.3 to 28.4
	Structural panels	4.0 to 4.7
	TOTAL	**32.9 to 38.4**

Table 1. — Material estimates for new construction and repair and remodeling.

assume 3.0 to 3.5 lb./BF, the total dry weight is approximately 10.6 to 12.4 million tons. No significant use of recycled fiber was reported for NRC. Combined U.S. wood fiber use for NRC was between 48.9 and 56.8 million dry tons in 2001.

Repair and Remodeling (R&R)

The same three wood-based components used in NRC – softwood and hardwood lumber, and structural panels – are also used for R&R. In 2001, R&R required approximately 24.3 to 28.4 million tons of softwood lumber wood fiber (around 30 percent of total U.S. softwood lumber consumption) (International Wood Markets Research 2000) (Table 1). This market also consumed approximately 4.6 to 5.3 million dry tons of hardwood lumber wood fiber for cabinets, millwork, and flooring (Carliner 2002). Again, where structural panels are concerned, the R&R industry consumed 2.7 billion BF, or an estimated 4.0 to 4.7 million dry tons (21.5% of total U.S. structural panel consumption) (Hayne 2003). The combined U.S. wood fiber use for R&R was between 32.9 and 38.4 million dry tons in 2001. No significant amount of recycled fiber is used for R&R.

Paper (excluding paperboard)

The U.S. pulp and paper industry consumes approximately half of U.S. industrial wood fiber production (Ince 2002). The paper industry manufactures two principal products: paper and paperboard. Paperboard is used to make packaging, primarily corrugated and boxboard boxes and containers. Since only a very small percent of product is shipped parcel and much of that is unitized during some of the logistic function, it is reasonable to assume all paperboard is used in unit loads. The remaining composition of papermaking wood fiber is used to manufacture non-packaging "paper" products, such as writing paper, newsprint, tissue, and specialty papers. For 2001, a sluggish economy slightly slowed paper consumption such that growth declined roughly 6 percent from 1999 record levels (Howard 2001). Because approximately 38 percent of paper is produced from recycled fiber, 33.5 million tons of virgin timber and 20.4 million tons of recycled material were used to produce non-packaging paper in 2001 (Table 2). Combined, the American Forest & Paper Association (AF&PA) determined that the U.S. consumption of non-packaging paper in 2001 was 53.9 million dry tons (AF&PA 2002).

Wood fiber use category	Virgin wt.	Recycled wt.	Total estimated wt.
Paper (excluding paperboard)	(million dry tons) 33.5	(million dry tons) 20.4	(million dry tons) 53.9

Table 2. — Material estimates for paper (excluding paperboard).

Unit Loads

Wood fiber used to manufacture unit loads includes the paper used for packaging (paperboard) as well as the wood or wood-based materials used for pallets. An estimated 433 million new wood pallets were manufactured in the United States in 2001, consuming approximately 6.6 billion BF of lumber (Bejune et al. 2002). This lumber included 33 percent softwoods and 67 percent hardwoods, which on a dry weight basis corresponds to 10.9 to 12.6 million dry tons of new wood pallets (Table 3). In addition, it was estimated that pallet recyclers recovered 299 million pallets in 2001, or approximately 4.46 billion BF of recovered pallet parts (Bejune et al. 2002). Eighty-eight percent were repaired and/or reused for pallets and pallet parts, increasing the wood fiber consumption for unit loads by an additional 7.4 to 8.6 million dry tons.

There are two primary wood fiber based materials used for paper packaging: containerboard and boxboard. Containerboard is used to manufacture corrugated (liner and medium) boxes. Boxboard is used to manufacture solid fiber (chipboard) boxes, also called "folding cartons." Collectively these are called paperboard. According to AF&PA, the U.S. consumption of paperboard in 2001 was 47.7 million tons (AF&PA 2002). Approximately 38 percent of this total was recovered wood fiber. Therefore, 32.0 million dry tons of virgin fiber and 17.7 million tons of recycled fiber was used in paperboard boxes in 2001 (Table 3). Collectively, wood pallets and paper packaging that make up unit loads consumed 68.0 to 70.9 million dry tons of wood fiber in 2001.

Figure 3 shows graphically that the unit load currently consumes roughly 30 percent more fiber than either non-paperboard paper or NRC, and almost twice as much fiber than what is used annually in the United States to remodel or repair homes.

Wood fiber use category	Materials	Virgin wt.	Recycled wt.	Total estimated wt.
		(million dry tons)	(million dry tons)	(million dry tons)
Unit loads	Paperboard pack.	32.0	17.7	49.7
	Wood pallets	10.9 to 12.6	7.4 to 8.6	18.3 to 21.2
	TOTAL	**42.9 to 44.6**	**25.1 to 26.3**	**68.0 to 70.9**

Table 3. — Material estimates for unit loads.

Efficiency of Distributing Consumer and Industrial Products

Component Design Versus System Design

From the previous discussion, it is clear that the collective decisions of packaging and logistics professionals have a significant impact on the utilization of timber and the supply of wood fiber. The goal of this group of professionals is supply chain cost reduction. That is, reducing the cost of activities associated with the movement of products and materials between the seller (manufacturer) and the buyer (consumer or customer), as shown schematically in Figure 4.

These supply chains are predominately unit load based material handling systems consisting of three primary components, regardless of the products being stored or shipped: packaging, pallets, and unit load handling equipment.

Associated with each component of this system is a community of designers, each charged with reducing the cost of the component in the system for which they are responsible. Raw material is the largest cost of each of the three logistics system components, and therefore cost reductions are typically associated with reducing raw material requirements by redesign of the package, pallet, or handling equipment. These three components mechanically and physically interact during product storage and shipping. The redesign of one component of the system will potentially affect the performance of one or both of the other components, and therefore impact the performance of the entire system. For example, to reduce the cost of roll conveyor systems, conveyor designers may choose to increase spacing between rollers in the unit load transport within a distribution center. This will effectively change the load distribution on the pallet in the unit load moving across the conveyor. The consequence of this design change, if no other changes are made in the

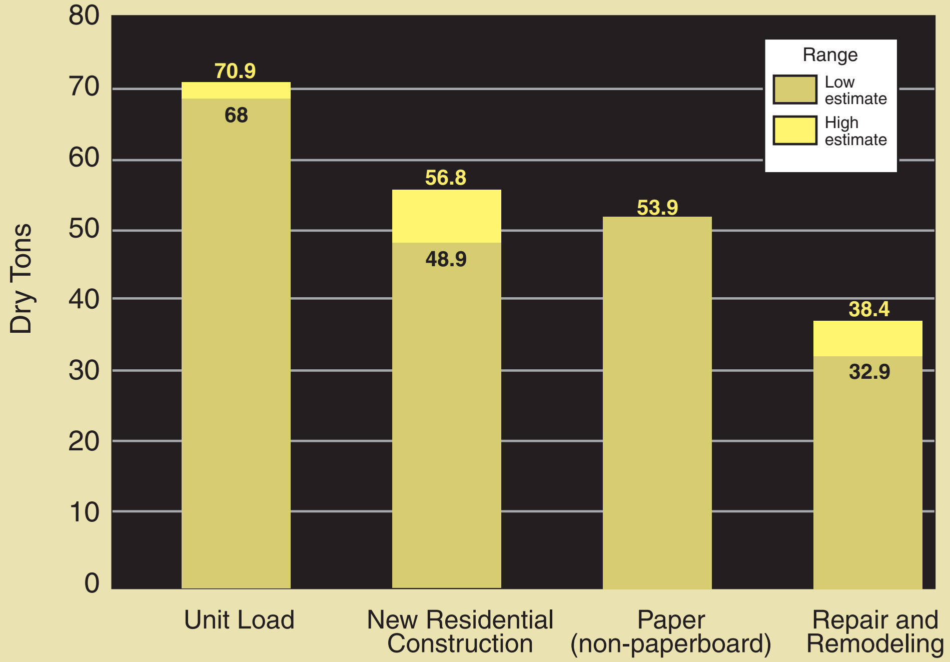

Figure 3. — Relative estimated wood fiber consumption by usage.

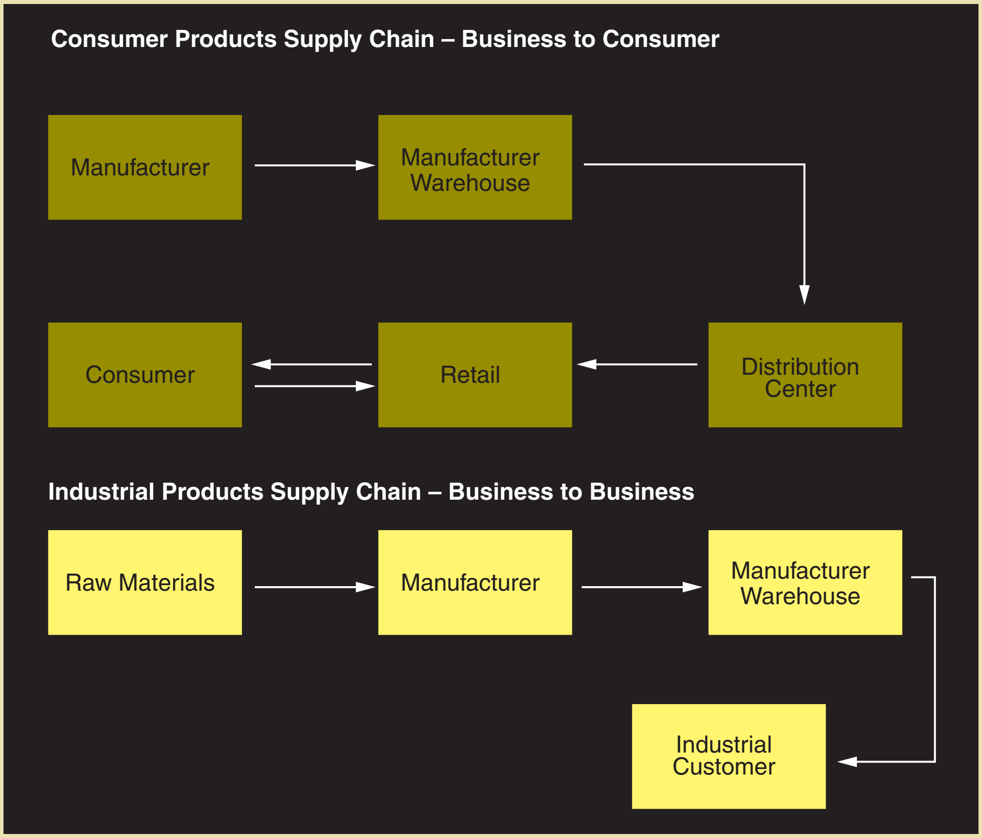

Figure 4. — Material flow diagram of supply chains for typical consumer products and industrial products.

unit load, will be altering the direction of movement, the velocity of the unit load, or the shape of the unit load in the form of load instability. Correspondingly, a packaging designer may reduce container cost by reducing liner weight or medium weight in a corrugated paperboard container. Doing this without corresponding changes in the pallet or handling equipment will alter the forces being applied to the contents of the container. This can result in product damage and it can also result in lowering the stiffness in the unit load. The subsequent increased deflections can alter the movement and storage efficiency of the unit load.

Today we have a logistics "system" that has been designed by "component." Package, pallet, and unit load materials handling equipment designers are unfamiliar with how the components interact, and are making decisions that may reduce "component" cost, but do not necessarily reduce the "system" operating cost.

The Existing Supply Chain Logistics System

The costs to U.S. citizens of this component-based logistics system for the storage and movement of consumer and industrial products are large and take many forms. For example, the annual operating expense of the U.S. supply chain logistics system for a $1.44 trillion product inventory was estimated to be $970 billion, or approximately 9.5 percent of 2001 gross domestic product (LeBlanc 2002). Of this, approximately $100 billion is the cost of packaging, pallets, and load stabilizer devices, which make up the unit load (Rausch Associates 2002/2003). Consumer products and industrial products require about 78 and 28 percent of the packaging used, respectively. The largest packaging sectors of consumer goods are the food and beverage industries (Rausch Associates 2002/2003). Equipment costs are also very large. According to the U.S. Department of Commerce Bureau of Census, the value of unit load handling equipment purchases in 2001 was $10 billion (USDC 2003). According to the American Trucking Association (ATA 1999), approximately 200,000 Class 8 trucks are purchased annually. Reductions in unit load mass or volume will reduce the cost and improve the operational efficiency of unit load handling equipment.

The most significant energy cost is fuel for the transportation and shipping of unit loads. About 57 percent of the total logistics cost is transportation,

Packaging	Generated	Recovered
	(million tons)	(million tons)
Glass	10.4	2.9
Steel	3.1	1.9
Aluminum	1.9	0.9
Paper	39.7	21.2
Plastics	9.3	0.7
Wood	7.3	0.6

Table 4. — Packaging contents in the municipal solid waste stream.

and 81.3 percent of total transportation revenue is trucking (Talarek 1999). In 1997, Class 8 trucks (weighing 33,000 lb. or more) consumed 16.8 billion gallons of diesel fuel, hauling approximately 1.051 billion tons of products in the United States (ATA 1999). This is roughly 16 gallons of diesel fuel per load ton. For truckloads that reach maximum allowable weight before the trailer volume is utilized, a reduction in unit weight mass can conserve fuel and improve transportation efficiencies. As reported earlier in this article, the wood fiber content of unit loads is 70 million dry tons. A 5 percent reduction of 3.5 million tons is an annual savings of about 56 million gallons of diesel fuel. For trailers that "cube out," that is their volume is filled with product before the weight limits are reached, a net reduction in unit load volume through packaging modifications can also result in significant fuel savings by improving the utilization of shipping space.

Added to these direct costs are the many indirect costs of operating the domestic supply chain. For example, in 2002, beverage and grocery products worth $1.6 billion could not be sold due to damage from poor packaging, unit load formation, and handling practices (Food Logistics 2002). Annual U.S. common carrier product damage claims are typically about $10 billion (McKinlay 2003).

There are environmental costs associated with operating the logistics system, for example, packaging solid waste and its impact on environmental quality. According to the U.S. Environmental Protection Agency (EPA) (2002), the components of unit loads represent 32 percent of municipal solid waste volume and 34 percent of municipal solid waste mass. In 1997, containers and packaging generated 71.8 million tons of waste, of which 28.3 million tons were recovered at landfills (Table 4).

In addition to the burden of unit load contents on landfill capacity, the EPA has linked municipal solid waste to climate change, specifically global warming due to greenhouse gas (GHG) emissions. The unit load impacts include: 1) GHG emissions associated with transportation and recycling; 2) emissions from incinerators; 3) methane emissions; and 3) a reduction in tree "carbon sinks" associated with the harvesting of timber (EPA 2003a).

The measure for GHG emissions is metric tons of carbon equivalent (MMTCE). According to the EPA (2003b), U.S. municipal solid waste generates about 65.1 MMTCE annually. If one assumes proportional evolution of GHG, then unit load components of municipal solid waste, which are 34 percent of the mass, will account for 22.1 MMTCE annually. This is only about 1.4 percent of total U.S. GHG evolution, but it is significant because the United States has committed to reduce GHG emissions over time. Source reduction and reuse of packaging is the most efficient way to reduce the environmental impacts of municipal solid waste on the climate.

Perhaps the greatest indirect cost of the logistics system is the cost to human health and safety, i.e., injuries and fatalities associated with accidents. According to research conducted by Radford University (2003), materials handling accounts for 25 percent of all occupational injuries. According to the U.S. Department of Labor (2003), in 2000 there were 566 fatalities from trucking and warehousing, 23,800 work loss injuries to stock handlers, and 131,100 work loss injuries to truckers. According to OSHA, in 2000 there were 85 fatalities and 34,900 serious injuries associated with forklift operation and 40 percent of these accidents were associated with forklifts tipping over and/or debris falling (Construction Site Injuries 2003). Many of these accidents can be related to faulty unit load design and handling procedures. The growth of Warehouse Club stores has placed shoppers into warehouse-like environments. Therefore, accidents and injuries associated with materials handling are not just occupational. Wal-Mart reported 150 injuries due to falling objects each day. Home Depot receives 185 claims per week of injuries from falling objects (Warehouse Stacking Safety Forum 2003)

Related to this issue of human health and safety is security. The threat of harm from terrorist activities has manifested itself within the supply chain logistics system, specifically related to the possible shipment of weapons or components to fabricate weapons. This threat can be somewhat mitigated by

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at least two characteristics of the packaging used in shipment: 1) the reliable identification of package contents; and 2) the documentation of any tampering of the contents. Systems to rapidly and effectively do these things are needed, and this will impact packaging design and handling systems of the future.

Using the Principles of System-Based Design

The supply chain logistics system for the storage and movement of consumer and industrial products can impact the following areas: the cost of consumer goods, the quality of our environment, and human health and safety. Many negative impacts can be avoided, or significantly reduced, by a transition from today's component-based design principles to a system-based design of the consumer and industrial product supply chain.

To do this requires an understanding of how packaging, pallets, and handling equipment physically and mechanically interact. The pallet is literally and figuratively the interface between the packaged product and the unit load handling equipment. It is, therefore, the critical component. Understanding how the pallet interacts with the other components is the key to developing a system-based design approach to product storage and distribution. The interactions referred to are many, including:

- Vibration interactions, which occur during shipping and conveying;
- Transfer of shocks and impact forces during forklift handling;
- Compressive forces associated with the complex interactions within the unit load during warehouse rack and block stack storage;
- Load shifting during unit load movement as affected by surface friction characteristics of all the components and the use of unit load stabilizers, such as stretch wrap, in the unit load; also included in this are dunnage, blocking, and bracing during shipment of unit loads.

An understanding of these and other interactions will lead to design technologies containing a new and common vocabulary understood by all of the design communities involved in logistics systems development. It will be the basis of communication and cooperation among the component suppliers. The unit load is a complex structure, which must withstand the many and varied static and dynamic forces of the distribution environment. The design options include many variations of packaging, pallet design, and handling equipment. They also include options to dictate how packaging is stacked on the pallet, as well as how the packaging is attached to the pallet and stabilized on the pallet. We are just beginning to understand how altering pallet design affects the distribution of stresses on packages, how different stabilizers affect vertical and horizontal displacement of packaging during movement, and how packaging load stabilizers and pallet design interactions affect overall unit load stiffness in automated warehouse storage systems.

Planning for the Future of Materials Handling

The opportunities for conserving natural resources, preserving environmental quality, improving human health and safety, and improving national and corporate competitiveness are significant if we make a fundamental shift from component-based to true system-based design of our industrial and consumer product storage and distribution system. What is needed is a coordinated national research and educational initiative. The USDA Forest Service supports a "Wood Use in Transportation" initiative. Perhaps a similar program "Wood Use in Materials Handling" should be considered. The Forest Products Society should consider sponsoring a technical group by the same name, and the International Union of Forest Research Organizations (IUFRO) should consider developing an international forum on this subject.

The issues presented in this article are related to the mission of many public agencies:

Environment – Environmental Protection Agency
Transportation – Department of Transportation
Occupational Health and Safety – Department of Labor
Timber Utilization – USDA Forest Service

National Security – Department of Homeland Security

Corporate Competitiveness – Department of Commerce

Because these issues transcend state and national borders, socioeconomic status, and potentially involve government regulations, Congressional support for program planning and program implementation is necessary. A government and industry partnership, with a focused mission, is a practical approach. This process can begin with Congressional sponsorship of a national conference bringing together experts in the technical disciplines impacted by unit load materials handling. The primary objective of such a conference would be developing a plan for implementing a true system-based design methodology for the movement of products.

It is clear that the scope of such an initiative must eventually be global. The global economy of this century will begin with a shift of export growth among non-industrialized countries, where materials handling system development is in its infancy. North America will give way to Asia as the economic engine of the 21st century. The timing is ideal, with the materials handling expertise of Europe and North America leading the way.

One result of an initiative to revise the design of the global supply chain will be the development of new international standards for packaging and shipping systems. Therefore, it is reasonable to include the International Organization of Standardization (ISO), the United Nations, and the World Trade Organization (WTO). The goal is a global supply chain of the 21st century that will significantly improve and preserve the welfare of the world's citizens.

It is clear that the scope of such an initiative must eventually be global. The global economy of this century will begin with a shift of export growth among non-industrialized countries, where materials handling system development is in its infancy.

Literature Cited

American Forest and Paper Association (AF&PA). 2002. Paper, paperboard, and wood pulp, 1991-2001. Statistical Summary. AF&PA, Washington, DC.

American Trucking Associations (ATA). 1999. Standard trucking and transportation statistics. Feb/March 1999. ATA, Alexandria, VA.

APA–The Engineered Wood Association (APA). 2001. U.S. estimated structural panel demand and production by market, 1996-2003. APA, Tacoma, WA.

Bejune, J., R. Bush, P. Araman, and D. Cumbo. 2002. Wood use trends in the pallet and container industry: 1992-1999. Virginia Tech Center for Forest Products Marketing and Management, Dept. of Wood Science & Forest Products, Virginia Tech, Blacksburg, VA.

Carliner, M. 2002. Background on lumber. National Assoc. of Home Builders, Washington, DC. September.

Construction Site Injuries. 2003. Fork lift accidents. www.construction-injuries.com

Food Logistics. 2002. Preventing damage before it begins. Food Logistics. Jan/Feb, 2003. pp. 29-32.

Gibson, S. and R. Smith. 2001. A hardwood market review. Virginia Tech Center for Forest Products Marketing and Management, Dept. of Wood Science & Forest Products, Virginia Tech, Blacksburg, VA.

Hayne, R.W. 2003. Analysis of the timber situation in the United States. 1952-2050. Tech. Rept. PNW-GTR-560. USDA Forest Serv. Pacific Northwest Res. Sta. Portland, OR.

Howard, J.L. 2001. U.S. forest products annual market review and prospects, 1999-2002. Res. Note FPL-RN-2082. USDA Forest Serv., Forest Prod. Lab., Madison, WI. 5 pp.

Ince, P.J. 2002. U.S. fiber supply: Steady and secure. Solutions! Official publication of TAPPI and PIMA. June. TAPPI, Norcross, GA. pp. 40-44.

International Wood Markets Research Inc. 2000. Wood markets: The solid wood products outlook, 2000-2004. Vancouver, BC, Canada.

LeBlanc, R. 2002. Logistics report focuses on agility in the market, sharing information. Pallet Enterprise. October. Industrial Reporting Inc., Richmond, VA.

McKinlay, A.L. 2003. Fundamentals of protective packaging. Institute of Packaging Professionals, Naperville, IL.

Modern Materials Handling. 2000. A report on pallet use and applications among buyers of materials handling systems. Cahners Research/Modern Materials Handling, Fitchburg, MA.

National Association of Home Builders (NAHB). 2002. Materials used in building a single-family home. NAHB, Washington, DC.

Radford University. Material handling and storage – Environmental health and safety. Radford Univ., Radford, VA.

Rausch Associates. 2002/2003. Rausch guide to the U.S. packaging industry. Rausch Associates, Bridgewater, NJ.

Talarek, J.T. 1999. Transportation as a competitive weapon today and beyond 2000. Warehouse of the Future Conference, June 7, 1999. Dallas, TX. The Distribution Management Assoc., Lancaster, PA.

USDA Forest Service, Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. Forest Prod. Society, Madison, WI.

U.S Department of Commerce, Census Bureau. 2003. Value of product shipments for product codes 3339221, 3339223, 333924: 2001. USDC, Washington, DC.

U.S. Department of Labor, Bureau of Labor Statistics. 2003. Occupational injuries, illnesses and fatalities. www.bls.gov.

U.S. Environmental Protection Agency (EPA). 2002. Municipal solid waste in the United States, facts and figures, 2002. Office of Solid Waste, Washington, DC. p. 2

__________. 2003a. What is the Link? State and Local Climate Change Program. Office of Economy and Environment, Washington, DC. June 4.

__________. 2003b. Inventory of U.S. greenhouse gas emissions and sinks, 1990-2001. EPA, Washington, DC.

Ward, R.E. 1993. Perspectives on material handling from the United States. Presentation at INTERMATEX 93. Material Handling Industry of America, Charlotte, NC. www.MHIA.org.

Warehouse Stacking Safety Forum. 2003. Warehouse shoppers beware. Safety Forum, Washington, DC. www.safetyforum.com.

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