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14 The Ships that Provide the Transport

Managers may believe that industry structures are ordained by the Good Lord, but they can – and often do – change overnight. Such changes create tremendous opportunities for innovation.

(Peter Drucker, *The Profession of Management*, 1998, p. 58)

14.1 WHAT TYPE OF SHIP?

The derived demand for ships

So far we have said much about shipping economics, but little about the ships themselves. A ship is a major investment, and with a wealth of different types and sizes on offer, investors are confronted with the difficult question of what type of ship to order. To help them in their decisions, they often ask shipping economists what will be the future demand, for example, for container-ships. The aim of this chapter is to discuss the different types of merchant ships and how their design features fit into the economic model discussed in Chapter 4.

First we must be clear about the meaning of *demand*. Although ships occupy centre stage, the product in demand is not a ship, but transport. It is not the container-ship that the customer wants; it is the transport of the container. Shipowners can use whatever ships provide the transport most profitably. Unfortunately this makes the shipping economist's job much more difficult. If containers could only be carried in container-ships, all the shipping economist would have to do is predict the trade in containers and work out the number of container-ships needed to carry the trade. But with several ship types available to carry the cargo which travels in containers, the demand calculation involves two additional questions. What options are open to the shipowner? And what economic criteria apply in choosing between them?

The answer depends on the type of shipping venture for which the vessel is intended. Although there are many different influences to consider, the most important can be summarized under the three following headings:

- *Cargo type*. The physical and commercial properties of the cargo to be transported set a limit on the ship types that can potentially be employed in the transport operation.

In a limited number of cases, such as liquid natural gas or nuclear waste, the cargo demands a specific type of ship, and the shipowner's choice is limited to general design and operating features such as speed and crew. For most cargoes, however, the shipowner can choose from several ship types. Crude oil can be carried in a specialist tanker or a combined carrier; dry bulk can be carried in a conventional bulk carrier, an open-hold bulk carrier or a combined carrier; containers in a container-ship, a 'tweendecker, an MPP vessel or a ro-ro.

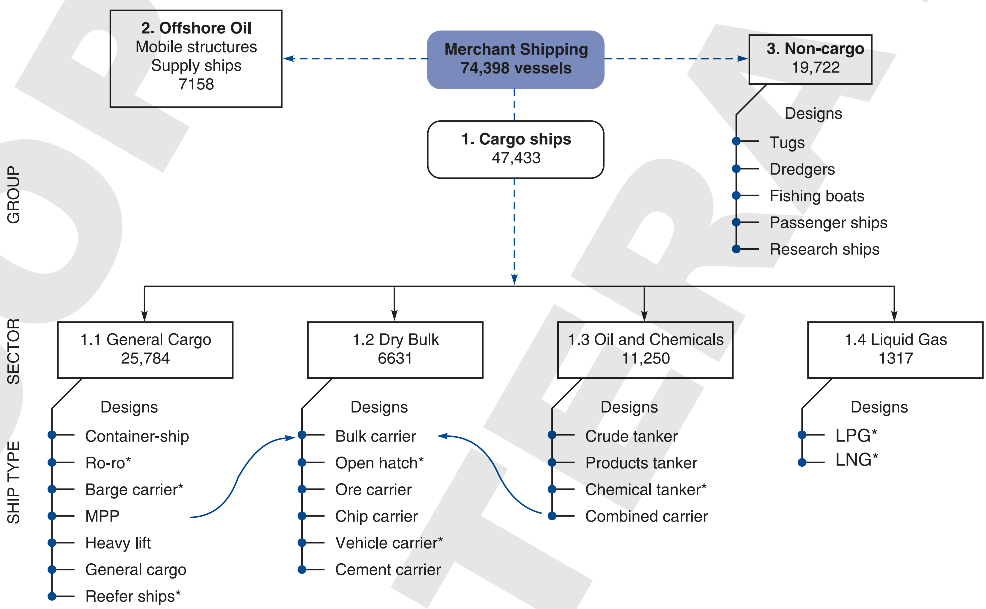
- *Type of shipping operation*. In the previous paragraph we assumed that the shipowner knows the precise type of cargo to be carried, but in practice his knowledge of both the cargo and other physical operating constraints will depend upon the type of shipping operation for which the vessel is intended. There are several different types of shipping operation, for example: *long-term charters*, where the shipowner has some knowledge from the charterer of the cargoes to be carried and the ports to be used; *spot charter market operations*, where the owner has only a general idea of the type of cargo to be carried and no knowledge of the ports to be visited; and *liner operations*, where the owner has a specific knowledge of the ports to be visited and the likely cargo volume, but where both may change during the operational life of the vessel. The design criteria for a shipowner choosing a vessel for a long-term time charter are likely to be quite different from those for the owner intending to trade on the spot market. For example, the former will be preoccupied with optimizing the ship to a specific operation, whereas the latter will be more concerned with such factors as the vessel's acceptability to charterers, and its short-term resale value.
- *Commercial philosophy*. The way in which the shipowner or shipping company approaches the business may extend or limit the range of options. For example, one shipping company may prefer vessels that are highly flexible, servicing a number of different markets and thereby reducing the risk. This philosophy might lead the shipowner to prefer a more expensive open-hold bulk carrier, which can carry both dry bulk cargo and containers. Another owner may follow a policy of specialization, preferring a vessel that is in every respect designed for the efficient carriage of a single cargo, offering greater efficiency or lower costs but at the price of less flexibility.

It follows that shipping economists cannot forecast the demand for a particular type of ship just by studying cargo movements. In the real world the choice of a particular ship type depends on all three factors – cargo type, shipping operation and commercial philosophy. This makes it difficult to predict which factors will predominate in the final decision. Market research techniques of the type discussed in Chapter 17 will certainly form part of this process, as will fashion and market sentiment.

The fleet by ship type

Since few ships are truly identical, one problem in discussing ship design is the sheer number of vessels involved.[1] So our first task is to classify the designs into types with common features, which we do in Figure 14.1. The world's 74,398 maritime vessels (Table 2.5) are first divided into the three groups of structures operating on the oceans: cargo shipping (group 1), offshore oil and gas structures (group 2) and non-cargo ships (group 3). Cargo ships, our main focus here, are split into four sectors based on economic activity: general cargo transport; dry bulk transport; oil and chemical transport; and liquid gas transport. At the third level the merchant ship sectors are divided into 19 ship types based on the physical design of the hull: for example, tankers have tanks, bulk carriers have holds and vehicle carriers have multiple decks designed to carry as many cars as possible. If this were a technical book we would probably stop there, but as economists we must recognize a fourth level of segmentation by ship size. Size restrictions on terminal facilities and waterways such as the Panama Canal divide ships of a particular type into segments.

This chapter is organized around the four sectors of the merchant fleet which transport general cargo, dry bulk, oil and chemicals, liquid gas, with a short section on non-cargo carrying vessels (see Figure 14.1). There are seven general cargo types, six dry bulk types, four oil and chemical types, two liquid gas types and four non-cargo types. Looking over this figure and Table 14.1, which shows how 19 segments of the fleet grew between 1990 and 2006 gives a sense of the way the ship type structure of the fleet is constantly changing. Between 1990 and 2006 the world fleet grew at an average of 2.7%



* Indicates specialized ship type discussed in Chapter 13

Figure 14.1
The commercial shipping fleet, 1 July 2007, classified by group, sector and ship type
Source: Ship numbers from Table 2.5

Table 14.1 World cargo fleet showing growth rates 1990–2006 of 19 ship type segments

		No.	Design Start	Fleet m.dwt 1990[a]	Fleet m.dwt 2006	Number 2006	Growth 1990–2006[b]	Key design issues
1. General cargo	Container	1	100–999 TEU	5	9	1,167	4.2%	Slow, geared
	Container		1,000–2,999 TEU	17	41	1,659	5.8%	Faster, some geared
	Container		3,000 + TEU	4	61	1,113	18.0%	Fast (25 kts), no gear
	Container		Total container	26	111	3,939	9.4%	
		2	Ro-ro	7	9	1,109	2.1%	Ramp access to holds
		3	MPP	17	23	2,533	2.0%	Open hatch, cargo gear
		6	Heavy lift	—	1	53		53 ships, excludes MMPs
		4	Barge carriers			6		
		5	Gen. cargo	27	11	1,024	–5.3%	Includes liner types and tramps
		7	Reefer	7	7	1,237	–0.1%	Refrigerated, palletized
			Total liner	84	163	9,901	4.2%	
2. Dry Bulk	Bulk carrier	8	Capesize	48	111	703	5.4%	Carry ore and coal
	Bulk carrier		Panamax	43	94	1,386	5.1%	Coal, grain, few geared
	Bulk carrier		Handymax	31	67	1,488	5.0%	Workhorse, mainly geared
	Bulk carrier		Handy	82	74	2,762	–0.7%	Smaller workhorse
	of which:	9	Open hatch	—	17	481		Designed for unit loads
		10	Ore carrier	9	9	51	–0.4%	Low cubic (0.6 m³/tonne))
		11	Chip carrier	—	6	129		High cubic (2 m³/tonne)
		12	Vehicle carrier	4	8	594	4.2%	Multiple decks
		13	Cement carrier			77		
			Total dry bulk	203	345	6,339	3.4%	
3. Liquid Bulk	Crude	14	VLCC	114	143	483	1.4%	Long-haul crude oil
	Crude		Suezmax	35	54	350	2.8%	Medium-haul crude
	Crude		Aframax	38	73	705	4.2%	Some carry products
	Crude		Panamax	14	23	305	3.0%	Very short haul
	Crude		Handy	50	76	2,414	2.6%	Mainly products
	Crude		Total oil	243	368	4,257	2.6%	
	of which:	15	Products tanker		49	1,196		Some overlap with chemicals
		16	Specialized tanker	10	41	2,517	9.1%	More tanks and pumps
		17	Oil/bulk/ore	32	10	95	–7.2%	dry and wet
		18	LPG	7	11	1,030	3.2%	Several freezing systems
		19	LNG	4	17.5	222	9.3%	–161°C
World Fleet				573.1	914.7		2.9%	

[a]Container-ship dwt 1990 estimated from TEU statistics

[b]To show the growth rate since 1990 it was necessary to use slightly different statistical groupings from those shown in Figure 14.1 and Table 2.5.

Source: Clarkson Registers April 2006 and Shipping Review and Outlook Spring 2007, CRS, London

per annum, but the growth rate differed significantly between segments. The container-ship fleet averaged 9.4% per annum whilst the general cargo fleet declined at 5.3% per annum, so the liner fleet as a whole averaged 4.2% growth. In the bulk carrier segment the bigger sizes grew at about 5% per annum whilst the fleets of small bulk carriers and ore carriers both declined, so the dry bulk fleet averaged 3.4%. The tanker fleet grew even more slowly, averaging 2.6% per annum, with Aframax tankers showing the fastest growth and the VLCC fleet the slowest. The specialized fleets all grew at very different rates, with LNG tankers expanding fastest and the reefer fleet declining. All of which demonstrates the dynamic way the fleet structure evolves over time in response to the changing trade flows. This makes selecting the right type even more tricky.

14.2 SEVEN QUESTIONS THAT DEFINE A DESIGN

Broadly speaking, each ship is a bundle of features blended to achieve a specific objective, but, for the reasons discussed in the last section, the design parameters are not always clear-cut and designing a ship is not a precise science that can be reduced to purely economic criteria. Benford develops this point in the following way:

> Whether we use computers, hand held calculators, or backs of envelopes one rule applies: the decision will be made by some person, or group of persons, and will not hinge simply on the best numerical projection of some measure of merit. Like nearly all else in our business, there is art as well as science in this. Indeed – and roughly speaking – the more important the decision the greater is the reliance upon art. That is what makes ship design so fascinating.[2]

On this theme, before looking at individual ship types, it is helpful to review seven questions analysts should ask when defining the particular bundle of features the investor needs.

How will the ship be traded?

The first question to ask is why the investor wants the ship. There may be lots of clever technology available which naval architects can use to produce the perfect ship, but investors have their own objectives. For example, they often value simplicity and robustness over technical perfection, in which case designing their ships is about optimizing commercial rather than technical performance. Clever and innovative technical designs make great conference papers but have a patchy history in the practical world of commercial shipping.

Anyway, investors often have only a rough idea about the type of cargo to be carried. If there is a *long-term charter* the shipowner probably knows the likely cargoes to be carried and possibly the ports to be used, but if the ship is to trade on the *spot market* there will be only a general idea of the type of cargo to be carried and no knowledge of the ports to be visited. In this case the investor is more interested in such factors as the vessel's acceptability to charterers and its short-term resale value. Ships built for *liner services* can often be designed for the particular route and tailored in such areas as reefer capacity, but these things change during the operational life of the vessel and container-ships are increasingly commoditized. The following examples illustrate some of the different angles from which investors may approach commissioning a new ship:

Example 1. A steel plant purchasing an iron ore carrier to service a long-term iron ore supply contract between Brazil and China. In this case, the cargo, the cargo volume and

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the trade route are all known in advance, and the ship will be dedicated to the trade over its life, so the design can be optimized to the shipping operation in terms of the cargo to be carried, the parcel size, the ports to be utilized and the opportunities for exploiting economies of scale. In addition, since the vessel is to be operated over a number of years, the shipowner is likely to take a close interest in any technology that will reduce operating costs – for example, automation and fuel-saving equipment.

Example 2. A dry bulk carrier operator purchasing a bulk carrier to trade on the voyage charter market. In this case, the shipowner has only a general idea of the cargoes and ports that the vessel will be required to service. Depending upon his style of operation, he may choose a small ship that can access many ports, or a larger ship that will be more competitive in some of the major bulk commodity trades. In particular, he wants the ship to be attractive to charterers, with a good resale value even after a short time. For this reason, a well-established standard design may be of interest and design features such as fuel saving equipment will only be of interest if they add to the ship's value in the second-hand market, which many do not.

Example 3. A company planning investment in a specialist bulk market such as motor vehicles or forest products may not have a precise future operating pattern, but will know what cargo features are needed to reduce operating costs and improve the service. This may lead to the design of a completely different type of ship such as a vehicle carrier, or a sophisticated version of a standard ship such as a forest products carrier. In such cases, the cargo figures prominently in the ship design, as do the range of ports, terminals and cargo-handling facilities servicing this particular trade.

Design sophistication comes at a price which makes it risky, and the preceding examples illustrate that investors have different requirements which determine how closely the ship is optimized to a particular cargo or trade route.

What cargo will the ship carry?

Cargoes come in all shapes and sizes. Some, like grain, are homogeneous whilst others, such as logs or steel products, consist of large regular or irregular units that present the ship designer with a different challenge. This is not just about the commodity, because the same commodity can be transported in many different ways. For example, china clay can be loaded into bags transported loose, on a pallet, or in a container; shipped loose in the hold of a bulk carrier; or mixed with water and shipped in a tanker as slurry. These are all examples of 'cargo units', the term used to describe the physical form in which a commodity is presented for transport, and 12 of the most common ones are summarized in Box 14.1.

In a few cases, such as LNG or nuclear waste, the cargo demands a specific type of ship, and the shipowner's choice is limited to general design and operating features such as size, speed and crew. For most cargoes, however, the shipowner can choose from several ship sizes and types. Crude oil is carried in different sizes of tanker or even a combined carrier; dry bulk can be carried in a conventional bulk carrier, an open hold bulk carrier or a combined carrier; containers principally move in different sizes of container-ship, but MPP vessels and ro-ros carry them as well. The first six items on

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BOX 14.1 PHYSICAL UNITS IN WHICH COMMODITIES ARE SHIPPED BY SEA

Cargo unit	Comment/commodity
Natural cargoes:	
General cargo	Small parcels of loose items – e.g. boxes, bags, packing cases, drums, a few cars, machines.
Dry bulk cargo	Cargo in ship- or hold-sized parcels that can be handled in bulk by gravity/pump loading and grab/suction/pump and stowed in its natural form – e.g. oil, iron ore, coal, grain and cargo.
Liquid bulk cargo	Liquid bulks raise four issues: parcel size which can vary from a few thousand tons to 300,000 tons; density of the liquids transported varies; some liquids are corrosive; some liquids are considered hazardous by regulators and require special transport.
Unit bulk cargo	Large quantities of units that must be handled individually – e.g. logs, sawn lumber, steel products, bales of wool or wood pulp.
Heavy and awkward cargo	Heavy loads up to 2,500 tons – e.g. project cargo, modular industrial plant, ship sections, oilfield equipment, locomotives, yachts, shiploader cranes.
Wheeled bulk cargo	Cars, tractors, lorries, etc. shipped in large quantities.
Artificial units	
Containers (ISO)	Standard boxes usually 8′ wide × 8′6″ high in lengths of 20′ and 40′, with a 20′ box typically handling 7–15 tons of cargo, typically stowing at 2.5–5 m^3 per ton.
Intermediate Bulk Container	Large bags typically 45″ in diameter with capacity of around 1 tonne of granular material and designed for efficient mechanical stacking, handling and discharging.
Pre-slung or banded	Usually used for sacks, bales and forest products, to speed up loading and discharge. The slings are left in place during transit.
Palletized cargo	Cargo is stacked on a pallet and usually held in place by steel or plastic bands or ‘shrink fit’ plastic – e.g. cartons of fruit. Can be handled by fork-lift truck. Dozens of sizes up to 6′ × 4′. Palletized cargo stows at about 4 m^3/ton.
Flats	Normally about 15′ × 8′, often with corner posts to allow stacking two high. Handled by fork-lift or crane.
Barges	LASH barges load about 400 tons cargo and Seabee about 600 tons. The barges are designed to be floated to the ship and loaded/discharged as a unit. Never caught on and now obsolete.

the list are ‘natural’ cargo units, that is, the cargo is shipped in its natural form without pre-packing. General cargo consists of loose items such as bags or boxes, without any special packing. This type of cargo is the most difficult and expensive to transport by sea. Packing it into the hold of a ship is time-consuming, requires skill, and there are associated problems of loss and damage in transit, as was explained in Chapter 13.

A dry bulk cargo unit is a ship- or hold-size parcel of homogeneous cargo – for example, 150,000 tonnes of iron ore, 70,000 tonnes of coal, 30,000 tonnes of grain, 12,000 tonnes of sugar – whilst liquid bulk cargoes range in size from 500 tonnes of a chemical to 450,000 tonnes of crude oil. Homogeneous bulk cargoes can be loaded and unloaded using grabs or suction as appropriate, and the aim is generally to design a ship that can load its full cargo deadweight of a single commodity, though in some trades that does not always apply. For example, in oil products many ships carry cargo parcels that do not fully utilize the ship's deadweight, such as naphtha, and may be designed with this in mind. In practice, the hold is the smallest size unit for dry bulk cargo and the cargo tank the smallest unit for liquid bulk. Unit bulk cargoes consist of ship-sized parcels made up of units each of which must be handled individually – for example, steel products, forest products or bales of wool. In such cases it may be possible to design 'tailored' vessels offering improved stowage or faster cargo handling. Finally, the other natural cargo units are heavy and awkward cargoes and wheeled cargoes. Heavy and awkward cargoes are worth singling out because they present special shipping problems in terms of handling and stowing the cargo. For example, the tunnel kiln for a cement plant or a small warship being shipped from Europe to the Far East both present stowage problems.

The remainder of Box 14.1 is concerned with cargo that is pre-packed for transport, usually so that it can be handled mechanically rather than requiring skilled manual handling and stowage. Standardization also allows cargo units to be moved seamlessly between rail, road and sea vehicles, improving the efficiency of integrated 'door-to-door' transport services. In practice, there are six main forms of artificial cargo units: containers; intermediate bulk containers; pre-slung or banded; pallets; flats; and the now little-used barges.

By far the most important artificial unit is the *ISO container*. Standard 20 ft and 40 ft containers give the shipowner a homogeneous cargo that allows mechanized loading and discharging systems and produces a major improvement in efficiency. However, the uncompromising size, shape and weight of the container box presents designers with a specific set of problems.

Intermediate bulk containers are large bags made of flexible fabric, designed for mechanical filling, handling and unloading of solid materials in powder, flake, or granular form. They were first manufactured in the late 1950s and are mainly used for minor bulks such as chemicals and high-value ores.

The use of *pallets* and *flats* provides a degree of unitization without requiring the high capital costs incurred by containers and trailers, and there are fewer problems in returning the empty units. Pallets have not become established as a base unit for a sea transport system in the same way as containers except on individual routes where they meet a special need, for example in the refrigerated cargo trade. The cargo is loaded on to a pallet, of which there are a variety of sizes, and secured with bands or a plastic cover shrunk to protect the cargo. Loading and discharge are still labour-intensive operations and rely on the skill of stevedores to pack the pallets into the ship efficiently. It is, however, dramatically more efficient than the handling of individual boxes, drums, sacks or bales. Finally, *barges* were introduced in the 1960s in an attempt to cater for the small

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bulk packages of medium-value cargoes, especially where an inland waterway system allows through water transport to inland destinations, but were never widely adopted.

How should the cargo be stowed?

The next issue is how best to tailor the cargo spaces to fit the cargo units the ship will carry. This presents more difficult choices because optimizing stowage often has adverse consequences for other aspects of the design. Buxton describes the problem in the following way:

> Merchant ships are mobile warehouses whose many different forms have evolved as a result of attempts to balance on the one hand the need for suitable storage capacity, against on the other hand the need for mobility. Thus a ship constructed as a simple rectangular box of appropriate dimensions could provide an ideal space for storing containers, but would be difficult to propel through the water, while an easily driven hull would offer relatively little useable cargo space. Ship design is largely a matter of solving such conflicts to produce vessels which are suited to the services in which they will be employed.[3]

A good starting point is the stowage factor, the volume of hold space in cubic metres occupied by a tonne of cargo. This varies enormously from one commodity to another, as the examples in Table 14.2 show. Iron ore, the densest cargo, stows at around 0.4 m^3 per tonne, whilst wood chips stow at around 2.5 m^3 per tonne and thus take up six times as much space. In between is heavy grain which stows at around 1.3 m^3 per tonne. If a ship designed for grain is loaded with iron ore, much of the internal space will be empty. At the other end of the scale, light cargoes such as logs need a lot more space. So a bulk carrier designed with a cubic capacity of 1.3 m^3 per tonne could take a full cargo of coal, but not a full deadweight of wood pulp which stows at 1.7 m^3 per tonne.

If a ship is to be used exclusively to carry only iron ore, it can be designed as an ore carrier with cargo spaces stowing at, say, 0.5 m^3 per tonne, but if it is to be used for other commodities such as coal or grain an internal cubic capacity of about 1.3 m^3 per tonne might be preferred (see Table 14.9 for the average stowage of the bulk carrier fleet). The same problem arises with container-ships. Twenty-foot containers typically stow at around 1.6–3.0 m^3 per tonne, one of the least dense commodities listed in Table 14.2. To utilize the ship's deadweight, containers are generally stacked on deck but the design deadweight per container slot is a matter of balance because the weight of cargo in the containers may change. We saw in Chapter 13 that the average container payload per TEU in the transpacific trade varies between 7 tonnes eastbound and 12 tonnes westbound. So a compromise is needed on the ship's loaded deadweight.

Hold dimensions are also important. Ships carrying containers, packaged timber or any standard unit must be designed with square 'open' holds that match the external dimensions of the units they are carrying and provide vertical access. For example, 'pallet-friendly' reefer vessels are designed with decks tailored to accommodate the maximum payload of standard pallets.

Table 14.2 Stowage factors for various commodity trades

Cargo type	Stowage factor		Density index[a]
	Cu. ft/ton	Cu. m./tonne	
Dry cargo			
Iron ore	14	0.40	31
Bauxite	28	0.80	62
Phosphate (rock)	30–34	1.00	77
Soya beans	44	1.20	92
Grain (heavy)	45	1.30	100
Coal	48	1.40	108
Barley	54	1.50	115
Wood pulp (bales)	60	1.70	131
Copra	73	2.10	162
Pre-slung timber	80	2.30	177
China clay (bagged)	80	2.30	177
Paper (rolls)	90	2.50	192
Wood chips	90	2.50	192
Logs	100	2.80	215
Containers, 20 ft	56–105	1.6–3.0	123–230
Containers, 40 ft	85–175	2.4–5.0	185–385
Cars (vehicle carrier)	150	4.2	323
Toys, footwear	300–400	8.5–11.3	230–869
Liquid cargo			0
Molasses	27.0	0.80	62
Heavy fuel oil	32.8	0.93	72
Heavy crude oil	33.7	0.95	73
Diesel oil	37.2	1.06	81
Light crude oil	37.6	1.07	82
Gas oil (light fuel oil)	38.6	1.10	84
Paraffin	40.3	1.14	88
Motor spirit (petrol)	43.2	1.23	95
Aviation spirit	45.1	1.28	98
Naphtha	46.4	1.32	101

[a]Density index based on grain (heavy) = 100. Big numbers take more hold space, whilst small numbers like iron ore take up little.

Source: Various

Where commodities with stowage factors that depart significantly from the average are shipped in large quantities, it may be economic to build specialist ships to carry them. Ore carriers, woodchip carriers and car carriers are three prominent examples, the first to deal with a high-density cargo and the latter two to deal efficiently with low density cargoes. Hoistable decks may be fitted to allow the head-room to be adjusted for different cargoes, for example to allow car carriers to transport larger units like trucks.

How should the cargo be handled?

Getting the cargo on and off the ship is one of the most important aspects of ship design, involving both the cargo characteristics and the extent to which the transport operation

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is part of a wider integrated transport network. There are many ways ship designs can be developed to improve cargo-handling efficiency, provided the dimensions of the units are known in advance. Some of the most important are as follows:

- *Cargo-handling gear*. Jib cranes, heavy lift derricks, or other cargo-handling gear such as gantry cranes may be fitted to speed up the loading and discharge of dry cargo ships. For tankers the there are three main issues to consider – the capacity of the pumps; corrosion resistance of pipe work; and segregation of tank cargo-handling systems.
- *Hatch design*. Bulk carriers for transporting unit loads such as containers or packaged lumber may be designed with hatch coamings that match the standard package size, thus facilitating the efficient stacking of packages in the hold and on deck. Wide (sometimes called 'open') hatches provide vertical access to all parts of the hold.
- *Cell guides*. In the case of containers the process of integrating the hold design into the cargo-handling operation goes a step further, and to speed up handling on container-ships, cell guides are fitted in the holds and occasionally on deck so that containers do not need to be secured individually below deck.
- *Cargo access ramps*. Ramps may be fitted to allow cargo to be loaded by fork-lift truck, or to be driven aboard on its own wheels. They may be located at the bow, the stern or into the side of the vessel, accessed through watertight doors in the hull.
- *Tank segregations*. For liquid cargoes the provision of 'self-contained' tanks capable of handling many different liquid parcels within a single ship increases flexibility. This generally involves the installation of separate pumping systems for each tank using submerged pumps and special coatings such as zinc silicate or stainless steel to allow difficult chemicals to be carried.

This is not an exhaustive list, but it illustrates the way in which ships may be adapted to the carriage of cargoes.

How big should the ship be?

With the issues over cargo handling and stowage out of the way, the next question facing the investor is the size of vessel to buy. There are numerous influences on the size of ship, but the principles of bulk shipping discussed in Chapter 11 suggest that the optimum size for a ship can be narrowed down to a trade-off between three factors: economies of scale; the parcel sizes in which cargo is available; and available port draught and cargo-handling facilities.

We discussed economies of scale in Chapter 7 and saw that substantial cost savings are achieved by using larger vessels, with the choice depending on the size of vessel used and the length of the voyage. The relative costs for large and small ships on short and long voyages are illustrated in Table 14.3. A 15,170 dwt vessel costs 2.7 times as much to run per ton of cargo as a 120,000 dwt ship on a 1000-mile round voyage, whilst on the 22,000 mile round voyage it costs 3.1 times as much.

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Table 14.3 Economies of scale in bulk shipping (% cost per ton mile)

Round voyage (miles)	Ship size (dwt)			
	15,170	40,540	65,500	120,380
1,000	100	53	47	37
6,000	56	34	27	20
22,000	52	30	24	17

Source: Goss and Jones (1971, Table 3).

This suggests that economies of scale are only slightly influenced by the length of haul, and the fact that smaller ships are generally used on short routes must have another explanation.

In practice, big ships face two important restrictions. The first is the maximum size of delivery that the shipper is able or willing to accept at any one time. If stockpiles are only 10,000 or 15,000 tonnes, a delivery of 50,000 tonnes would be too large. Second, there is the constraint on ship size imposed by port draught since deep-draught vessels, have access to fewer ports than shallow-draught vessels, as shown in Table 14.4. Limits may also be placed on overall length or beam or both (either by ports or by canals). The measure of accessible ports is very crude, since some ports are more important than others in the bulk trades and depth varies substantially from berth to berth within ports, but the broad relationship is valid. At the lower end of the scale, a small bulk carrier of 16,000 dwt is likely to have a draught of 7–9 metres and is able to access about three-quarters of the world's ports. A final point is that ship designers can vary the draught–deadweight ratio within certain limits by changing other aspects of the design such as the beam.

Table 14.4 Relationship between ship draft and port access

Ship draught		Average size	Standard deviation*	% of world ports
feet	metres	dwt	dwt	accessible
25–30	7.6–9.1	16,150	3,650	73
30–35	9.2–10.7	23,600	3,000	55
36–38	10.8–11.6	38,700	5,466	43
39–44	11.7–13.4	61,000	5,740	27
45–50	13.5–15.2	89,200	8,600	22
51–55	15.3–18.5	123,000	9,000	19

Source: Sample of bulk carriers from the Clarkson *Bulk Carrier Register* and *Ports of the World*
*Standard deviation is the spread of the average size

How fast should the ship go?

In terms of cargo delivery economics, size and speed are to some extent interchangeable because a ship's transport capacity can be increased by increasing either its size or its speed. However, the two methods have very different economic and physical consequences. From a design viewpoint the fast ship will generally be more expensive to build and achieving the higher speed may call for a longer hull with less efficient cargo stowage. But the fast ship needs less cargo capacity to achieve a given cargo delivery volume and it can access shallower draft ports and make more frequent deliveries, reducing inventory requirements. Speed also reduces the transit time and the inventory cost of cargo in transit, which can be very significant for high-value cargoes such as television sets which can be worth around $44,000 per tonne (Table 14.5). If a company's cost of capital is 10% per annum, a 10-tonne cargo of television sets worth $44,000 per ton would, on a two-month voyage, incur interest charges of $7,000. Cutting the journey to one month saves $3,500, so the shipper should be willing to pay for faster transport. In fact air freight often competes with sea transport for this sort of cargo and, although the tonnages are small, the competition is significant because it is premium cargo. But these benefits of speed come at a cost. To be efficient, fast ships need a long hull and use far more fuel, as can be seen from Table 14.7 which shows the speed and fuel consumption of container-ships. For example, it shows that the average container-ship of between 6,000 and 12,000 TEU has a speed of 25.2 knots burns 211.3 tonnes a day, more than twice as much as a 15 knot VLCC.

At the other end of the range, some bulk commodities such as iron ore and coal have very low values, for example iron ore at $35 per tonne and coal at around $47 per tonne (Table 14.5). These commodities are generally shipped in very large consignments (up to 300,000 tonnes) and, since they have a low inventory cost, the emphasis is on minimizing the unit transportation cost by using the most economical speed. For these cargoes the relevant cost is the cost of the ship, not the cargo. Ship designers will generally work out the optimum operating speed for the vessel, taking account of the anticipated level of capital, operating and bunker costs on the assumption that the freight is not time sensitive. However, an important qualification is that if the ship is to

Table 14.5 Value per ton of sea imports

Commodity	$ per tonne f.o.b.	Quantity traded, (million tonnes)	Value trade $m
Stone, sand, gravel	9	101	888
Iron ore	35	650	22,750
Coal	47	682	32,054
Grain	200	273	54,600
TV sets	43,076	—	—
World imports	1,341	6,893	9,244,700

Source: UNCTAD (2006) Table 41 and Annex 2 and various

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be traded on the spot market the investor may specify a design speed above this minimum so that he can complete more voyages during periods of high freight rates when he is making premium profits.

How flexible should the ship be?

Finally, there is the flexibility of the ship to consider – should the ship be designed to service several markets? Specialist tonnage is shut out from markets that could be serviced by more flexible vessels, or at least incurs a cost penalty, so naturally ship designers have devoted a great deal of attention to this question. This can raise issues over speed, cargo handling, cargo access, size, stowage and various less fundamental but expensive options such as tank coatings – for example, should a new Aframax tanker have tank coatings so that it can switch into the long-haul clean products trade?

A way of illustrating the degree of cargo unit flexibility of different ship designs is shown in Figure 14.2, which lists on the left-hand side the various cargo units we have discussed and on the right-hand side a range of recognized ship types. A line links each cargo unit to the various ships that are capable of transporting it, and for each ship type the lateral cargo mobility (LCM) coefficient records the number of different cargo units that the vessel can carry.

Four ships are sufficiently specialized to have an LCM rating of 1 – the container-ship, the vehicle carrier, the bulk carrier and the tanker. All these vessels are restricted to a single type of cargo unit. The combined carrier has an LCM rating of 2, reflecting its ability to switch between dry bulk and crude oil, while the open hatch bulk carrier can transport containers, pallets and pre-slung cargo in addition to dry bulk parcels. The ro-ro is even more flexible, with the ability to carry almost any cargo except bulk and barges, giving it an LCM rating of 6. However, the most flexible of all is the MPP cargo liner, which can carry everything except liquid bulk parcels and barges.

The trade-off between cost and operational performance in its main trade is central to the design of flexible ships. Often the flexible ship is more expensive

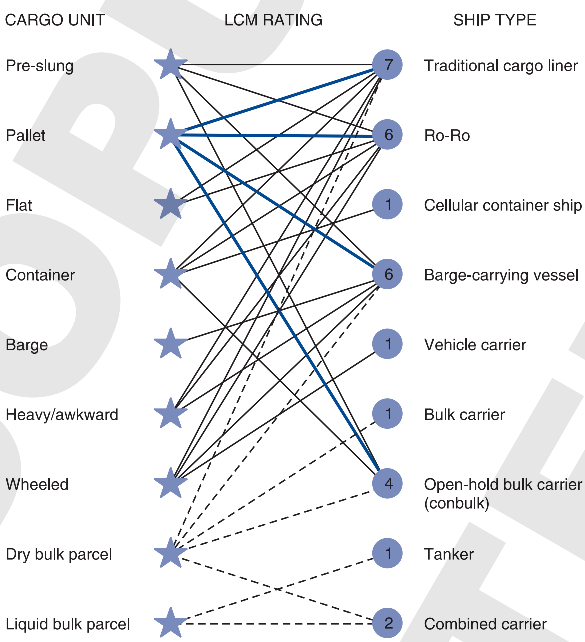

Figure 14.2
Analysis of flexibility
Source: Martin Stopford 2007
Note: Lateral cargo mobility (LCM) rating reflects the number of different types of cargo units that the vessel can carry, i.e. its flexibility. The higher the number, the greater the flexibility.

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Table 14.6 Principal dimensions of flat roof steel containers

	Dimensions	
	20′ × 8′ × 8′6″	40′ × 8′ × 8′6″
Length (metres)	6.1	12.2
Width (metres)	2.44	2.44
Height (metres)	2.6	2.6
Cubic capacity (cubic metres)	32.9	67
Stacking capacity	9 high	9 high
Maximum weight (metric tonnes)	24	30.5

Source: UNCTAD (1985, p.141).

to build and does not perform as well as a single purpose vessel in any of the trades for which it is built. So the key is whether it can gain benefits such as reducing ballast voyages or carrying more cargo (see the example of open-hatch bulk carriers at the beginning of Chapter 12). In this context, design technology can be important in addressing operational issues. Although the case for flexible ships which reduce risk and increase earnings sounds great, in practice relatively few shipping investors follow this strategy. Today the merchant fleet is dominated by single-purpose ships such as tankers, bulk carriers and container-ships, all of which have an LCM ratio of 1. In contrast, the flexible ship types such as cargo liners, ro-ros, barge carriers and combined carriers have recently been noticeably sluggish or in retreat. This suggests that in the modern shipping industry the economic benefits of specialization outweigh the economic benefits from flexibility – a useful reminder that simplicity is a guiding principle of successful ship design. Sophisticated ships make interesting conference papers, but in the harsh commercial world simple vessels which do one job well seem to do better.

14.3 SHIPS FOR THE GENERAL CARGO TRADES

This is the trade segment where ships have changed most in the last fifty years. Indeed, it is rare in shipping to find such a radical change as the substitution of container-ships for the flexible cargo liners which started in the 1960s. Like the switch from sail to steel, the transition took many years to accomplish and a large number of vessels left over from the cargo liner era continued to be used and in some cases were still being replaced fifty years after the first container was shipped in 1956. By 2006 the container-ships had taken over all but the fringe liner services, though there were still a few services using ro-ros, MPP vessels and even a handful of barge-carrying vessels (BCVs), and ’tweendeck tramps.

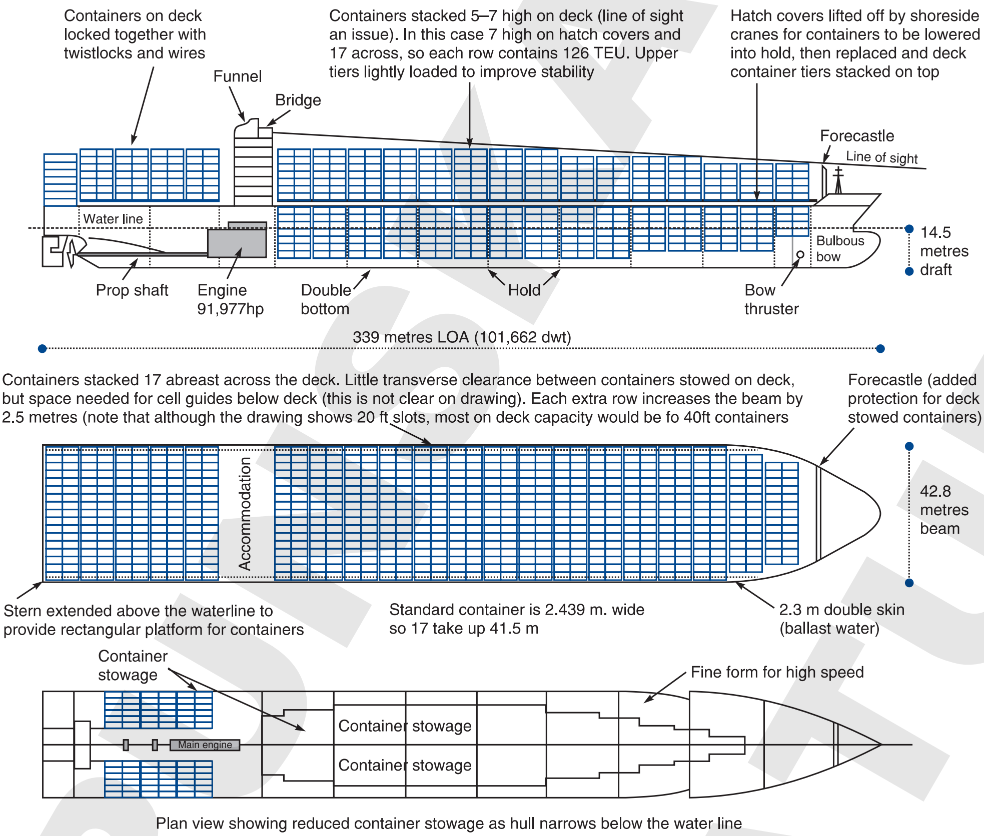
Container-ships

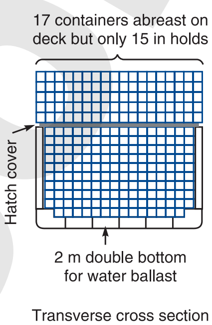
All the major liner trades now use container-ships. A container-ship is, in principle, an open-top box in which containers can be stacked. It has hatches the width of the holds, fitted with cell guides so that containers can be dropped into place and held securely during the voyage without lashing. The hatches are sealed with strengthened hatch covers which provide the base for stacking more containers above deck. Since these have no supporting structure they must be lashed in place with twistlocks and wires. Some companies have experimented with hatchless designs which avoid the labour-intensive procedure of clamping containers.

Details of a large 8200 TEU container ship are shown in Figure 14.3. Since the sole purpose of this ship is to carry containers, its design centres on container dimensions. ISO standards identify a range of containers, the most widely used sizes being the 20 ft and 40 ft containers with dimensions as shown in Table 14.6. Container-ships are generally designed around the 8 ft 6 in. high module, though this also allows a mix of 8 ft and 9 ft 6 in. containers to be stowed as well. The containers are arranged in bays, with 30 forward of the accommodation and 10 at the stern. Below deck the containers are lowered into cell guides and the number of tiers which can be accommodated in the hold varies with the curvature of the hull, as illustrated by the longitudinal cross section in Figure 14.3. On-deck containers are stacked on the hatch covers and held in place by twistlocks and wires and stacked in tiers the height of which depends on visibility. In this example the number of tiers varies between five and seven. The ISO also specifies a weight standard, which is a maximum of 24 tonnes for 20 ft containers and 30 tonnes for 40 ft containers. These are well above the average values likely to be found in practice, which may range between 10 and 15 tonnes depending on the trade and the type of cargo. Although this ship has a nominal capacity of 8189 containers, its homogeneous capacity at 14 tons per TEU is 6,130.

At first, container-ship designs were categorized into 'generations', reflecting the evolving technology, but as the fleet grew to more than 4,000 ships in 2007 it polarized into size categories shown by the fleet statistics in Table 14.7. Each sector has a different place in the market. Smaller container ships of less than 1,000 TEU, often referred to as 'Feeder' (0–499 TEU) and 'Feedermax' (500–999 TEU) vessels, are generally used on short-haul operations. They distribute the containers brought to regional load centres or 'hub' ports such as Rotterdam by deep-sea services and carry coastal traffic. There is a sizeable fleet of Handy vessels of 1,000–3,000 TEU which are small enough to be used intraregionally, but large enough to be used in the North–South trades where port restrictions or cargo volume do not permit the use of a larger vessel. Bigger ships over 3,000 TEU are used on long-haul trades where they spend up to 80% of their time at sea. There are three groups of these vessels, referred to as Panamax (3,000–4,000 TEU) and post-Panamax (over 4,000 TEU), with an evolving group of very large box carriers (VLBCs) over 6,000 TEU. Since the different fleet segments have different functions they also have different design characteristics, especially speed and cargo-handling facilities.

Speed is a central feature of container-ship design; with the larger vessels having higher speeds, as can be seen in Table 14.7. In 2006 the average Feeder vessel had a speed of 14 knots, compared with an average speed of 24.5 knots for the average post-Panamax vessel. With each step up in size the speed increases, though the pace of increase slows sharply over 3,000 TEU. The economic explanation of this trend is that





8,200 TEU Container-ship

HULL	CARGO	MACHINERY
Deadweight (design): 84,200	Maximum TEU capacity: 8,189	Engine: MAN-B&W
Deadweight (scantling): 101,662	on deck 4,148	Power output (hp): 91,977
Gross tonnage: 88,600	in holds	4,041 at 97 rpm (67.6 MW)
dimensions	TEU capacity @14t per TEU: 6,130	Six bladed propeller
Overall length (m): 339		Maximum speed (Kn): 25.4
Overall beam (m): 42.8	Container tiers/rows:	Speed, service 90% MCR*
	On deck: 7/17	15% sea margin 24.4 knots
Draft (m): scantling 14.5	In holds: 8/15	Consumption: 271 tons/day
Draft (m): design 13.0	TEU bays on deck: 19	Bunker capacity:
Width of double side: 2.23 m	TEU bays below deck: 18	heavy oil 10,900 m^3
Height of double bottom: 2.00 m	Reefer containers: 700 electric	diesel oil 700 m^3
Percent high tensile steel 60%	sockets to supply 40' boxes	Diesel alternators 5
	complement	Alternator output:
	Officers 16	3×2200 kW and 2×2800 kW
Tin free SPC paint, 5 year life	Ratings 18	Exhaust gas scrubbing plant
	Suez crew 6	Bow thruster 1×2500 kW

*MCR is the maximum continuous rating i.e. maximum power

Figure 14.3
Example of typical 8,200 TEU container-ship design
Source: Drawing by Martin Stopford, based on container-ships built by Hyundai Heavy Industries

Table 14.7 The container-ship fleet, by size and hull characteristics

		Container-ship fleet size			Hull characteristics					
	Ship size TEU	No	Av. TEU	Tot TEU (000s)	Capacity dwt/TEU	Beam metres	Draft metres	Speed knots	Cons. t/day	% Geared
Feeder	0–499	443	310	137	17.2	17.1	6.1	14.0	15.7	29%
Feedermax	500–999	695	722	502	14.1	21.1	7.7	16.8	27.5	48%
Handy	1000–1999	1012	1412	1429	14.9	26.3	9.7	19.0	49.2	53%
Sub-Panamax	2000–2999	596	2504	1492	14.2	31.0	11.5	21.2	79.3	43%
Panamax	3000–3999	297	3411	1013	13.8	32.3	12.0	22.5	104.5	9%
Post-Panamax	4000–5999	533	4817	2567	12.9	35.4	13.3	24.5	159.5	0%
VLBC	6000–12000	215	7419	1595	12.6	41.9	14.2	25.2	211.3	0%
Total	Grand total	3791	2304	8736	13.6	27.6	10.0	19.7	64.5	34%

Source: *Container-ship Register* 2006, Clarkson Research Services Ltd, London

the bigger ships are generally used on long-haul routes where speed is an important aspect of the service. High speed brings a cost penalty in terms of fuel consumption and restricted hull design, since high speeds require a fine hull form. For short-haul trades where there are many port calls, speed is less important than economy and cargo payload. Conversely, on long hauls speed is highly productive, reducing journey times and the number of ships required to run a service. Whatever the economic justification, and it is complex, the relationship between speed and size in container-ships is clear.

Cargo-handling gear also varies with size, following a similar pattern to the bulk carrier fleet. Many of the smaller vessels carry cargo gear and the larger container-ships rely exclusively on shore-based cargo-handling facilities. In 2006, 29% of the Feeder vessels, 48% of the Feedermaxes, 53% of the Handy container-ships, and 43% of sub-Panamax container-ships had cargo gear, but only 9% of post-Panamax container-ships.

One of the most important ways of increasing container-ship versatility is to carry *refrigerated containers*, enabling the container companies to compete with reefer operators for the trade in meat, dairy products and fruit. This can be achieved by insulating the containers which have their own refrigeration units that plug into a power plug on the ship. If a substantial regular volume of reefer cargo is available (e.g., on the Australia to UK route), a central refrigeration plant may be built into the ship. This blows cold air through ducts into the insulated containers. At the loading and discharging ports the insulated containers must be stored in special refrigerated reception facilities or portable refrigeration plants are used. Containers with their own refrigeration plant can be plugged into electrical socket adjacent to each container slot. In addition to fast cargo handling, refrigerated containers offer shippers precise temperature control through the journey and a better-quality product, which in the case of fruit and vegetables may result in a higher selling price.[4]

Finally, there has also been much research into containers for transporting small bulk cargoes. These include the use of ventilated containers for agricultural commodities such as coffee and cocoa beans, tank containers for bulk liquids, and containers with special loading and discharging facilities for the fast automated handling of minor bulk commodities. As we saw in Chapter 13, bulk cargoes such as wool, rubber, latex, cotton and some forest products can now be containerized.

Other general cargo ships

Although container-ships dominate the transport of general cargo, in 2006 there was a fleet of 4717 other general cargo ship types operating in this market segment. The statistics are summarized in Table 14.8 which covers six ship types: ro-ro ships; MPP vessels; heavy lift; traditional liner types; tramps; and barge carriers. These fleet categories are not precise, since the dividing line between, for example, a liner type and a tramp is blurred. From the analyst's viewpoint this is a difficult segment because it has two different components. The first is a group of obsolete traditional liner vessels which, year by year, are being squeezed out by the more efficient container-ships. Liner types and tramps are obvious examples of vessels which fall into this category, and for them there is no question of replacement. But there is a second group of ships, possibly overlapping with the first group, which carry the cargo that container-ships cannot carry. Ro-ro vessels, MPPs and heavy lift ships all fall into this category. Unfortunately, in statistical terms we cannot precisely divide the fleet, but the consequences of this division are important for ship demand. Obsolete vessels will be replaced by container-ships, but the second group focusing on non-containerizable cargo is likely to continue to grow because there will always be a large number of cargos which do not conveniently fit in a standard container.

The key issue for vessels operating in these trades is the flexibility to carry containers, but the ability to also transport uncontainerizable general cargo which, for the reasons discussed in Section 12.6, cannot be transported in container-ships. Common examples are project cargos, forest products, palletized cargo, and wheeled vehicles. In the following paragraphs we will discuss seven different categories of ships which fall into this class.

RO-RO SHIPS

Cargo ro-ros offer a more flexible alternative to containerization for transporting a mix of containerized and wheeled cargo with cargoes ranging from mini-bulks in intermediate

Table 14.8 The general cargo fleet, by size and hull characteristics

Type	TEU '000s	Number	Av. TEU	Av. dwt	Age (yrs)	Av. speed (units)
Ro-ro	1,440	1,109	1,604	12,132	20	17.1
MPP	1,057	2,533	417	9,142	16	14.2
Heavy lift	15	40	364	18,031	21	13.9
Liner type	89	401	222	13,822	29	16.1
Tramp	93	624	149	8,970	16	12.9
Barge carrier	10	10	1,006	25,642	24	15.8
Grand total	2,703	4,717	627	14,623	21	15.0

Source: *Containership Register* 2006, Clarkson Research Services Ltd

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bulk containers and pallets through to heavy lift units of 90 tonnes. These are interesting ships and several designs were developed, but in concept the ro-ro is a cargo liner with 'through decks' and roll-on access by means of ramps, rather than via hatches in the weather deck. Key design features are access ramps, open decks allowing fast manoeuvring of fork-lift trucks, tractor/trailers and wheeled vehicles, good access between decks, and deck and ramp loadings for heavy cargoes. They are particularly suitable for carrying any cargo that can easily be handled by a fork-lift truck (pallets, bales, containers, packaged timber, etc.) and also for wheeled cargo (cars, loaded trucks or trailers, tractors, etc.). A major advantage of the ro-ro vessel is its ability to provide fast port turnaround without special cargo-handling facilities.

Apart from some Scandinavian devotees, ro-ros never found a market in the deep-sea cargo trades (though they were more successful in the short-sea passenger-cargo ro-ro market) and in 2006 the fleet of 1109 vessels had an average age of 20 years, suggesting that the fleet is not being replaced (Table 14.8). There were only two small vessels on order. Although ro-ros have never been adopted on the scale of cellular container-ships, the existing fleet continues to be used in some trades where the cargo mix and port facilities favour this type of operation, for example the Atlantic Container Line ships discussed in Chapter 12. The explanation for this poor performance seems to be that although ro-ros have highly flexible cargo capacity, with an LCM coefficient of 6, and can handle cargo efficiently even in ports with very basic facilities, this flexibility has a price that makes it unacceptable to investors. The ships have much less efficient stowage than container-ships and, since the cargo is more difficult and labour-intensive to secure, the loading times are generally slower. In addition, ro-ros are very management-intensive, requiring careful stowage planning.[5] However, their greatest disadvantage is that they lack the simple integration with other transport systems which is the chief asset of the container-ship fleet. As a result the ro-ro fleet is very much smaller than the container fleet, and even on routes such as the West Africa trade where suitable conditions exist, ro-ros account for only about 10% of the tonnage employed.[6]

MULTI-PURPOSE VESSELS

Where there is a continuing demand for flexible liner tonnage, MPP or lo-lo (lift on, lift off) vessels are used. Ships of this type are typically between 8,000 and 22,000 dwt with three to five holds, each containing a 'tween deck. The main difference from earlier traditional liners is that they are designed to carry a full load of containers as well as general cargo and heavy lift. This is achieved by designing the lower hold and the 'tween deck with dimensions compatible with containers and container cranes capable of 35–40 tonne lift. Table 14.8 shows that in 2006 there was a fleet of 2,533 MPP ships with an average size of 9,142 dwt and an average age of 16 years. The fleet grew at 2.6% per annum between 1996 and 2006 (Table 12.12), demonstrating that there is a positive demand which has become more apparent as the container business has matured.

In economic terms, MPP vessels are a compromise for use in trades that are partly containerized, especially for heavy and awkward cargoes which cannot be containerized, and their ability to pick up bulk cargoes helps to increase deadweight utilization.

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The downside is reduced efficiency handling containers, since they do not have cell guides and they are expensive to build. However, even basic MPPs often have a lateral cargo mobility rating of 5, with the ability to carry pre-slung cargo, palletized cargo, flats, containers, heavy and awkward cargo, and wheeled vehicles, but designs vary a great deal. Since there are many permutations it is useful to review some examples which illustrate the principal features of this ship type and how they can be varied.

An example at the top end of the size range is a 23,700 dwt MPP vessel aimed mainly at the container and packaged bulk cargo markets. It has a container capacity of 1050 TEU, five holds with mechanically operated 'tween decks and a relatively fast speed of 18.5 knots on 50 tons a day. The cranes are of 35 tonne and 26 tonne capacity, so this is quite a high specification. In addition to containers, the vessel can carry wood products, steel products, construction materials, general cargo and project cargo including yachts and heavy machinery. Fragile or non-unitized cargoes such as packaged consumer items, perishable produce and chemicals can also be accommodated and the ship has capacity for 150 refrigerated containers. Containers can be stacked up to four high in the holds and three high on the hatch covers, and the holds and open hatches are designed to accommodate containers of 20 ft or 40 ft in length.

Figure 14.4 shows outline drawings for a smaller MPP aimed more at the heavy lift and project cargo markets. It is 12,000 dwt and can carry 684 TEU. Two cranes capable of lifting up to 80 tonnes, a big open deck and removable 'tween decks allow it to service a whole range of project and heavy lift cargoes. This particular vessel has been designed to a gross tonnage of 8,999, to comply with the Dutch manning requirements, and it has a crew of 13.

Basically this is a single-deck open-hatch design, with two very long holds, hydraulic folding hatch covers, and a removable 'tween deck. The 'tween deck is made up of 15 panels which can be lifted out and stowed at the aft end of no. 2 hold when not in use. The design is heavily focused towards the transport of containers, carrying 372 TEU on deck and 312 TEU in the holds. Four tiers of containers can be stacked in the hold, two below the 'tween deck and two above, allowing mixed container and unit cargoes to be carried in the holds when the 'tween deck is in place. Another two to four tiers of containers can be stacked on the deck, with the height of the foreward tiers reduced for better visibility from the bridge. There are also 80 reefer plugs. Six rows of containers can be accommodated in the hold and seven rows on deck.

For project and heavy lift cargoes, the ship has two electric hydraulic deck cranes, each capable of lifting 30–80 tonnes (at 80 tonnes the lift is restricted to a 14 metre radius, whilst at 30 tonnes the radius extends to 32 metres). In order to leave the stowage space on deck open for project cargos, the cranes are built into the side shell (i.e. the double side – see Figure 14.4). This means that the ship has an open deck/hatch area over 100 metres long on which to carry project cargoes. An anti-heeling pump for use during cargo operations is located in the space between holds nos 1 and 2 along with air drying equipment.

The advantage of this arrangement is that the vessel can carry a mix of containers and general cargo in the hold, whilst having the option to carry heavy project cargos on deck, or a full load of containers if no such cargoes are available. Taken together, this

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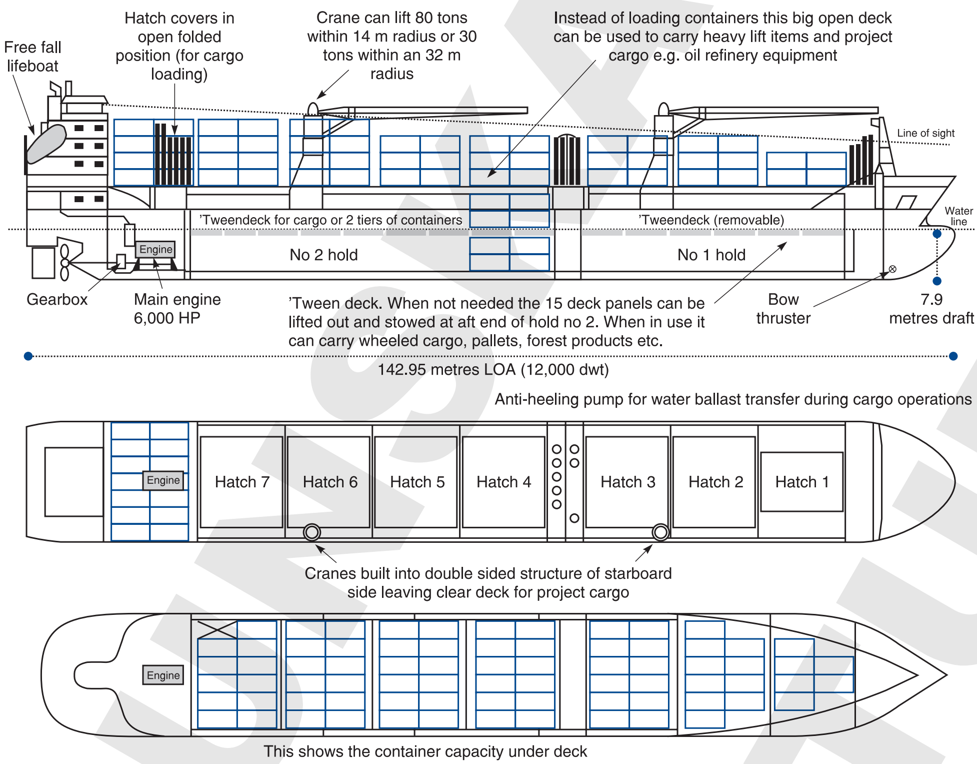

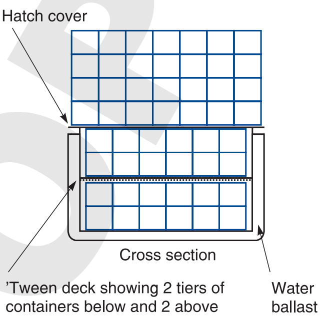

12,000 Deadweight MPP Ship

CAPACITY	HULL	PROPULSION & EQUIPMENT
Maximum TEU capacity: 684	Ice strengthened to class 1A	Engine: Caterpillar MaK
on deck 372	*dimensions*	Power output (hp): 6,000 4.4 MW
in holds 312	Overall length (m): 142.9	Gearbox: 1 output 121 rev/min
Reefer plugs: 80	Overall beam (m): 18.9	Propeller diameter: 5000 mm
	Depth, to main deck 10.95	Maximum speed (knots): 16
On deck: 4 tiers and 7 rows	Draft (m): scantling 8.08	Consumption: 25 tons/day
Below deck: 4 tiers and 6 rows	Draft (m): design 7.93	Bunker capacity:
TEU bays on deck: 8	Width of double side: 2.23 m	heavy oil 765 m^3
TEU bays below deck: 7	Height of double bottom: 2.00 m	diesel oil 105 m^3
Cargo capacity: 17,273 m^3	No 1 Hold (m): 40.9×15.8×10.5	Water ballast 4790 m^3
	No 2 Hold (m): 55.9×15.9×10.5	Alternator main engine driven: 1
Deadweight (scantling): 12,000	'Tween deck: 15 removable panels*	Alternators diesel driven: 3
Deadweight (design): 11,650	*cargo gear*	3×430 kW/1500 rpm
Gross tonnage: 8,999	Cargo cranes**: 2 Liebherr	Exhaust gas scrubbing plant
compliment	electric-hydraulic; cylinder luffing	Bow thruster 1×730 kW
Officers 8	Lift (tonnes) Radius	
Crew 5	80 14 m	hatch covers: hydraulic, folding
Suez crew 4	Max lift 40 28 m	Mooring winches: 2
	30 32 m	Anti-heeling pump: 1

*the 'tween deck panels stow at the aft end of hold no 2 when not in use. Can be used as grain divisions.
**crane structure built into double side, leaving deck and hatch cover space clear for project cargo.

Figure 14.4
Multi-purpose heavy lift ship, 12,000 dwt
Source: Drawing by Martin Stopford, based on Damen Shipyard Combi-Freighter design

offers a high degree of flexibility and good operating efficiency, but it is a very different design philosophy from the dedicated container-ship reviewed in Figure 14.3. Ships of this sort fill an important role in the shipping market and because they are generally expensive to build and require careful marketing to achieve the best mix of cargo, the business philosophy is very different from the deep-sea container and commodity trades.

HEAVY LIFT VESSELS

Heavy lift ships focus exclusively on large awkward cargo items. They range from items of industrial plant to offshore equipment, project cargo, and container cranes. As far as the ship design is concerned, there are basically three ways of dealing with heavy unit loads. The first is to lift it on and off the ship, generally using cranes with a high lifting capacity. MPP vessels with heavy lift capacity and ro-ros can carry unit loads of up to 100 tonnes, but there is a demand for small vessels capable of carrying much larger loads (e.g. up to 500 tonnes) or on routes where liner companies do not offer heavy lift capabilities. The second is to roll the cargo on or off the ship using a strengthened ramp, of the type fitted to some ro-ros. Modern vehicle carriers often have strengthened ramps and hoistable decks so that they can load heavy wheeled vehicles and industrial plant. The third is the float-on, float-off method in which the ship itself is submerged, allowing the heavy unit such as dredging plant to be floated on to the vessel for loading, and then removed in the same way. The market for these vessels is discussed in Section 12.6.

CARGO LINER TYPES

Finally, we come to the general cargo fleet, which in 2006 was 401 ships with an average size of 13,800 dwt and an average age of 29 years (Table 14.8). These are history, the last remnants of the multi-deck ships used in the liner services, for example Ocean's *Priam* class cargo liner built in the 1960s. They had 'tween decks for mixed general cargo, tanks for carrying liquid parcels, refrigerated capacity and could also carry small bulk parcels (e.g. minor amounts of ore, copra, steel) in the lower hold. Often they had cargo-handling gear with heavy lift ability, but little attention was paid to container capacity. Some are still in service but, needless to say, they are not being replaced.

'TWEENDECKER TRAMPS

The 'tweendecker tramps are simpler versions of the cargo liner types. In 2006 there were over 624 ships of 5.5 m.dwt in service. Typically these vessels range in size from 10,000 to 22,000 dwt and are essentially small bulk carriers with a 'tween deck so that they can carry a mix of general cargo and bulk cargoes such as grain. Since the mid-1950s, the rapid growth of parcel size in the bulk trades and containerization of general cargo has resulted in the 'tweendecker being replaced by MPP vessels, but the type is still used in some trades. In 2006 the average fleet age was 16 years and the average ship was 8970 dwt with a speed of 12.8 knots trading largely in the Third World.

BARGE-CARRYING VESSELS

The 1960s was a decade of great experimentation in the liner trades. The barge carrier was an extreme design developed to extend the benefits of unitization to the mini-bulk cargoes previously carried as bottom cargo. The concept involved grouping 'floating holds' (i.e. barges), generally of 400–1,000 tonnes, within a single ship. These barges could be filled with general cargo or small bulk parcels, making barge systems at least as flexible as the traditional cargo liner in terms of range of cargoes carried. The main design feature is the method employed for getting the heavy barges into the barge carrier – the LASH system used a shipboard crane, and the BACAT system floated the barges on to the ship. The barge carrier system has not been widely adopted. In 2006 there were only ten barge carriers, but not all were operating.

REFRIGERATED VESSELS

Refrigerated vessels (reefers) were developed in the late nineteenth century to carry meat from New Zealand and Australia to the UK (see Chapter 12 for a discussion of the trade). Reefer cargo is frozen or chilled, in which case the temperature is maintained just above freezing. To achieve this reefer vessels have insulated cargo holds with cargo handled horizontally through side ports and vertically through hatches.

Modern vessels have their cargo spaces designed for palletized cargo and there may also be reefer container capacity on deck or in the holds plus conventional container capacity. For example a 14,800 dwt vessel delivered in 2006 had 460,000 cubic feet of refrigerated capacity, 880 TEU, and 144 reefer plugs. The speed was 20.5 knots on 67 tons per day. For fruit and vegetables the cargo continues to ripen during transit, so the refrigeration system must maintain a precisely controlled temperature in all parts of the cargo spaces. Since fruit cargoes such as bananas are frequently loaded in developing countries with poor port facilities, there is often a need to make the ships self-sufficient in terms of cargo handling. Cars are often carried as a backhaul.

Although reefers dominated the refrigerated cargo trade, the fleet of 1,800 vessels is now very old, with an average age of 23.9 years (see Table 2.5). Refrigerated foods are increasingly transported in reefer containers.

14.4 SHIPS FOR THE DRY BULK TRADES

In the bulk cargo market, the focus is on low-cost transport. The bulk carrier fleet (Table 14.9) consists of over 6,000 vessels of 369 m.dwt. The fleet falls into four main parts generally referred to as Handy bulk carriers (10,000–39,999 dwt), Handymax bulk carriers (40,000–59,999 dwt), Panamax (60,000–99,999 dwt)[7] and Capesize (over 100,000 dwt). These ships carry a wide spectrum of bulk cargoes ranging from grain, phosphate rock, iron ore and coal, to parcels of chemicals, with a premium on economy and flexibility.

The bulk carrier

Nowadays the major bulk cargoes and the great majority of minor bulk cargoes are transported in bulk carriers. These are all single-deck ships with a double bottom, vertical cargo access through hatches in the weather deck and speeds generally in the range of 13–16 knots, though the average for most sizes is about 14.5 knots. Since the mid-1960s

Table 14.9 Bulk carrier fleet, February 2007, by size and hull characteristics

	Bulk carrier fleet size			Hull characteristics						
Size	No	Av.dwt 000s	Total dwt	Length m.	Beam m.	Draft m.	Speed knots	Cons. t/day	Cubic m^3/tonne	% geared
Handy										
10–19,999	611	15,679	9.6	136	22	8.7	14.1	22.5	1.22	73%
20–24,999	487	23,025	11.2	154	24	9.7	14.3	26.1	1.27	89%
25–29,999	820	27,627	22.7	166	25	9.9	14.3	28.6	1.28	93%
30–39,999	917	35,270	32.3	178	27	10.7	14.4	31.3	1.25	87%
Handymax										
40–49,999	969	44,761	43.4	182	31	11.4	14.4	30.4	1.31	94%
50–59,999	498	53,026	26.4	186	32	12.1	14.5	34.4	1.28	80%
Panamax										
60–79,999	1,292	71,350	92.2	218	32	13.4	14.4	36.7	1.18	7%
80–99,999	121	87,542	10.6	230	37	13.7	14.3	42.0	1.14	2%
Capesize										
100–149,999	173	137,714	23.8	257	43	16.6	14.2	49.8	1.10	2%
150–199,999	468	170,227	79.7	276	45	17.6	14.5	53.9	1.09	0%
199,999+	74	229,096	17.0	303	52	18.9	14.0	60.3	0.87	1%
Grand total	6,430	57,355	368.8	191	30	11.9	14.4	33.4	1.18	60%

Source: *Bulk Carrier Register* 2006, Clarkson Research Studies, London

there has been a steady upward trend in the size of ship used in most bulk trades. For example, in 1969 only about 5% of the iron ore was shipped in vessels over 80,000 dwt, but by the early 1990s over 80% of the trade was shipped in vessels of this size, mainly 150,000–180,000 dwt.

In fact the bulk carrier market has evolved into several different size bands, each focusing on a different sector of the trade, and as a result the ships in the bulk carrier fleet are spread fairly evenly across the size range, with the greatest concentration by numbers in the smaller sizes as shown in Table 14.9. At the smaller end of the range, Handy bulk carriers of 10,000–40,000 dwt fill the role of flexible workhorses in trades where parcel size and draft restrictions demand small ships. Typically they carry minor bulks and smaller parcels of major bulks such as grain, coal and bauxite and in busy maritime areas such as Asia can often complete two loaded voyages for every ballast voyage. This is a great improvement over the larger bulk carriers which often alternate loaded and ballast voyages.

As ports have improved over the last 20 years, a new generation of larger 40,000–60,000 dwt Handy bulkers has emerged, generally referred to as Handymax bulk carriers. Like the Handy bulkers, these vessels are generally geared. In the centre of the market are the Panamax bulk carriers of 60,000–100,000 dwt, which service the trades in coal, grain, bauxite and the larger minor bulk parcels. These medium-sized ships are named Panamaxes because they can transit the Panama Canal, but vessels at the larger end of the range are too big to do so, at least until the Canal is extended. The upper end is served by bulk carriers of 100,000–300,000 dwt, which are heavily dependent on the iron ore and coal trades. There is a good deal of interchange between these size groups and in the last resort the choice is a trade-off between unit cost and cargo flexibility: the small vessel is flexible but expensive to run, while the large vessels become progressively cheaper and more inflexible.

Bulk carriers are generally designed for cheapness and simplicity. Key design features are cubic capacity, access to the holds, and cargo-handling gear. Hold design is important because cargoes such as grain can easily shift and, if unchecked, can capsize the ship. To prevent this, bulk carriers generally have self-trimming holds in which the topside wing tanks are sloped in such a way that granular cargoes can be loaded by gravity without having to trim the cargo out into the wings of the hold.

On conventional bulk carriers, hatch openings are generally 45–60% of the beam (width) and around 65–75% of the hold's length. This arrangement has the disadvantage that hatch openings are too narrow to allow vertical access to all parts of the cargo hold, with the result that it is difficult to handle large cargo units such as rolls of paper, steel products, pre-slung timber, cars loaded in pallets or containers in a single operation. However, because the deck makes an important contribution to the structural strength of the ship, wider hatches can only be accommodated by adding structural steel to reinforce the vessel, considerably increasing costs. The hatch widths described above represent a trade-off between cargo-handling speed and building cost that has been found to work well in practice.

Most bulk carriers are fitted with steel hatch covers, of which there are several designs available. The self-supporting type is the most popular. Each hatch cover has four to six sections extending across the hatchway, with rollers operating on a runway. The covers are opened by rolling them to the end of the hatch where they tip automatically into a vertical position so that they are not in the way during cargo handling. Another consideration is whether or not to fit cargo-handling gear. Cargo-handling gear is normally fitted to smaller bulk carriers, since they are more likely to operate into ports with inadequate shore-based facilities. Table 14.9 shows that few bulk carriers over 50,000 dwt have cargo-handling gear, compared with 80–90% of smaller vessels. This is because the transport operations for bigger ships generally involve specialist terminals with purpose-built cargo-handling facilities so that they can turn around quickly.

The cargo gear is generally cranes, since derricks are now largely obsolete. A common arrangement for Handymax bulk carriers is to fit four 30- or 35-tonne cranes serving holds 1–4 and 5. Occasionally gantry cranes on rails are fitted, especially for the forest products trade, whilst continuous self-discharging bulk carriers take an even more radical approach to cargo handling. They use a shipboard conveyor system fed by gravity from the bottom of the holds. This allows them to unload cargo at rates of up to 6,000 tonnes per hour, though the high cost and the weight of the cargo-handling equipment mean that they are most economic in short-haul trades involving many cargo-handling operations.

The bulk carrier illustrated in Figure 14.5 is a 77,000 dwt Panamax vessel, one of the new generation with a double hull. It has seven holds, each with a grain capacity of around 13,000 cubic metres, or around 11,000 tonnes of cargo, depending on density.

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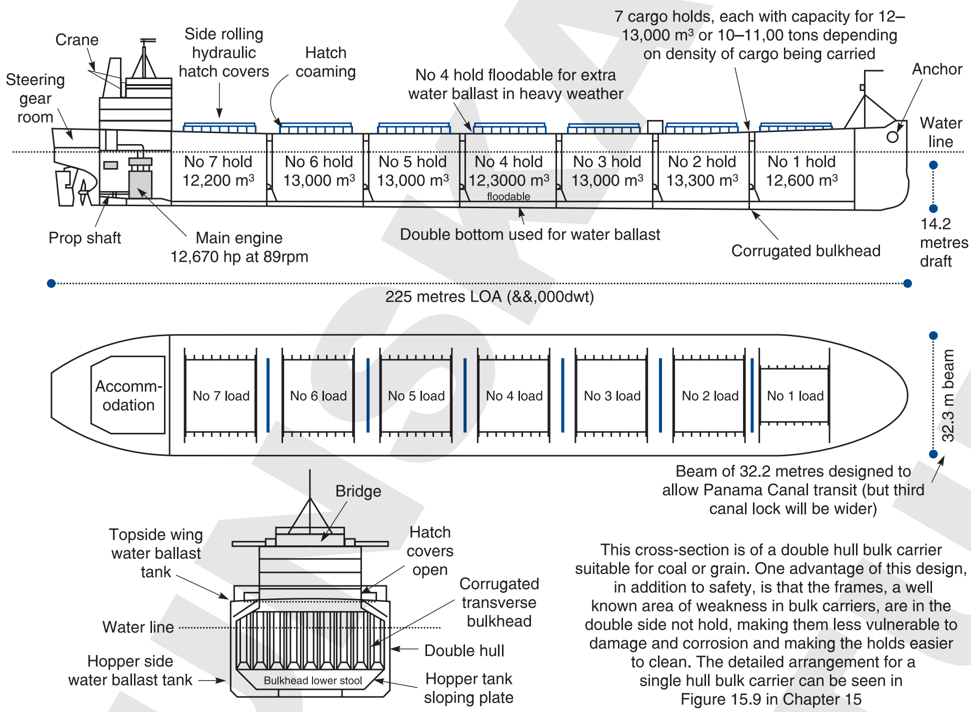

77,000 Deadweight Panamax Bulk Carrier

HULL	CARGO			MACHINERY & EQUIPMENT	
Deadweight (summer draft): 77,053	Strengthened for heavy cargoes			Engine: MAN B&W 5S60MC-C two-stroke	
Deadweight (winter draft): 75,073	Bale capacity: 89,121 m³			Power max (hp): 12,670@89 rpm (9.32 MW)	
Gross tonnage: 40,424	*hatches*			Power continuous: 10,135@83 rpm (7.45 MW)	
Net tonnage (international): 25,482	Hatch dimensions: 1 18.8×14.1			Maximum speed (knots): 14.5 (15% SM)	
	6 17.9×19.3			Fuel consumption: 35 tons/day	
dimensions (all in metres)	hatch covers: side rolling, hydraulic				
Length, overall (m): 225.0	*Cargo capacity of holds*			*auxiliary engines*	
Length between perpendiculars: 220.0		Grain 000 m³	000 tonnes	Generators: 2 AC generators 475 KVA	
Overall beam (m): 32.3	No 1 Hold:	12.6	10.5 at 1.2m³/t	Generator engines: 2×570 hp diesels	
Summer draft (m): scantling 14.19	No 2 Hold:	13.3	11.1 typical of	Aux boiler: 1 cylindrical composite boiler	
Winter draft (m): scantling 13.90	No 3 Hold:	13.0	10.9 coal	Emergency generator: 120 KVA	
	No 4 Hold:	12.3	10.3	Ballast pumps: 2 centrifugal type 800 m³/h	
tank capacities	No 5 Hold:	13.0	10.9	Fire pumps: 2 centrifugal type	
heavy oil 2,193 m³	No 6 Hold:	13.0	10.9	*Crew*	
diesel oil 145 m³	No 7 Hold:	12.2	10.2	Officers:	9
lubricating oil 114 m³	Total	89.5	74.6	Petty officer:	3
water ballast 37,164 m³	Holds, Nos 2, 4 and 6 may be empty			Ratings, pilot, 2 spare	14
	with dense iron ore in holds 1, 3, 5, and 7			Total	24 + 2 spare

Figure 14.5
Panamax bulk carrier (77,000 dwt), built 2006
Source: Drawing by Martin Stopford based on vessel built by Oshima Shipbuilding Co., Japan

The holds are separated by corrugated bulk heads and the hatch covers are very wide, about 60% of the beam of the vessel, giving improved vertical access to the holds. Since this is a Panamax vessel the beam is 32.3 metres, the maximum which can transit the Panama Canal (before it is widened). The vessel has a slow-speed two-stroke engine generating 12,670 hp at 89 rpm and the speed is a comparatively modest 14.5 knots on a consumption of 35 tonnes per day, which is normal for a bulk carrier. There are two AC generators driven by diesel engines, an auxiliary boiler and an emergency generator. In addition, the ship has two ballast pumps handling 800 cubic metres an hour and ballast water is carried in the topside tanks, the double bottom and hopper side tanks and a floodable hold for use in heavy weather.

The open hatch bulk carrier (conbulker)

There was a fleet of 480 open hatch bulk carriers in 2006 ranging in size from 10,000 to 69,000 dwt. They are designed to offer direct access to the hold through hatches which extend the full width of the vessel, allowing large cargo units to be lowered into place. Where possible the holds/hatches are designed around standard cargo unit sizes, including containers, with special attention paid to shipboard cargo-handling gear, and sometimes a gantry crane is fitted. All this is expensive because when the hatches are widened extra steel is needed to provide strength and the cargo-handling gear adds to the cost. As a result, a high-specification open-hatch bulk carrier can cost up to 50% more than a conventional vessel of the same size. Typically the 'open' hatches extend the full width of the vessel. This is particularly useful for forest products, which stow at anything from 2.3 cubic metres per tonne for pre-slung timber to 2.8 cubic metres per tonne for logs, and the heavy units are difficult to handle through the narrow hatches of a conventional bulk carrier or 'tweendecker. Open-hatch bulk carriers can also be used to carry containers on the outward leg, and dry bulk on the return leg which is particularly useful for repositioning empty containers between regions.

Woodchip carriers

Woodchip carriers have a high internal cubic capacity to accommodate the low-density woodchips. There were 129 ships in the bulk fleet in 2006 ranging in size from 12,000 to 74,000 dwt and typically cargo stows at around 2.5 m^3 per deadweight compared with 1.3 m^3 per deadweight for a general-purpose bulk carrier. Some are fitted with gantry cranes, though shore-based pneumatic handling equipment is often used.

Ore carriers

Ore carriers originally found a market because of the high density of iron ore, which stows at approximately 0.5 m^3 per tonne, compared with a normal bulk carrier's capacity of 1.3–1.4 m^3 per ton. They are built with holds designed for this high-density cargo, though general-purpose bulk carriers with strengthened holds or combined carriers are preferred owing to their more flexible trading opportunities. A few very large ore carriers have been built and some converted from single-hull tankers. In 2006 there were about 51 ore carriers in the fleet.

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Pure car carriers

Another trade for which specialized bulk ships have been built is wheeled cargo. This is a rapidly growing segment, with 594 vessels in 2006. Initially cars were shipped in cargo liners but, as the volume of seaborne trade increased in the 1960s, bulk shipment became economically viable. The first development was to fit bulk carriers with car decks that could fold up to allow other bulk cargoes to be carried – a classic combined voyage was cars from Emden to San Francisco, returning with grain to Rotterdam. However, the low carrying capacity of car bulkers (one car per 13 dwt), combined with the additional weight of the decks, the slow loading and a high risk of damage in transit, made them a poor compromise.

As the car trade grew in size in the 1970s, vehicle carriers were purpose-built to carry new cars and small commercial vehicles such as vans and pick-ups. They have multiple decks (anything from 4 to 13 depending on size) with a high cubic capacity to deadweight ratio (e.g. one car per 3 dwt), high speed (around 20 knots for the bigger ones), ro-ro loading/discharging facilities, and internal decks and ramps carefully designed to speed cargo handling and minimize damage.

The fleet varies in size and operation from ships of 499 grt with four decks each, carrying 500 cars in the European short-sea trades, up to Wallenius' *Madame Butterfly* of 27,779 dwt carrying 6,200 cars world-wide, though in 2008 the largest vessels on the orderbook were 29,000 dwt with a capacity of 8,000 vehicles. Specialization brought a cost in terms of restricting the cargo to motor cars and light trucks. With the more volatile market of the late 1970s there was a move towards developing vehicle carriers capable of handling a wider range of cargo. The *Undine* (2003) can carry 7200 cars on 13 decks. To carry large, heavy cargoes the stern ramp can carry loads up to 125 tonnes. Decks 4, 6 and 8 are strengthened and their height is adjustable by hoistable sections in decks 5, 7 and 9. This allows bulk parcels of cars to be supplemented by consignments of large vehicles such as trucks, buses, agricultural machinery and heavy plant, which cannot be accommodated between the low-headroom decks of a conventional car carrier.

Cement carriers

Cement is a difficult and dusty cargo to handle, and some specialist cement carriers have been built. Typically they use pneumatic cargo-handling gear with totally enclosed holds and moisture control systems. For example, a 20,000 dwt bulk cement carrier might have four pairs of cargo holds and be designed to handle two grades of Portland cement, with a weight of up to 1.2 tonnes per cubic metre. Shore-based chutes deliver the cement to a single-point receiving system on each side of the ship at a rate of 1,000 tonnes per hour. A dust collection system may also be fitted. The cement is discharged at a rate of 1,200 tonnes per hour using the ship's own cargo-handling gear. Aeration panels in the tank top of each hold fluidize the cargo, allowing it to be pumped out of the hold by blow pumps located in a pump room amidships and discharged to

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shore-based reception facilities using the ship's boom conveyor. In principle, ships like this can be used to carry any cargo with a fine particle size.

14.5 SHIPS FOR LIQUID BULK CARGOES

The transportation of bulk liquids by sea generally requires the use of tankers. The main types of tanker are for the transport of crude oil, oil products, chemicals, LPG and LNG.

Crude oil tankers

Oil tankers (Table 14.10) form by far the largest fleet of specialist bulk vessels, with over 6,000 vessels, accounting for 37% of the merchant fleet measured in tonnes deadweight. The size of individual tankers ranges from below 1,000 dwt to over 400,000 dwt; up to 1,245 feet (380 metres) in length; up to 222 feet (68 metres) in breadth; and drawing up to 80 feet (24.5 metres) of water.[8] This fleet can usefully be subdivided into six segments: small tankers (under 10,000 dwt), Handy (10,000–59,999 dwt), Panamax (60,000–79,999 dwt), Aframax (80,000–119,999 dwt), Suezmax (120,000–199,999 dwt, and VLCC (over 200,000 dwt). Each of these segments operates as a separate market and, from a ship design viewpoint, each has its own specific requirements.

Table 14.10 The tanker fleet, January 2006

Tanker fleet size					Hull characteristics				Performance	
Size 000 dwt	No.	Total dwt (mill.)	Av dwt	Age 2006	Beam m	Draught m	Capacity 000 bbl	Tanks (number)	Speed (knots)	Fuel cons (t/day)
Small										
1–5	921	2.6	2,783	19	12.7	5.1	19	11	12.2	7.9
5–9	1115	7.7	6,867	16	17	6.8	48	13.6	13	13
Handy										
10–19	728	11	15,051	14	21.7	8.6	106	16.5	14	22.5
20–29	313	8.3	26,611	19	25.5	10.3	201	19	14.7	29.9
30–39	589	21	35,626	13	28.8	11	254	18.1	15.1	37
40–60	740	34	45,895	9	31.8	12.1	320	13.4	14.7	34.1
Panamax										
60–79	325	22.6	69,466	11	32.8	13.4	482	10.9	14.8	39.1
Aframax										
80–120	721	72.9	101,100	10	41.7	14.3	702	10.9	15	46
Suezmax										
120–200	361	54.4	150,673	10	46.7	16.6	1,011	11.9	14.9	62.9
VLCC										
200+	488	142.7	292,412	9	58.4	21.2	2,040	14.2	15.3	85.7
Total/Av.	6,301	377	59,834	12.9	31.7	11.9	518	13.9	14.4	37.8

Source: Clarkson Research Studies, *Tanker Register* 2006, London

The Handy tankers under 50,000 dwt are mainly used for the transport of oil products (see the next section for details) and the larger vessels for the transport of crude oil.

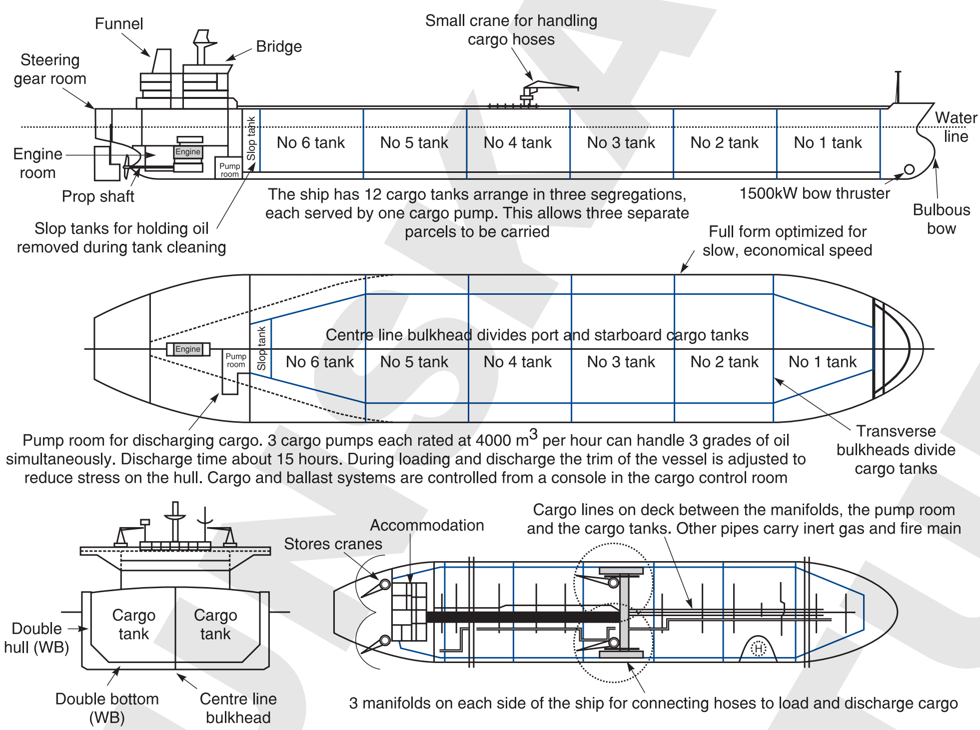
There are two different designs for oil tankers, single hull and double hull. Until the 1990s most crude tankers had a single skin, using the hull as the main containment vessel. The single hull design had longitudinal bulkheads running the length of the ship from the bow to the engine room, dividing the hull into three sets of tanks, the port wing tanks, the centre tanks, and the starboard wing tanks. Transverse bulkheads running across the ship divide these three sets of tanks into separate cargo compartments. In single-hull vessels two or more sets of wing tanks act as ‘segregated ballast tanks’, which means they are only used for ballast water.

Single-hull tankers are now obsolete. IMO Regulation 13F required tankers ordered after 6 July 1993 to have double hulls as a protective measure against oil loss. A typical arrangement is shown in Figure 14.6. The regulations lay down precise rules regarding the width of the double sides and the double bottom, but the principle is simple enough. There must be a second skin to limit the outflow of oil in the event of collision or grounding damage to the outer hull. In December 2003 IMO passed Resolution MEPC.111(50) to phase out all remaining single-hull tankers by 2010, though it allowed local administrations to permit continued trading on a bilateral basis.

Cargo handling is an important aspect of tanker design. Rapid loading and discharge requires powerful pumps. Crude tankers rely on shore-based facilities for loading, but carry their own cargo pumps for discharge. The pumps are generally located in a pump room between the cargo tanks and the engine room, though tankers carrying different cargo parcels in different holds often have submerged deep well pumps. Pipes running along the deck link the cargo tanks to two banks of manifolds, one on each side of the ship. To load or discharge cargo the manifolds are connected to the shore-based storage tanks by flexible hoses, or fixed Chicksan arms, which are handled by the ship’s cranes. The flow of oil is controlled by valves operated from a panel in the cargo control room and must conform to a plan which minimizes stress on the hull – an incorrect load or discharge sequence can literally break a ship in two.[9]

Figure 14.6 shows an example of a 157,800 dwt Suezmax tanker delivered in 2006. This is a medium-sized crude tanker, but the broad design features do not differ significantly for the smaller Aframax and the larger VLCC designs. The tanker has a double skin and scantling deadweight of 157,800 tonnes, with a cargo capacity of 175,000 m^3. However the design of the hull is optimized to a smaller 145,900 dwt, which would allow the ship to carry a 1 million barrel parcel of light (API 30) crude oil. This is a commonly traded parcel size and the arrangement gives the ship the flexibility to carry a full parcel of heavier crude oils than the design standard or extra cargo deadweight if necessary. This arrangement is very common in ships designed for the products trade where some cargoes such as naphtha have a very low specific gravity (see Table 11.5). It is all a matter of deciding what cargoes are likely to be carried and finding the best trade-off between tank volume and design cargo deadweight.

The hull was constructed using 53% high tensile steel, which is relatively high, but the structure was designed for a fatigue life of 40 years, with particular attention paid



Suezmax 157,800 dwt crude oil tanker (87,167 gt)

HULL		MACHINERY		OTHER	
Main Dimensions (m)		Speed & Main Engine		Navigation Equipment	
Deadweight (design)	145,900 dwt	Speed,	15.2 kts 15% sea margin	Radar plant	2
Scantling (scantling)	157,800 dwt	Engine Type	Man B&W 6S70MC-C	Auto pilot/Gyro compass	1
Length over all (m)	274	Power output	22,920 bhp×91 rpm (16.8 MW)	DGPS navigator	2
Length between perp.	264	NCR (90% DMCR)	20,630 bhp×87.9 rpm (15.2 MW)	Painting System	
Breadth, moulded (m)	48	D.F.O.C at NCR	60.5 MT/day	Under water hull:	epoxy anti-corrosive
Depth, moulded (m)	23.2	Cruising range	22,900 NM	Antifouling	+ Tin free SPC
Draught (design) (m)	16		Power Supply	Cargo tanks	Tar free epoxy
Draught (scantling) (m)	17	Main generators	Diesel: 3 Sets × 950 kW	Water ballast tanks:	Tar free epoxy
Tank Capacity (m^3)		Emergency generator	1 Set × 300 kW	(Bottom & up to 0.5 m deck head	
Cargo tanks inc. slop	175,000		Steam Generating Plant	and down to 1.7 m only)	
Heavy fuel oil tanks	4,300	Aux. boiler	: 2 Sets × 35 ton/h		
Diesel oil tanks	200	Economizer:	1 Set × 1.8 ton/h	Crew	28
Fresh water tanks	400		Water Ballast System	% high tensile steel	53%
Ballast water tanks	54,500	System	Two main line		
Cargo System		Pump	2 pumps × 2,500 m^3/h × 30m head		
Segregation	Three groups		Vertical centrifugal type		
Pump	3 Sets × 4,000 m^3/h × 135mc		1-Electric motor driven		
Vertical centrifugal, steam turbine driven			1-Steam turbine driven		

Figure 14.6
'Suezmax' crude oil tanker (157,800 dwt) design
Source: Drawing by Martin Stopford, based on design by DSME Shipbuilding Group, S. Korea

to known areas of weakness such as the end connections of the longitudinal stiffeners to the transverse webs and bulkheads. It has 12 cargo tanks plus two slop tanks, arranged in three segregations. Three steam turbine pumps are located in the pump room between the engine room and the cargo tanks. Each pump serves a separate segregation, allowing the ship to handle three grades of cargo simultaneously, which is useful for carrying a combination of smaller parcels and for multi-port discharge. The cargo tanks are coated with tar-free epoxy, another useful extra.

The speed of 15.2 knots on 60.5 tonnes per day is typical for a ship of the size, as can be seen from Table 14.10. Electrical supplies are obtained from three 950 kW diesel generator sets, with one smaller emergency back-up generator and two auxiliary boilers. In addition, a waste heat economizer is fitted, another useful extra to improve fuel efficiency.

A final and less usual feature of a tanker this size is its ice class 1A classification. This means the hull is strengthened and an ice knife is built into the stern. In addition, all deck equipment can operate at –30°C. For example, deck hydraulics are heated to prevent freezing and electric motors are used in preference to air motors. The ice class certification makes the tanker acceptable to charterers for trades where ice is a problem, and is more common on the smaller products tankers, especially those trading in the Baltic. However, new trades are developing, especially out of Russia, where the bigger ships can be used.

Products tankers

Products tankers form a separate category of vessel within the oil tanker fleet, but one which is not clearly defined in statistical terms because the distinction between crude, products tankers and chemical tankers is blurred. Products tankers are similar to crude oil tankers but generally smaller and are divided into clean products tankers, which carry light products such as gasoline and naphtha, and dirty products tankers, which carry the black oils such as fuel oil (see Table 11.5 for details) and a submerged cargo pump in each hold (deep well pumps), allowing separate grades of cargo to be carried on each voyage. Products tankers generally have tank coatings to prevent cargo contamination and reduce corrosion.

Chemical tankers

In Chapter 12 we reviewed transport of chemicals by sea and in Table 12.3 split the fleet into three categories of vessels – chemical parcel tankers, chemical bulk tankers, and chemical/products tankers. These categories, which are mainly based on the number of segregations in the ship, make a good starting point, but when we dig a little deeper we find at least six characteristics of this trade which influence ship design:

- Many different types of chemicals are shipped, including products such as vegetable oils, lube oils, molasses, caustic soda, BTX, styrene and a whole range of specialist chemicals (see Chapter 12).
- Values are high, often over $1,000 per tonne, and the products transported are sensitive to cargo contamination.
- Parcel sizes are small, ranging from 300 tonnes to 6,000 tonnes, with a few larger industrial chemical trades such as caustic soda and MTBE which travel in parcels of up to 40,000 tonnes.

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- Small parcels are frequently traded interregionally, and if a small chemical tanker of the appropriate size is used, the freight cost is very high, on a long journey from Europe to the Far East reaching as much as $150 per tonne.
- Some chemicals are corrosive and require special cargo handling and tank characteristics.
- Some chemicals are subject to the IMO regulations on the transport of hazardous cargoes, as discussed below.

Starting with the commodities, the chemicals to be transported vary enormously. The products carried by the chemical tanker fleet were discussed in Chapter 12 and include some bulk chemicals such as naphtha, BTX, alcohols and a large number of specialized chemicals, many of which travel in small parcels and require special handling because of physical characteristics which can damage the ship, the environment or both. In addition, liquid cargoes such as lubricating oils, vegetable oils and molasses fall into this trade group, along with cargoes such as molten sulphur which need much higher temperatures (80°C and above) than other cargoes. As a result, the design of chemical tankers involves many compromises to provide a design which will offer the right balance of cargo flexibility and capital costs.

In addition the ship design must comply with IMO regulations for the carriage of dangerous substances. Carriage of chemicals in bulk is covered by IMO regulations in SOLAS Chapter VII (Carriage of Dangerous Goods and MARPOL Annex II (Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk); see Chapter 16. Both conventions require chemical tankers built after 1 July 1986 to comply with the International Bulk Chemical Code, which gives international standards for the safe transport by sea in bulk of liquid dangerous chemicals, by prescribing the design and construction standards of ships involved in such transport and the equipment they should carry so as to minimize the risks to the ship, its crew and to the environment, having regard to the nature of the products carried. The ship must be capable of dealing efficiently with four hazardous properties of commodities transported: flammability, toxicity, corrosivity, and reactivity. Chemical tankers are classed as being suitable for the carriage of IMO Type 1, Type 2, or Type 3 chemical and oil products, depending on their design characteristics.

All of this leaves the designers juggling characteristics such as cargo tank size and segregations; heating coils; tank coatings; special valve operating gear; and safety systems. In addition to carrying many cargo parcels, chemical tankers tend to load and discharge at several ports, and often different berths within the port. To achieve this flexibility, each cargo tank has a separate cargo-handling system, allowing the ship to carry many small chemical parcels on a single voyage. Vessels operating in liner services on long-haul routes may have 30 or 40 segregated tanks, allowing them to carry a wide range of regulated cargoes. Tank coatings are used to deal with corrosivity and reactivity and three different tank protection methods are used – stainless steel for corrosive cargo and zinc silicate or epoxy coatings which suit most others. Tanks for the most toxic and pervasive substances classified as Type 1 by IMO must be located not

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less than one-fifth of the ship's breadth from the ship's sides, measured at the water line. All in all it is a complex business for both the investor, who must decide what level of sophistication makes commercial sense, and the designer, who must create a ship which will operate successfully for 20–30 years.

The main features of the sophisticated chemical tanker illustrated in Figure 14.7 will be familiar from the discussion of the crude oil tanker earlier in this section. The ship has a double hull with cargo tanks laid out either side of a corrugated longitudinal bulkhead, separated by corrugated transverse bulkheads. However, this chemical tanker has a number of very significant features which differentiate it from the crude tanker.

The ship is designed to carry IMO Type 2 cargos in 18 tanks and two slop tanks, all constructed from stainless steel with stiffeners on the outside (for example, they can be seen on the deck), giving smooth internal surfaces for easy tank cleaning and stainless steel heating coils to maintain the cargo at 82°C. Heavy cargoes with a specific gravity of up to 1.55, for example caustic soda, can be loaded in all tanks. Each of the18 tanks has a separate cargo-handling system with its own submerged cargo pump and separate pipelines to the manifold located amidships, where the cargo lines can be connected to hoses leading to storage tanks onshore. There are two cranes to handle the hoses and the manifold has ten hose connections, five on each side of the ship. All the pipes and valves are constructed of stainless steel, and five pumps can work simultaneously to discharge cargo through the five manifold outlets giving a total discharge rate of 1500 m^3 per hour.

Propulsion is provided by a medium-speed diesel engine operating at 500 rpm, with a gearbox which reduces the propeller speed to 140 per rpm. The operating speed is 14.2 knots on 20.5 tonnes of fuel per day, and electricity for ship equipment is provided by three diesel-powered alternators. There is also a shaft generator which provides electricity when the main engine is running. The gearbox also has a power 'take in' which in an emergency can use electricity from the three alternators to drive the vessel at 7 knots, or to top up the power of the main engine.

Since the vessel was designed to operate in the Baltic Sea, encountering ice regularly, it is ice class 1A. In addition to the features mentioned for the crude oil tanker in Figure 14.6, its deck cargo lines and valves are encased in a tunnel running from the poop deck to the enclosed forecastle, an unusual feature, but an interesting example of an owner paying for an extra feature that will make the ship easier and safer to operate in difficult weather conditions. In summary, this is a very sophisticated tanker, designed with specific operating conditions in mind, and the owner made a considerable investment to achieve this performance.

Combined carriers

Combined carriers deserve a section to themselves, if only as an example of the problems facing investors in ships for niche markets (see Section 14.2). To give the ships greater flexibility, oil/bulk/ore carriers (often referred to as OBOs or combined carriers) are designed to carry a full cargo of dry bulk or crude oil. This means the ships can

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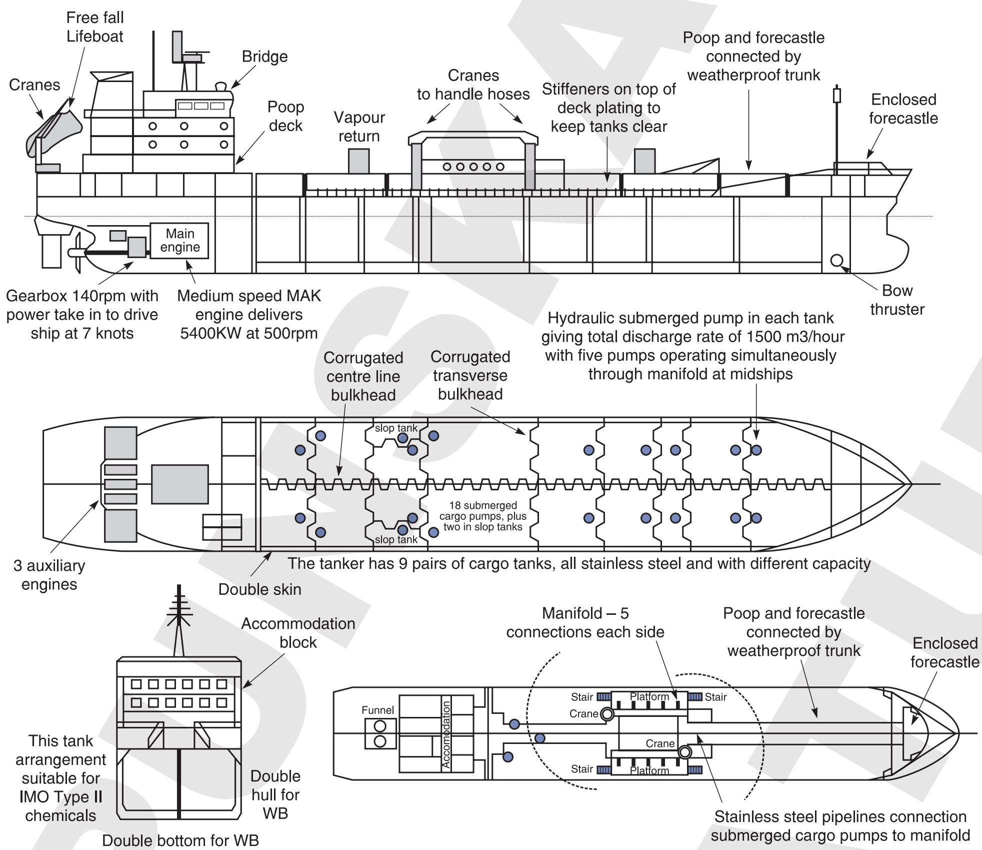

Chemical Tanker 11,340 dwt

HULL		MACHINERY		OTHER	
Main Dimensions (m)		Propulsion Machinery		Cargo System	
Gtoss tons	7,903 gt	Speed,	14.17 kts 90% MCR	Tank segregations	18 plus 2 slop tanks
Deadweight (design)	9,751 dwt	Engine Type	Caterpillar MAK 6M43	Tanks on deck	$2 \times 120\,m^3$
Scantling (scantling)	11,339 dwt	Power output	5400 kW at 500 rpm	Cargo grades	IMO II and oil products
Length over all (m)	126.2	Fuel Consumption – main	20.5 MT/day	Pumps (submerged)	18 plus 2 slop tanks
Length between perp. (m)	119.2	– auxiliaries	2.9 MT/day	Pump capacity	$14 \times 300\,m^3$/hr and $6 \times 100\,m^3$/hr
Breadth, moulded (m)	19	Cruising range	9,124 NM	Total discharge rate	1500 m^3 per hour
Depth, moulded (m)	10.7	Prop shaft	140 rpm	Vapour collector for shore return	
Draught (design) (m)	7.6	-shaft generator	1000 kW	2 tank washing appliances per tank	
Draught (scantling) (m)	8.34	-emergency prop motor	1000 kW	Stainless steel heating coils to maintain tanks at 82°C	
Lightweight (tonnes)	4,300	-main engine boost	5,400 kW + 1000 kW	Vertical centrifugal, steam turbine driven	
Tank Capacity (m^3)		Propellor diameter	4,600 mm	Fire extinguishing system	
Cargo tanks	12,120	Power Supply		Fire detection system	
Tank construction	Stainless, inc. pipes	Shaft generator	1000 kW at 1800rpm	Complement	
Heavy fuel oil tanks	550	Diesel alternators	3×660 kW at 900 rpm	Officers	6
Diesel oil tanks	162		3×600 kW at 900 rpm	Ratings	8
Ballast water tanks	4300	Power take-in on gearbox can drive ship at 7 kts		Spare	3
Paint System		Boilers	2×6 ton/h	Total	17
Under water hull: epoxy anti-corrosion				Class: Ice Class 1A	
Antifouling	+ Tin free SPC	Bow thruster	1×600 kW	High tensile steel	8%
Cargo tanks	Tar free epoxy				
Water ballast tanks:	Tar free epoxy bottom & up to 0.5 m, deck head and down to 1.7 m only				

Figure 14.7
Chemical parcel tanker, 11,340 dwt
Source: Drawing by Martin Stopford, based on vessel built by INP Heavy Industries Co. Ltd, S. Korea

triangulate, for example shipping oil from the Middle East to Europe and returning to Asia with a cargo of Polish coal. They could also switch between the tanker and dry bulk markets to take advantage of a rate differential, or to reduce ballast time by carrying dry and liquid cargoes on alternate legs ('triangulation voyages'). In practice, the rewards for flexibility have been slim.

The concept of flexible ships carrying oil on the main leg and returning with a different cargo date back to the early days of the oil trade and in general has not been very successful. The first ocean-going tank steamer, the *Vaderland* (1872), was designed to carry passengers from Belgium to the USA and return with a cargo of petroleum. Unfortunately the owners could not obtain a licence to carry passengers and oil in the same ship so the *Vaderland* ended up carrying general cargo in the petroleum tanks.[10] In the 1920s two ore/oilers, the *Svealand* and the *Amerikaland*, were designed to carry iron ore from Peru to Baltimore, returning with a cargo of oil. This time the plan was frustrated by the high transit charges for the Panama Canal and they never carried oil. However, in the 1950s and 1960s combined carriers achieved greater success, capitalizing on the newly emerging oil and dry cargo trades.

Two different designs were used. The first to enter service in the 1950s were the ore/oilers. These vessels had holds in the centre of the ship to carry high-density iron ore, with side and bottom tanks designed to carry a full cargo of oil. The use of separate compartments avoided the need for cleaning between cargoes, but was wasteful of space and the dry leg was limited to high-density iron ore. The second design, which appeared in the mid-1960s, was the OBO which carried oil or dry bulk in the same cargo spaces. Typically these vessels have double bottoms and holds to carry oil, of which up to six can be used for ore or dry bulk. Hatch covers are oil-tight and gas-tight. Because they could switch between wet and dry markets, they made handsome profits during the three tanker booms in 1967, 1970 and 1973 (see Chapter 2).

So great was the enthusiasm for combined carriers that by the mid-1970s a fleet of 49 m.dwt had been built. Unfortunately this fleet far exceeded the available return cargoes, so the competitive advantage was lost. In addition, the time and difficulty of cleaning the cargo holds when switching between oil and dry cargo made the vessels difficult to charter, especially to oil companies. The resulting indifferent commercial performance of combined carriers was compounded by the fact that the ships were complex to build, maintain and operate, costing about 15% more to run than a comparable tanker or bulk carrier and oil charterers preferred a conventional tanker. In the early 1990s operators of combined carrier fleets were reporting a 10–15% revenue premium (say $2,000–3,000 per day), which paid the extra cost of operating the ship, but left little surplus to cover the higher capital cost. To make matters worse, the large combined carrier fleet ensured that surplus capacity was transmitted between the tanker and dry bulk markets, helping to moderate market peaks. As a result, from the mid-1970s onwards few new ships were ordered and by 2007 the combined carrier fleet had fallen to 8 m.dwt. In retrospect the commercial failure of the combined carrier fleet had less to do with the concept, which was perfectly sound, than with the economic obstacles it faced in a competitive market such as shipping.

14.6 GAS TANKERS

Basic gas tanker technology

Transporting liquid gas by sea presents many complexities, one of which is the number of different cargo systems which are currently in use. So at the outset it is useful to define the various options available. The starting point is the containment system, and there are three options. The first is to use a 'self-supporting' tank system, which sits on a cradle which separates it from the hull. The second is the 'membrane' system which moulds the tank to the hull, which provides its strength, with insulation sandwiched between the tank membrane and the hull. The membrane must be able to cope with extreme temperature changes. The third option is the 'prismatic' system, which is a hybrid, using self-supporting tanks with an inner and outer skin, but tied into the main hull structure. Although the design details vary enormously, all gas tankers fall into one of these categories.

The gas is liquefied onshore prior to loading and there are three ways to keep it liquid during transport: by pressure;[11] by insulating the tanks; or by reliquefying any gas which boils off and returning it to the cargo tanks (petroleum gas remains liquid at around –48°C). In practice it is all a matter of economics, and various different permutations of refrigeration and pressure are used. Some small LPG tankers rely entirely on pressure, but this is uneconomic for large cargo parcels which use an on-board refrigeration plant to reliquefy boil-off gas and return it to the cargo tanks. Prior to 2006 LNG tankers did not carry refrigeration equipment, relying entirely on speed and heavy insulation to minimize the boil-off. Any burned-off gas was burnt in the ship's boilers.

Liquid petroleum gas tankers

The term 'LPG tanker' is confusing because gas tankers carry a mix of petroleum gases such as propane, butane and isobutene and chemical gases such as ammonia, ethylene, propylene, butadiene and vinyl chloride. Most of these gases liquefy at temperatures ranges from –0.5°C to –50°C (see Table 12.4), but some liquefy at much lower temperatures (e.g. ethylene at –103.9°C). Gas tankers must be able to maintain gas at the required temperature during transport. In addition to temperature, the volume of cargo and the distance over which it is transported are also important. For example, LPG is shipped in large volumes on long-haul routes, especially from the Arabian Gulf to Japan, and the biggest LPG tankers are built for these trades. From a design viewpoint the LPG tankers in common use can be divided into four groups, depending largely on the size of the cargo being shipped.

Fully pressurized vessels carry liquefied gas in pressure tanks strong enough to prevent the gas cargo regasifying, even at ambient temperatures – typically 20 bar is required. The tanks are very heavy and this method is mainly used for small LPG tankers. In 2006 there were 540 pressurized vessels in the gas fleet, ranging in size from 100 to 11,000 m^3. LPG and anhydrous ammonia are the most common cargoes, and the design pressure is optimized for propane at about 18 bar. Pressurized tankers have two to six cylindrical carbon steel pressure vessels resting on saddles built into the hull, or

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on deck. Cargo is carried at ambient temperature, and a compressor is usually provided to pressurize the cargo tanks during discharge or to transfer the cargo vapour when loading or discharging. Cargo handling is important because these short-haul ships make many port calls in a year. Because the cylindrical pressure tanks use the under-deck space inefficiently and are heavy, with a cargo to tank weight ratio of about 2 : 1, this system is mainly used for smaller ships.

Semi-refrigerated vessels have pressurized tanks constructed of carbon steel (typically 5–7 bar) with insulation to slow the boil-off and refrigeration plant to reliquefy the gas that escapes and return it to the tanks. These lighter-pressure vessels are located inside the hull (the cargo to tank weight ratio is typically about 4 : 1), and this is the preferred system for medium-sized LPG tankers. There were 280 semi-refrigerated ships in 2006, ranging in size from 1,000 to 30,000 m^3. Depending on ship size and specification, the cargo is carried at minimum temperatures of about −50°C. Cargo handling is an issue, and when cargoes are loaded from fully pressurized storage tanks on shore it may also be necessary to refrigerate the cargo during loading by drawing off the vapours from the top of the tank. This process usually determines the size of the refrigerating plant if a reasonable loading rate is to be maintained.

Fully refrigerated vessels are generally built for the long-haul trades. In 2006 there were 197 fully refrigerated LPG vessels, ranging in size from 1,000 m^3 to 100,000 m^3. For example, a typical 82,276 m^3 LPG tanker delivered in 2003 was 224 metres in length with a service speed of 16.75 knots. LPG weighs 0.6 tonnes per m^3, so it was only 59,423 dwt with a draft of 12.6 metres (a similar sized crude oil tanker would be 87,000 dwt with a draft of 15.6 metres).[12] Cargo is carried at –46°C in unpressurized free-standing prismatic cargo tanks built of heat-treated carbon steel or alloy with centre line and transverse bulkheads to prevent 'sloshing'. The space between the hull and the tanks is insulated. Refrigeration plant reliquefies the boil-off gas and a cargo heater may also be fitted for discharging to storage tanks not constructed of low-temperature materials. The liquid gas is discharged through thermally insulated land-based pipes using the ship's pumps.

Ethylene an important intermediate product of the petrochemicals industry, which liquefies at −104°C and usually travels in small *ethylene carriers* ranging in size from about 2,000 m^3 to 30,000 m^3 (see Section 12.3). These are sophisticated vessels and some can carry ethane, LPG, ammonia, propylene butadiene, vinyl chloride monomer and even LNG. The tanks are insulated and may be self-supporting, prismatic or membrane type. Impurities such as oil, oxygen and carbon dioxide must be kept within acceptable limits when pumping, refrigerating, purging and inerting the gas cargo.

The choice between these four systems is a trade-off between the initial cost, cargo flexibility and operating cost, but the pressurized system is generally more economic for small ships and refrigeration for big ones. Broadly speaking, petrochemical gases are transported in semi-refrigerated or fully pressurized vessels under 20,000 m^3, and LPG and ammonia gases are transported in fully refrigerated vessels, ranging in size from 20,000 to 80,000 m^3, for long-haul, large-volume transportation. Some semi-refrigerated vessels can carry ethylene (−104°C) and ethane (−82°C); and in a few cases LNG. To a lesser extent, these smaller vessels are sometimes used to transport LPG and ammonia over short-haul routes, where the fully pressurized vessels mainly operate.

Liquefied natural gas tankers

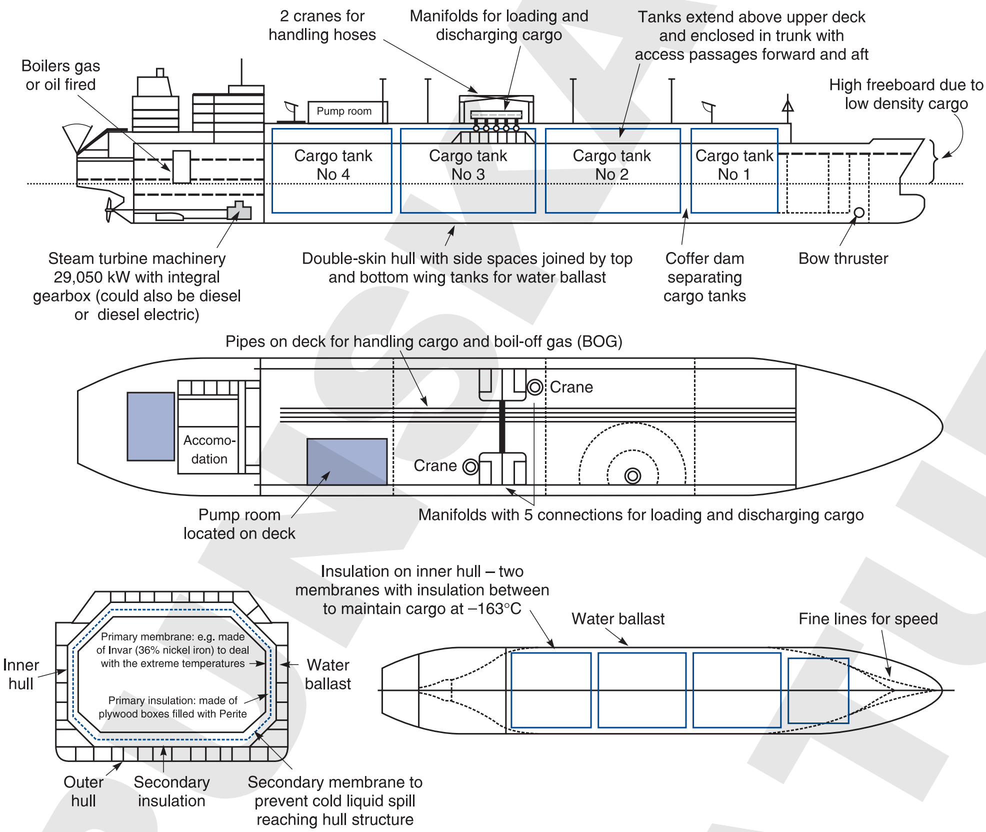
Natural gas is primarily an energy source. It is a high-volume commodity and very price-sensitive, so the cost of transport plays a major part in the trade's economics and ship design. LNG tankers generally form part of a carefully planned gas supply operation involving a substantial investment in shore-based liquefaction and regasification facilities. In 2007 there was a fleet of 240 vessels, with another 140 on order. These are the biggest gas tankers and in 2007 they ranged in size up to 153,000 m^3, with a new generation of 270,000 m^3 vessels on order for the long-haul Middle East to USA trades.

Natural gas liquefies at −161.5°C, at which temperature it is reduced to 1/630 times its original volume. However, this low temperature raises various issues for the ship designer. Before loading, the methane gas is liquefied by refrigeration in the terminal (the plant which does this is called a 'train') and pumped into the ship's insulated tanks at atmospheric pressure. Apart from keeping the gas at the required temperature, the tank system must be able to deal with the large temperature changes which occur when cargo is loaded and unloaded. LNG tankers rely on insulation and up to 0.3% of the cargo boils off per day. In the past LNG tankers did not reliquefy this gas as LPG tankers do, because of the high power required to do this.[13] Instead they burned it in the ship's boilers, which explains why steam turbines survived so long in this trade. Although less efficient than diesel engines, the boil-off provided 75% of the daily fuel consumption of a 75,000 m^3 vessel, making this an economic solution. However, the first LNG tankers with medium-speed diesel engines were delivered in 2006, and ships with reliquefaction plant and conventional slow-speed diesel engines in 2007.

Self-supporting, membrane and prismatic tank systems are all used for LNG tankers. The Moss system uses distinctive self-supporting spherical tanks with a single insulation layer. The membrane tank system offered by Gaz Transport has a primary and secondary thin membrane made of Invar (36% nickel iron) with insulation constructed of plywood boxes filled with Perlite, whilst the Technigaz system uses a stainless steel membrane. The two companies merged in 1994. IHI offers a prismatic system. In 2003 the Moss system had a 51% market share, whilst Gaz Transport had 37% and Technigaz 11%.

An example of an LNG tanker using the membrane system is shown in Figure 14.8. The vessel has a double skin with top and bottom wing tanks to carry water ballast. There are four cargo tanks separated by coffer dams and constructed in accordance with the GTT Mark 3 containment system for the carriage of LNG cargos. The tanks extend above the deck and are enclosed in a trunk which provides both protection and access passages.

The cargo tanks are moulded to the inner hull of the ship and insulated by the four-layer system described in previous paragraphs. A primary membrane protects the primary insulation, behind which is a secondary membrane and the secondary insulation which is attached to the ship's inner hull. With this level of insulation the boil-off gas is restricted to 0.15% of the cargo volume, and this is burnt in the ship's engine. However, some recent designs have reliquefaction equipment and return the gas to the cargo holds. It is all a matter of economics. The liquid gas is discharged using the ship's



LNG Tanker 145,600m^3

HULL		MACHINERY		OTHER	
Main Dimensions (m)		Propulsion Machinery		Cargo System	
Deadweight (design)	71,450 dwt	Speed,	20.6 kts 85% MCR	Cargo tanks	4 IMO Type 2 Membrane
Scantling (scantling)	81,450 dwt	Engine Type	Steam turbine	Pump type	submerged electric
Gross tons	95,508 gt	Power output	39,500 hp, 29,050 kW	Pump capacity	8×1800 m^3/hr
Length over all (m)	283	Main boilers	2×66 tonnes sleem/hour	Discharge rate	12,100 m^3/hour
Length between perp.	270	Consumption – main	171.1 MT/day	Boil off rate per day	0.15%
Breadth, moulded (m)	43.4	Cruising range	9,124 miles		
Depth, moulded (m)	26	Prop shaft	90 rpm	Bow thruster	1×2500KW
Draught (design) (m)	11.4	Propellor diameter	8,600 mm fixed pitch	Complement	
Draught (scantling) (m)	12.4	Power Supply		Crew	41
Lightweight (tonnes)	30,740	Turbo alternators	2×3450 kW at 1800 rpm	Suez crew	6
Tank Capacity (m^3)		Diesel alternator:-			
Cargo tanks	145,600	- engine	1×3664 kW at 720 rpm		
Tank construction	GTT Membrane	- alternator	1×3450 kW at 720 rpm		
Heavy fuel oil tanks	7,490				
Diesel oil tanks	440				
Ballast water tanks	57,000				

Figure 14.8

LNG tanker design with membrane tank system, 145,600 m^3 capacity, with steam turbine

Source: Drawing by Martin Stopford, based on vessel built by Samsung Heavy Industries Co. S. Korea eight submerged electric cargo pumps, each with a capacity of 1700 m^3 per hour, and the cargo can be discharged in 12 hours.

Propulsion is provided by a traditional steam turbine system. Two water tube boilers, which burn fuel oil or boil-off gas, provide steam to a reversible steam turbine engine. The gearbox is integrated with the turbine, outputting 91 rpm to the propeller. The service speed of the ship is 20 knots and the consumption is 171 tons of fuel oil per day. Although turbines are the traditional power source for LNG tankers, diesel engines and diesel electric systems are also used.

This LNG tanker is a very sophisticated and expensive vessel, but the broad features are similar to the other tankers discussed in this chapter. The big difference is the engineering skills, materials and technology required to load, transport and discharge a liquid cargo at a temperature of −161.5°C.

14.7 NON-CARGO SHIPS

Non-cargo and service vessels cover a wide variety of ships from a 200 grt tug to a 100,000 gt cruise liner. This makes it difficult to analyse the demand for each type with any authority. Although these vessels represent only 7% of the fleet in gross tonnage terms, they are much more important to the industry in value and number. Over 70% of non-cargo carrying vessels may be under 500 gt, but by number they make up nearly half of the world's shipping fleet.

The fishing fleet

Fishing vessels account for nearly half the non-cargo carrying fleet by tonnage. The fleet includes both fishing vessels and fish factories. The world fishing fleet grew rapidly at 15% per annum in the 1960s and then started to stabilize in the face of overfished oceans, escalating costs and the uncertainty of offshore limits.

Supply ships and service craft

Supply ships and service vessels such as anchor handling tugs are used in the offshore oil and gas industry, and in July 2007 there was a fleet of 4394 of these vessels. With the increasing depth and distance from shore at which the work is taking place, proportionally more and larger vessels are needed. There has also been a trend towards building more highly powered, sophisticated, MPP vessels, especially for use in the bad weather areas of the North Sea and Gulf of Alaska.

Tugs and dredgers

Tugs, dredgers and research craft form part of the fleet related to the coastal seabed activity, and there has also been a growing demand from harbour and canal authorities. One of the reasons for the faster growth was the change in trading patterns towards the developing countries and the use of larger ships. The growing interest in the resources of the seabed also generated a growing market for research, survey vessels and icebreakers.

14.8 ECONOMIC CRITERIA FOR EVALUATING SHIP DESIGNS

So far we have discussed the options that may confront a shipowner contemplating an investment decision. For the many practical reasons discussed, it is not easy to evaluate these options in financial or economic terms, and there is a temptation to suggest that ship design is a matter for commercial flair or 'gut feeling' rather than rigorous economic analysis. But despite this the commercial world expects such major investment decisions to be supported by some form of economic analysis.

There is substantial literature on the evaluation of alternative ship designs.[14] For practical purposes, the analysis needs to be carried out at two levels, which we will refer to here as market research and financial analysis.

Market research

Market research is concerned with analysing the economic performance of the ship within the company's overall shipping activities. For a charter market operator this analysis might involve an examination of the type of vessel that will be easy to charter and its potential resale value. A liner operator might study the size of ship required to handle changes in the pattern of trade or competition on major routes and features such as speed and reefer capacity. This is closely aligned to the market research analysis described in Chapter 17. Through market research the owner can develop a specification for the type of shipping operation in which the vessel is to be used and the performance parameters that the vessel must satisfy.

Financial analysis

The next step is to identify the ship design that meets the performance requirements most effectively, using some form of financial measure of merit. For example, the designer may be told that the owner requires a product tanker with the following features: a draught of not more than 10 metres; a length of not more than 170 metres; ability to carry simple chemicals such as caustic soda; cargo tanks that are cheap to clean; an operating speed of 14 knots; and design optimized to a 40,000 ton cargo of naphtha, but capable of carrying a 45,000 dwt of denser cargo. Although this list of requirements appears to be highly specific, in practice there may not be a unique solution. On examination, it may transpire that some of the requirements are inconsistent or very difficult to achieve. For example, it may be difficult to achieve the design draught within the other specified parameters, or doing so may result in a vessel with poor fuel economy. Did the shipowner appreciate this when he laid down the specification and is he prepared to pay the cost? These are all issues that have to be tackled at the operational analysis stage.

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The task of the ship designer is to evaluate the various options in economic terms to see which gives the best overall result, recognizing both cost and operational performance. Buxton suggests two different ways of doing this, depending on the circumstances, net present value and required freight rate.[15]

The net present value technique, which is discussed in Section 6.7, involves setting up a projected cashflow for each of the options under consideration. Revenues and costs are projected on an annual basis over the life of the ship and the net cashflow in each year is calculated, taking account of capital payments, trading income, expenditure, taxation (if any) and probably the final resale value of the vessel. These annual cash-flows are then discounted back to the present (using a minimum acceptable rate of return, for example 10% per annum) and summed, giving the NPV of each of the options. The option giving the highest NPV is generally preferred.

The advantage of this method is that it takes account of both the cost and revenue flows and produces a single figure, which makes the comparison of options a simple matter. On the negative side, if the revenue flow is difficult to predict, especially for vessels trading on the spot market, with the results that some near-arbitrary assumption about the potential earning power of the vessel is made, this can distort results. For this reason, the NPV approach is most appropriate when evaluating ships being constructed for a long-term time charter.

The required freight rate method avoids the problem of predicting revenue by comparing the relative unit transport cost of different ship types. The RFR is calculated by computing the annual average cost of running the ship (operating plus voyage costs), adding the capital costs and dividing by the annual tonnage of cargo transported to calculate the cost per tonne of cargo. These costs can then be discounted in exactly the same way as the NPV calculation and a discounted RFR calculated. There are several different ways of carrying out this calculation, but all aim to show which ship design will give the lowest unit transportation cost within the parameters specified by the owner. It is left to the investor to weigh up whether the project has a reasonable chance of earning enough revenue to cover the RFR. This may be an absolute evaluation, or used for comparing alternative designs or investment projects. For example is it better to order a new floating production, storage and offloading system or to buy a second-hand tanker and convert it? Although there are many very subjective variables in such an analysis, the process of working through the financial comparison can help to clarify the decision.

There are several variations on these two methods, notably the yield or internal rate of return, which is closely related to the NPV method (being the interest rate that produces an NPV of zero), and the permissible price (i.e. the maximum price payable for a ship to yield the required rate of return), which can be derived from either method.

14.9 SUMMARY

This chapter has reviewed the ships used in the shipping business. We started with two important observations. First, because the demand for merchant ships is derived from

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the demand for transport, we cannot determine the demand for merchant ships simply by examining the cargo flows. Shipowners are free to use whatever ships they think will provide the service most profitably. We must consider a wider range of economic factors which include the type of cargo, the type of shipping operation and the owner's commercial philosophy. Second, ship types should not be viewed in terms of physical design characteristics. From the shipowner's point of view, ships of the same type are substitutes in the market place. In particular, size plays an important part in determining ship type.

An examination of the relationship between cargo units and ship types shows that some ships, such as the MPP cargo liners or ro-ros, are highly flexible and capable of carrying six or seven different types of cargo units, while others, such as the container-ship, the gas carrier or the crude oil tanker, are highly specialized and are capable of carrying only one cargo. In terms of the revenue maximization calculations described in Chapter 3, the flexible ship has a better chance of achieving a high level of loaded days at sea and deadweight utilization because it is capable of carrying many different cargo types. The cost of this flexibility occurs in terms of higher capital cost per unit of capacity and, in some cases, lower operating efficiency than the more specialized vessel. Recently the trend has been decisively towards specialized ships with low LCM ratings.

In the liner business, the three main types of purpose-built vessels are container-ships, MPP cargo ships and ro-ros. Most of the ships employed in the liner trades are purpose-built within these general categories. There used to be an enormous number of different and unique ship specifications designed to fit particular trades, but container-ization has brought a high degree of standardization to ships used in the liner trades. There are still a few ships in the fleet designed for cargo flexibility, notably the MPP ships which can carry general cargo, project cargo, containers and even dry bulk. The popularity of these ships with investors declined during the 1980s, but the fleet has started to grow again.

In the dry bulk market, the trend towards single-purpose vessels continues. The general-purpose bulk carrier dominates the business, despite being restricted to the carriage of dry bulk cargoes and specialized bulks such as forest products and steel products. More flexible dry bulk vessels are the 'tweendecker which can trade either in bulk or general cargo; the open-hold bulk carrier which can trade in homogeneous dry bulk; containers and specialized bulks such as forest products; and the combined carrier which can alter-nate between dry bulk and crude oil and other liquids. All have been losing market share, especially the combined carrier.

Finally, there is a range of specialist ships designed for the bulk transport of specific cargoes. The most prominent of these are liquefied gas carriers, refrigerated cargo ships, car carriers, heavy lift ships, and cement carriers. In some cases, such as gas carriers, these ships are totally specialized and are in competition only with other ships of the same type, whereas others, such as the refrigerated cargo ship, the car carrier and the heavy lift vessel, face competition from MPP vessels.

The key point in all of this is that most cargoes can be transported in several different types of ship. In the last resort, the ship in which the cargo travels is determined by commercial performance rather than its specific technical design characteristics.