coastal and shelf seas, driven by a variety of mechanisms. The dynamics controlling the structure and position of fresh water fronts and shelf sea tidal mixing fronts are relatively well understood. Fresh water fronts result from the relaxation of a horizontal density gradient, arrested either by the diversion of flow caused by the Earth's rotation or by the interaction between nearbed cross-frontal flows and a sloping seabed. Tidal mixing fronts are controlled by the competition between the rate of supply of mixing energy (supplied either by tidal current stress against the seabed or by wind stress against the sea surface) and the rate of stratification (produced by surface heating). For fronts at the shelf edge/slope region, the change in the slope of the seabed must play a pivotal role, but the full dynamics controlling the fronts are less clear. Partially this is due to the difficulty in collecting observations of sufficient resolution, in both time and space, against which to test hypotheses. Also, in particular contrast with the tidal mixing fronts, there appears to be no dominant process controlling these fronts.

All fronts are observed to be regions of enhanced surface primary production. The common feature causing this production is likely to be the reduced stability close to surface fronts allowing increased vertical turbulent mixing of nutrients into the well-lit surface water. Fronts close to the shelf edge, or other regions of steep bathymetry, have the additional feature of locally generated internal waves providing enhanced mixing across the shallowing pycnocline. This increased primary production is often seen to be associated with increases in zooplankton and larger fish, ultimately supporting populations of sea birds and providing an important fisheries resource for people.

There are still important questions that remain to be answered concerning the physics of fronts. For instance, direct measurements of turbulent mixing have only recently become possible, so the potential for horizontal gradients in rates of vertical turbulent exchange still needs to be addressed. Shelf slope fronts are perhaps the most lacking in terms of a coherent theory of their dynamics (assuming such a general approach is possible), and have particular questions related to cross-frontal transfers that still require attention. The link between the physics of fronts and the closely coupled biology and chemistry is perhaps the area of greatest research potential. Oceanographic instrumentation is developing rapidly to allow the biological and chemical environment to be observed at the same spatial and temporal scales as the controlling physics.

See also

Carbon Cycle. Dispersion in Shallow Seas. Ekman Transport and Pumping. Primary Production Distribution. Primary Production Methods. Primary Production Processes. Tides. Turbulence in the Benthic Boundary Layer.

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SHELF-SEA MODELS

See **REGIONAL AND SHELF SEA MODELS**

SHIPPING AND PORTS

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Introduction

Ships and ports have been an important medium for trade and commerce for thousands of years. Today's maritime shipping industry carries 90% of the

world's 5.1 billion tons of international trade. Total seaborne cargo movements exceeded 21 trillion ton-miles in 1998. Shipping is an efficient means of transport, and becoming more so. World freight payments as a fraction of total import value were 5.24% in 1997, down from 6.64% in 1980. Modern container ships carry a 40-foot container for < 10 cents per mile – a fraction of the cost of surface transport.

Segments of the shipping industry exhibit varying degrees of technological sophistication and economic efficiency. Bulk shipping technology has changed little in recent decades, and the bulk industry is economically efficient and competitive. Container shipping has advanced technologically, but economic stability remains elusive. The shipping industry has a history of national protectionist measures and is governed by a patchwork of national and international regulations to ensure safety and guard against environmental damage.

Units

Two standard measures of ship size are deadweight tonnage (dwt) and gross tonnage (gt). Deadweight describes the vessel's cargo capacity; gross tonnage describes the vessel's enclosed volume, where 100 cubic feet equal one gross ton. In container shipping, the standard unit of capacity is the twenty-foot equivalent unit (TEU), which is the cargo volume available in a container 20 feet long, 8 feet wide, and 8 feet (or more) high. These containers are capable of carrying 18 metric tons but more typically are filled to 13 tons or less, depending on the density of the cargo.

World Seaborne Trade

Shipping distinguishes between two main types of cargos: bulk (usually shiploads of a single commodity) and general cargos (everything else). Major dry bulk trades include iron ore, coal, grain, bauxite, sand and gravel, and scrap metal. Liquid bulk or tanker cargos include crude oil and petroleum products, chemicals, liquefied natural gas (LNG), and vegetable oil. General cargo may be containerized, break-bulk (noncontainer packaging), or 'neo-bulk' (automobiles, paper, lumber, etc.). **Table 1** shows that global cargo weight has grown by a factor of 10 during the second half of the twentieth century, and by about 4% per year since 1986. Tanker cargos (mostly oil and oil products) make up about 40% of all cargo movements by weight.

Both the dry bulk and tanker trades have grown at an average rate of about 2% per year since 1980.

Table 1 World seaborne dry cargo and tanker trade volume (million tons) 1950–1998

Year	Dry cargo	Tanker cargo	Total	% change
1950	330	130	460	—
1960	540	744	1284	—
1970	1165	1440	2605	—
1986	2122	1263	3385	3
1987	2178	1283	3461	2
1988	2308	1367	3675	6
1989	2400	1460	3860	5
1990	2451	1526	3977	3
1991	2537	1573	4110	3
1992	2573	1648	4221	3
1993	2625	1714	4339	3
1994	2735	1771	4506	4
1995	2891	1796	4687	4
1996	2989	1870	4859	4
1997	3163	1944	5107	5
1998	3125	1945	5070	−1

Current bulk trades total some 9 trillion ton-miles for dry bulk and 10 trillion ton-miles for tanker cargos.

Before containerization, general cargo was transported on pallets or in cartons, crates, or sacks (in general cargo or break-bulk vessels). The modern container was first used in US domestic trades in the 1950s. By the 1970s, intermodal services were developed, integrating maritime and land-based modes (trains and trucks) of moving containers. Under the 'mini land-bridge' concept, for example, containers bound from Asia to a US east coast port might travel across the Pacific by ship and then across the USA by train. In the 1980s, intermodal services were streamlined further with the introduction of double-stack trains, container transportation became more standardized, and shippers began to treat container shipping services more like a commodity. Today, $> 70\%$ of general cargo moves in containers. Some 58.3 million TEU of export cargo moved worldwide in 1999; including empty and domestic movement, the total was over 170 million TEU. The current total container trade volume is some 300 billion TEU-miles. Container traffic has grown at about 7% per year since 1980.

Table 2 lists the major shipping trade routes for the most significant cargo types, and again illustrates the dominance of petroleum in total global cargo volume. The most important petroleum trade routes are from the Middle East to Asia and to Europe, and within the Americas. Iron ore and coal trades are dominated by Australian exports to Asia, followed by exports from the Americas to Europe and Asia. The grain trades are dominated by American exports to Asia and Europe, along with

Table 2 Cargo volume on major shipping routes (million tons) 1998 (for containers: millions of TEU, 1999)

Cargo type	*Route*	*Cargo volume*	*% of total for cargo*
Petroleum	Middle East–Asia	525.0	26
	Intra-Americas	326.5	16
	Middle East–Europe	229.5	12
	Intra-Europe	142.7	7
	Africa–Europe	141.4	7
	Middle East–Americas	137.7	7
	Africa–Americas	106.1	5
Dry bulk: iron ore	Australia–Asia	116.8	28
	Americas–Europe	87.1	21
	Americas–Asia	63.3	15
Dry bulk: coal	Australia–Asia	118.4	25
	Americas–Europe	61.3	13
	S. Africa–Europe	37.8	8
	Americas–Asia	35.2	7
	Intra-Asia	29.3	6
	Australia–Europe	27.3	6
Dry bulk: grain	Americas–Asia	60.2	31
	Americas–Europe	20.6	10
	Intra-Americas	33.1	17
	Americas–Africa	15.2	8
	Australia–Asia	15.1	8
Container	Trans-Pacific (Asia/N. America)	7.3	14
	Asia/Europe	4.5	8
	Trans-Atlantic (N. America/Europe)	4.0	8

intra-American routes. Container traffic is more fragmented; some of the largest routes connect Asia with North America to the east and with Europe to the west, and Europe and North America across the Atlantic.

The World Fleet

The world's seaborne trade is carried by an international fleet of about 25 000 ocean-going commercial cargo ships of more than 1000 gt displacement. As trade volumes grew, economies of scale (lower cost per ton-mile) led to the development of larger ships: ultra-large crude oil carriers (ULCCs) of $> 550\,000$ dwt were launched in the 1970s. Structural considerations, and constraints on draft (notably in US ports) and beam (notably in the Panama Canal) have curbed the move toward larger bulk vessels. Container ships are still growing in size. The first true container ships carried around 200 TEU; in the late 1980s, they reached 4000 TEU; today they are close to 8000 TEU. The world container fleet capacity was 4.1 million TEU in 1999.

Table 3 shows the development of the world fleet in dwt terms since 1976. Total fleet capacity has grown by an average of 1.5% per year, although it contracted during the 1980s. The significant growth in the 'other vessel' category is due largely to container vessels; container vessel dwt increased faster than any other category (nearly 9% annually) from 1985 to 1999. Specialized tankers and auto carriers have also increased rapidly, by around 5% annually. Combos (designed for a mix of bulk and general cargo) and general cargo ships have decreased by $> 5\%$ per year.

Four standard vessel classes dominate both the dry bulk and tanker fleets, as shown in **Table 4**. Panamax bulkers and Suezmax tankers are so named because they fall just within the maximum dimensions for the Panama and Suez Canals, respectively. Capesize bulkers and VLCCs (very large crude carriers) are constrained in size mostly by the limitations of port facilities (draft restrictions).

In addition to self-propelled vessels, ocean-going barges pulled by tugs carry both bulk and container cargos, primarily on coastal routes.

Dry Bulk Carriers

The dry bulk fleet is characterized by fragmented ownership; few operators own more than 100 vessels. Most owners charter their vessels to shippers through a network of brokers, under either long-term or single-voyage ('spot') charter arrangements (see **Table 5**). The top 20 dry bulk charterers account for about 30% of the market. The dry bulk charter market is, in general, highly competitive.

Table 3 World fleet development (million dwt) 1976–1998

Year	Oil tankers	Dry bulk carriers	Other vessels	Total world fleet	% change
1976	320.0	158.1	130.3	608.4	–
1977	335.3	174.4	139.1	648.8	7
1978	339.1	184.5	146.8	670.4	3
1979	338.3	188.5	154.7	681.5	2
1980	339.8	191.0	160.1	690.9	1
1981	335.5	199.5	162.2	697.2	1
1982	325.2	211.2	165.6	702.0	1
1983	306.1	220.6	167.8	694.5	−1
1984	286.8	228.4	168.1	683.3	−2
1985	268.4	237.3	168.0	673.7	−1
1986	247.5	235.2	164.9	647.6	−4
1987	245.5	231.8	163.5	640.8	−1
1988	245.0	230.1	162.0	637.1	−1
1989	248.4	231.4	166.9	646.7	2
1990	257.4	238.9	170.5	666.8	3
1991	264.2	244.0	176.1	684.3	3
1992	270.6	245.7	178.3	694.6	2
1993	270.2	251.3	194.4	715.9	3
1994	269.4	254.3	220.3	744.0	4
1995	265.8	259.8	241.5	767.1	3
1996	271.2	269.6	252.2	793.0	4
1997	272.5	277.8	263.0	813.3	3
1998	279.7	271.6	274.0	825.3	2

Capesize bulkers are used primarily in the Australian and South American bulk export trades. Grain shipments from the USA to Asia move mainly on Panamax vessels. Some bulk vessels, such as oil/bulk/ore (OBO) carriers, are designed for a variety of cargos. Others are 'neo-bulk' carriers, specifically designed to carry goods such as automobiles, lumber, or paper.

Tankers

Ownership of the tanker fleet is also fragmented; the average tanker owner controls fewer than three vessels; 70% of the fleet is owned by independent owners and 25% by oil companies. Like dry bulk ships, tankers are chartered to shippers on longer time charters or spot voyage charters (see **Table 5**). The top five liquid bulk charterers account for about 25% of the market. Like the dry bulk market, the tanker charter market is highly competitive.

VLCCs are used primarily for Middle East exports to Asia and the USA. In addition to liquid tankers, a fleet of gas carriers (world capacity: 17 million gt) moves liquefied natural gas (LNG) and petroleum gas (LPG).

General Cargo/Container Ships

Ownership is more concentrated in the container or 'liner' fleet. ('Liner' carriers operate regularly

Table 4 Major vessel categories in the world's ocean-going cargo ship fleet, 2000

Cargo type	Category	Typical size	Number in world fleet
Dry bulk	Handysize	27 000 dwt	2700
	Handymax	43 000 dwt	1000
	Panamax	69 000 dwt	950
	Capesize	150 000 dwt	550
Tanker	Product tanker	45 000 dwt	1400
	Aframax	90 000 dwt	700
	Suezmax	140 000 dwt	300
	VLCC	280 000 dwt	450
General cargo	Container	> 2000 TEU	800
	Container feeder	< 2000 TEU	1800
	Ro/Ro	< 2000 TEU	900
	Semi-container	< 1000 TEU	2800

VLCC, very large crude carrier; RoRo, roll-on/roll-off.

Table 5 Average daily time charter rates, 1980–2000

Cargo type	*Vessel type*	$/day
Dry bulk	Handysize	6000
	Handymax	8000
	Panamax	9500
	Capesize	14 000
Tanker	Product tanker	12 000
	Aframax	13 000
	Suezmax	16 500
	VLCC	22 000
Container	400 TEU geared	5000
	1000 TEU geared	9000
	1500 TEU geared	13 500
	2000 TEU gearless	18 000

VLCC, very large crude carrier.

scheduled service between specific sets of ports.) Of some 600 liner carriers, the top 20 account for 55% of world TEU capacity. The industry is expected to consolidate further. Despite this concentration, liner shipping is competitive; barriers to entry are low, and niche players serving specialized cargos or routes have been among the most profitable. Outside ownership of container vessels and chartering to liner companies increased during the 1990s.

Large ships (> 4000 TEU) are used on long ocean transits between major ports, while smaller 'feeder' vessels typically carry coastwise cargo or serve niche markets between particular port pairs. In addition to container vessels, the general cargo trades are served by roll-on/roll-off (RoRo) ships (world fleet capacity: 23 million gt) that carry cargo in wheeled vehicles, by refrigerated ships for perishable goods, and by a diminishing number of multi-purpose general cargo ships.

Passenger Vessels

The world's fleet of ferries carries passengers and automobiles on routes ranging from urban harbor crossings to hundreds of miles of open ocean. Today's ferry fleet is increasingly composed of so-called fast ferries, > 1200 of which were active in 1997. Many of these are aluminum-hull catamarans, the largest capable of carrying 900 passengers and 240 vehicles at speeds between 40 and 50 knots. Fast ferries provide an inexpensive alternative to land and air travel along coastal routes in parts of Asia, Europe, and South America.

The cruise ship industry was born in the 1960s, when jet aircraft replaced ships as the primary means of crossing oceans, and underutilized passenger liners were converted for recreational travel. The most popular early cruises ran from North America to the Caribbean. Today, the Caribbean remains the main cruise destination, with more than half of all passengers; others are Alaska and the Mediterranean. The US cruise market grew from 500 000 passengers per year in 1970 to 1.4 million in 1980 and 3.5 million in 1990. Today, more than 25 cruise lines serve the North American cruise market. The three largest lines control over 50% of the market, and further consolidation is expected; 149 ships carried 6 million passengers and generated $18 billion in turnover in 1999. The global market saw 9 million passengers. Cruise vessels continue to grow larger due to scale economies; the largest ships today carry more than 2000 passengers. Most cruise lines are European-owned and fly either European or open registry flags (see below).

Financial Performance

Shipping markets display cyclical behavior. Charter rates (see **Table 5**) are set by the market mechanism of supply and demand, and are most closely correlated with fleet utilization (rates rise sharply when utilization exceeds 95%). Shipping supply (capacity) is driven by ordering and scrapping decisions, and sometimes by regulatory events such as the double hull requirement for tankers (see below). Demand (trade volume) is determined by national and global business cycles, economic development, international trade policies, and trade disruptions such as wars/conflicts, canal closures, or oil price shocks. New vessel deliveries typically lag orders by 1–2 years. Excessive ordering of new vessels in times of high freight rates eventually leads to overcapacity and a downturn in rates; rates remain low until fleet contraction or trade growth improves utilization, and the cycle repeats.

Average annual returns on shipping investments ranged from 8% (dry bulk) to 11% (container feeder ships) and 13% (tankers) during 1980–2000, with considerable volatility. Second-hand ship asset prices fluctuate with charter rates, and many ship owners try to improve their returns through buy-low and sell-high strategies.

Law and Regulation

Legal Regimes

International Law of the Sea The United Nations Convention on the Law of the Sea (UNCLOS) sets out an international legal framework governing the oceans, including shipping. UNCLOS codifies the rules underlying the nationality (registry) of ships, the right of innocent passage for merchant vessels through other nations' territorial waters, etc. (see the entry in this volume on the Law of the Sea for details).

International Maritime Organization The International Maritime Organization (IMO) was established in 1948 and became active in 1959. Its 158 present member states have adopted some 40 IMO conventions and protocols governing international shipping. Major topics include maritime safety, marine pollution, and liability and compensation for third-party claims. Enforcement of these conventions is the responsibility of member governments and, in particular, of port states. The principle of port state control allows national authorities to inspect foreign ships for compliance and, if necessary, detain them until violations are addressed.

In 1960, IMO adopted a new version of the International Convention for the Safety of Life at Sea (SOLAS), the most important of all treaties dealing with maritime safety. IMO next addressed such matters as the facilitation of international maritime traffic, load lines, and the carriage of dangerous goods. It then turned to the prevention and mitigation of maritime accidents, and the reduction of environmental effects from cargo tank washing and the disposal of engine-room waste.

The most important of all these measures was the Marine Pollution (MARPOL) treaty, adopted in two stages in 1973 and 1978. It covers accidental and operational oil pollution as well as pollution by chemicals, goods in packaged form, sewage, and garbage. In the 1990s, IMO adopted a requirement for all new tankers and existing tankers over 25 years of age to be fitted with double hulls or a design that provides equivalent cargo protection in the event of a collision or grounding.

IMO has also dealt with liability and compensation for pollution damage. Two treaties adopted in 1969 and 1971 established a system to provide compensation to those who suffer financially as a result of pollution.

IMO introduced major improvements to the maritime distress communications system. A global search and rescue system using satellite communications has been in place since the 1970s. In 1992, the Global Maritime Distress and Safety System (GMDSS) became operative. Under GMDSS, distress messages are transmitted automatically in the event of an accident, without intervention by the crew.

An International Convention on Standards of Training, Certification and Watchkeeping (STCW), adopted in 1978 and amended in 1995, requires each participating nation to develop training and certification guidelines for mariners on vessels sailing under its flag.

National Control and Admiralty Law The body of private law governing navigation and shipping in each country is known as admiralty or maritime law. Under admiralty, a ship's flag (or registry) determines the source of law. For example, a ship flying the American flag in European waters is subject to American admiralty law. This also applies to criminal law governing the ship's crew.

By offering advantageous tax regimes and relatively lax vessel ownership, inspection, and crewing requirements, so-called 'flags of convenience' or 'open registries' have attracted about half of the world's tonnage (see **Table 6**). The open registries include Antigua and Barbuda, Bahamas, Bermuda, Cayman Islands, Cyprus, Gibraltar, Honduras, Lebanon, Liberia, Malta, Mauritius, Oman, Panama, Saint Vincent, and Vanuatu. Open registries are the flags of choice for low-cost vessel operation, but in some instances they have the disadvantage of poor reputation for safety.

Protectionism/Subsidies

Most maritime nations have long pursued policies that protect their domestic flag fleet from foreign

Table 6 Fleets of principal registries (in 1000s of gt) 1998 (includes ships of 100 gt)

Country of registry	*Tankers*	*Dry bulk*	*General cargo*	*Other*	*Total*	*% of world*
Panama	22 680	40 319	26 616	8608	98 223	18.5
Liberia	26 361	16 739	8803	8590	60 493	11.4
Bahamas	11 982	4990	7143	3601	27 716	5.2
Greece	12 587	8771	1943	1924	25 225	4.7
Malta	9848	8616	4658	952	24 074	4.5
Cyprus	3848	11 090	6981	1383	23 302	4.4
Norway	8994	4041	4153	5949	23 137	4.4
Singapore	8781	4585	5596	1408	20 370	3.8
Japan	5434	3869	3111	5366	17 780	3.3
China	2029	6833	6199	1443	16 504	3.1
USA	3436	1268	3861	3286	11 851	2.2
Russia	1608	1031	3665	4786	11 090	2.1
Others	33 448	46 414	57 350	34 917	172 129	32.4
World total	151 036	158 566	140 079	82 213	531 894	100.0

competition. The objective of this protectionism is usually to maintain a domestic flag fleet and cadre of seamen for national security, employment, and increased trade.

Laws that reserve domestic waterborne cargo (cabotage) for domestic flag ships are common in many countries, including most developed economies (although they are now being phased out within the European Union). The USA has a particularly restrictive cabotage system. Cargo and passengers moving by water between points within the USA, as well as certain US government cargos, must be carried in US-built, US-flag vessels owned by US citizens. Also, US-flag ships must be crewed by US citizens.

Vessels operating under restrictive crewing and safety standards may not be competitive in the international trades with open registry vessels due to high operating costs. In some cases, nations have provided operating cost subsidies to such vessels. The US operating subsidy program was phased out in the 1990s.

Additional subsidies have been available to the shipping industry through government support of shipbuilding (see below).

Liner Conferences

The general cargo trades have traditionally been served by liner companies that operate vessels between fixed sets of ports on a regular, published schedule. To regulate competition among liner companies and ensure fair and consistent service to shippers, a system of 'liner conferences' has regulated liner services and allowed liner companies, within limits, to coordinate their services.

Traditionally, so-called 'open' conferences have been open to all liner operators, published a single rate for port-to-port carriage of a specific commodity, and allowed operators within the conference to compete for cargo on service. The US foreign liner trade has operated largely under open conference rules. By contrast, many other liner trades have been governed by closed conferences, participation in which is restricted by governments. In 1974, the United Nations Conference on Trade and Development (UNCTAD) adopted its Code of Conduct for Liner Conferences, which went into effect in 1983. Under this code, up to 40% of a nation's trade can be reserved for its domestic fleet.

In the 1970s, price competition began within conferences as carriers quoted lower rates for intermodal mini land-bridge routes than the common published port-to-port tariffs. By the 1980s, intermodal rates were incorporated fully in the liner conference scheme. The 1990s saw growing deregulation of liner trades (for example, the US 1998 Ocean Shipping Reform Act), which allowed carriers to negotiate confidential rates separately with shippers. The effect has been, in part, increased competition and a drive for consolidation among liner companies that is expected to continue in the future.

Environmental Issues

With the increased carriage of large volumes of hazardous cargos (crude oil and petroleum products, other chemicals) by ships in the course of the twentieth century, and especially in the wake of several tanker accidents resulting in large oil spills, attention has focused increasingly on the environmental effects of shipping. The response so far has concentrated on the operational and accidental discharge of oil into the sea. Most notably, national and international regulations (the Oil Pollution Act (OPA) of 1990 in the US; IMO MARPOL 1992 Amendments, Reg. 13F and G) are now forcing conversion of the world's tanker fleet to double hulls. Earlier, MARPOL 1978 required segregated ballast tanks on tankers to avoid the discharge of oil residue following the use of cargo tanks to hold ballast water.

Recently, ballast and bilge water has also been identified as a medium for the transport of non-indigenous species to new host countries. A prominent example is the zebra mussel, which was brought to the USA from Europe in this way.

Liability and Insurance

In addition to design standards such as double hulls, national and international policies have addressed the compensation of victims of pollution from shipping accidents through rules governing liability and insurance. The liability of ship owners and operators for third-party claims arising from shipping accidents historically has been limited as a matter of policy to encourage shipping and trade. With the increased risk associated with large tankers, the international limits were raised gradually in the course of the twentieth century. Today, tanker operators in US waters face effectively unlimited liability under OPA 90 and a range of state laws.

Most liability insurance for the commercial shipping fleet is provided through a number of mutual self-insurance schemes known as P&I (protection and indemnity) clubs. The International Group of P&I Clubs includes 19 of the largest clubs and collectively provides insurance to 90% of the world's ocean-going fleet. Large tankers operating in US waters today routinely carry liability insurance coverage upward of $2 billion.

Shipbuilding

Major technical developments in twentieth century shipbuilding began with the introduction of welding in the mid-1930s, and with it, prefabrication of steel sections. Prefabrication of larger sections, improved welding techniques, and improved logistics were introduced in the 1950s. Mechanized steel prefabrication and numerically controlled machines began to appear in the 1970s. From 1900 to 2000, average labor hours per ton of steel decreased from 400–500 to fewer than 100; and assembly time in dock/berth decreased from 3–4 years to less than 6 months.

South Korea and Japan are the most important commercial shipbuilding nations today. In the late 1990s, each had about 30% of world gross tonnage on order; China, Germany, Italy, and Poland each accounted for between about 4 and 6%; and Taiwan and Romania around 2%. The US share of world shipbuilding output fell from 9.5% in 1979 to near zero in 1989.

Shipbuilding is extensively subsidized in many countries. Objectives of subsidies include national security goals (maintenance of a shipbuilding base), employment, and industrial policy goals (shipyards are a major user of steel industry output). Direct subsidies are estimated globally around $5–10 billion per year. Indirect subsidies include government loan guarantees and domestic-build requirements (for example, in the US cabotage trade).

An agreement on shipbuilding support was developed under the auspices of the Organization for Economic Cooperation and Development (OECD) and signed in December 1994 by Japan, South Korea, the USA, Norway, and the members of the European Union. The agreement would limit loan guarantees to 80% of vessel cost and 12 years, ban most direct subsidy practices, and limit government R&D support for shipyards. Its entry into force, planned for 1996, has been delayed by the United States' failure to ratify the agreement.

Ports

Commercial ships call on thousands of ports around the world, but global cargo movement is heavily concentrated in fewer than 100 major bulk cargo ports and about 24 major container ports. The top 20 general cargo ports handled 51% of all TEU movements in 1998 (see **Table 7**).

Most current port development activity is in container rather than bulk terminals. Port throughput efficiency varies greatly. In 1997, some Asian container ports handled 8800 TEU per acre per year, while European ports averaged 3000 and US ports only 2100 TEU per acre per year. The differences are due largely to the more effective use of automation and lesser influence of organized labor in Asian ports. Because container traffic is growing rapidly and container ships continue to increase in size, most port investment today is focused on the improvement and new development of container terminals.

In many countries, the public sector plays a more significant role in port planning and development than it does in shipping. Most general cargo or

Table 7 Top 20 container ports by volume, 1998

Port	*Country*	*Throughput (1000s TEU)*
Singapore	Singapore	15 100
Hong Kong	China	14 582
Kaohsiung	Taiwan	6271
Rotterdam	Netherlands	6011
Busan	South Korea	5946
Long Beach	USA	4098
Hamburg	Germany	3547
Los Angeles	USA	3378
Antwerp	Belgium	3266
Shanghai	China	3066
Dubai	UAE	2804
Manila	Philippines	2690
Felixstowe	UK	2524
New York/New Jersey	USA	2500
Tokyo	Japan	2169
Tanjung Priok	Indonesia	2131
Gioia Tauro	Italy	2126
Yokohama	Japan	2091
San Juan	Puerto Rico	2071
Kobe	Japan	1901

'commercial' ports are operated as publicly controlled or semi-public entities, which may lease space for terminal facilities to private terminal operators. Bulk cargo or 'industrial' ports for the export or import/processing of raw materials traditionally have been built by and for a specific industry, often with extensive public assistance. The degree of national coordination of port policy and planning varies considerably. The USA has one of the greatest commercial port densities in the world, particularly along its east coast. US commercial ports generally compete among each other as semi-private entities run in the interest of local economic development objectives. The US federal government's primary role in port development is in the improvement and maintenance of navigation channels, since most US ports (apart from some on the west coast) are shallow and subject to extensive siltation.

Future Developments

A gradual shift of the 'centroid' of Asian manufacturing centers westward from Japan and Korea may in the future shift more Asia–America container cargo flows from trans-Pacific to Suez/trans-Atlantic routes. Overall container cargo flows are expected to increase by 4–7% per year. Bulk cargo volumes are expected to increase as well, but at a slower pace.

Container ships will continue to increase in size, reaching perhaps 12 000 TEU capacity in the course of the next decade. Smaller, faster cargo ships may be introduced to compete for high-value cargo on certain routes. One concept calls for a 1400 TEU vessel capable of 36–40 knots (twice the speed of a conventional container ship), making scheduled Atlantic crossings in 4 days.

Port developments will center on improved container terminals to handle larger ships more efficiently, including berths that allow working the ship from both sides, and the further automation and streamlining of moving containers to/from ship and rail/truck terminus.

Conclusions

Today's maritime shipping industry is an essential transportation medium in a world where prosperity is often tied to international trade. Ships and ports handle 90% of the world's cargo and provide a highly efficient and flexible means of transport for a variety of goods. Despite a history of protectionist regulation, the industry as a whole is reasonably efficient and becoming more so. The safety of vessels and their crews, and protection of the marine environment from the results of maritime accidents, continue to receive increasing international attention. Although often conservative and slow to adopt new technologies, the shipping industry is poised to adapt and grow to support the world's transportation needs in the twenty-first century.

See also

International Organizations. Law of the Sea. Marine Policy Overview. Ships.

Further Reading

Containerization Yearbook 2000. London: National Magazine Co.

Shipping Statistics Yearbook. Bremen: Institute of Shipping Economics and Logistics.

Lloyd's Shipping Economist. London: Lloyd's of London Press.

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SHIPS

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Introduction

Oceanographic research vessels are shipboard platforms which support the conduct of scientific research at sea. Such research may include mapping and charting, marine biology, fisheries, geology and geophysics, physical processes, marine meteorology, chemical oceanography, marine acoustics, underwater archaeology, ocean engineering, and related fields.

Unlike other types of vessels (i.e., passenger, cargo, tankers, tugs, etc.) oceanographic research vessels (RVs) are a highly varied group owing to the diverse disciplines in which they engage. However, characteristics common to most RVs are relatively small size (usually 25–100 m length overall); heavy outfit of winches, cranes, and frames for overboard work; spacious working decks; multiple