Operating and Maintenance Features of Container Handling Systems

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Chapter 1

INTRODUCTION

1.1 Preface

1.1.1 These training materials deal with the main operating and maintenance features of container-handling equipment. They have been developed for World Bank staff involved in the preparation and appraisal of port projects which include investment in container-handling systems. The materials will also be valuable to those senior policy makers and managers in the governments and port authorities of developing countries who are involved in the selection of equipment and the preparation and appraisal of projects submitted to the World Bank and other international lending agencies.

1.1.2 The desired outcomes of the training are a more informed and productive communication between the principals involved in port container investment projects and an improvement in the equipment selection process. The materials will also focus attention on the equipment management function and assist port authorities and terminal operators to select the most appropriate equipment for the operating conditions and maintenance capabilities of their ports.

1.1.3 The material is presented in two forms: a videotape of 10-20 minute segments, each dealing with one of the featured equipment types, and this reference text presenting full details of the equipment in readily accessible format. The equipment covered includes all the major types used on dedicated container terminals: quayside gantry cranes, straddle carriers, rail-mounted and rubber tyred yard gantry cranes, tractor-trailer units and lift trucks ('front-end loaders').

The materials have been prepared for individual use. The video material can be viewed segment by segment or in its entirety as convenient, and followed up by reading the relevant sections of the manual and consulting further publications listed in the bibliography. The text format is designed to assist the search for technical details and the rapid and sure evaluation of proposals and plans. The videotape can also be carried on overseas missions, for showing to representatives of governments and port authorities as an aid to discussion.

1.1.4 The videotape and the reference text are organized in the same way, as a sequence of separate numbered Sections, each dealing with one type of container handling equipment. Within each Section, the information is organized into seven subsections:
1. an introductory description of each major container-handling equipment type and its application, origin and development;

2. the equipment specification;

3. the operating features of the equipment, including manning and deployment;

4. equipment performance, including estimates of asset life and annual operating costs;

5. its maintenance - facilities and costs, component reliability and engineering manpower skills;

6. features to look out for in procuring that type of equipment, including safety considerations and required driver skills;

7. a review of future equipment trends and developments.

The final chapter of the text reviews the major features of each type of equipment and system, and offers a series of tables and comments to assist in evaluating equipment selection.

1.1.5 Several sources of information have been used in compiling these materials. The principal sources of specific operating and maintenance data (and in particular costing) have been the responses to an extensive questionnaire which was distributed to leading port authorities and container terminal operating companies in North-West Europe: Europe Container Terminus BV (Rotterdam), Felixstowe Dock and Railway Company, Port of London Authority (Tilbury), Port of Bremen (PTC), Port of Antwerp (Gylsen and Hessenatie) and Gray Mackenzie Overseas Ltd. (Port Rashid). These data have been supported by a search of published material, particularly surveys undertaken by the technical press (notably Containerisation International and Cargo Systems). Other sources of information have been consultants' reports, literature from and correspondence and conversations with equipment manufacturers, and publications of such agencies as the United Nations Conference on Trade and Development (UNCTAD) and the International Cargo Handling Coordination Association (ICHCA). A bibliography is provided at the end of Chapter 8.

1.1.6 The data, inevitably, relate primarily to operating conditions and practices in North-West European ports (though the published surveys covered all areas of the world). In particular, all capital and operating costs (expressed in US$ at 1987 prices) are Euro-orientated, and the extent to which such data are relevant to conditions in developing countries must be taken into account. However, it is felt that the collective experience and knowledge of European ports, extending over two decades, are relevant and, suitably interpreted, can provide a useful basis for senior port officials and Bank staff in evaluating and procuring container-handling equipment.

1.1.7 The remaining sections of this Introduction briefly survey the background to the current importance of cargo-handling equipment in ports, define the relevant equipment types, introduce some important operational considerations and discuss the validity of the data collected in this exercise and the terms and definitions used.
1.2 Background

1.2.1 Maritime transport has experienced unprecedented developments in the past two decades, stemming from an enormous expansion in international seaborne trade, major advances in technology and significant changes in the legal and institutional framework of shipping and related industries. Foremost among technological developments has been containerization, which has expanded rapidly since the early 1970s: world container traffic increased five-fold, from 47 million tonnes to over 400 million tonnes, between 1970 and 1986 an annual growth rate of 15%. Over the same period, the container ship fleet grew by 18% a year and its capacity rose from 195,000 TEUs ('twenty-foot equivalent units') to 2.57 million TEUs, while the world's population of containers increased from 450,000 to 4.78 million TEUs - a mean annual growth rate of 20%.

1.2.2 Nowhere has the impact of containerization been greater than on ports and the way they handle container ships and their cargoes. Container handling in ports grew by 14% a year between 1970 and 1986, from about 7 million TEU to 56 million TEUs - eight times the 1970 figure. This did not affect the ports of developing countries too severely in the early days, since much of their unitized cargo arrived in conventional vessels and used existing port facilities, but then containers and new container ships began increasingly to reach routes serving developing countries so that, by 1986, developing countries handled over 35% of the world's container traffic. The process of containerization is still continuing today, at a significant rate, in the ports of the world; consultants forecast an annual port throughput of 115 million TEUs in the year 2000.

1.2.3 This rapid change to container handling is placing considerable pressure on port authorities and cargo-handling organizations in developing countries. They are rapidly having to provide new facilities, adapting existing berths, or constructing or expanding container terminals, to meet shipowners' needs. Deep-water entrance and approach channels have had to be dredged, new quay walls constructed and larger land areas provided for storage and cargo handling. New cargo-handling practices have had to be introduced, much more dependent on expensive equipment than conventional traffic, often with a degree of automation and much less reliant on manpower.

1.2.4 Container terminal operations are totally dependent on high capacity, specialized handling equipment. For example, a terminal designed to handle second or third generation cellular container vessels (those capable of carrying up to 3000 TEUs) and with a relatively modest annual throughput of 250,000 TEUs, may have a total investment in equipment alone of over US$30 million. Operating and maintaining that equipment is a further enormous expense - perhaps $6-9 million a year. The total life cycle cost of one straddle carrier can exceed $3 million, while that for a quayside container crane can be as much as $16 million. Nevertheless, ports have no option but to provide this specialized equipment if they are to meet the needs of containerization and remain competitive.

1.2.5 But what equipment types and capacities should a terminal select and how many units does it need? Manufacturers offer a very wide range of equipment suitable for different types and scales of terminal activity, and
designs continue to evolve rapidly - provision for semi-automated or even fully automated operation is already available. Correct selection depends on, among other factors, the trading patterns of the port, the available land area, civil engineering factors, and the port's ability to operate and maintain the equipment safely and efficiently. Today's longer asset lives, continual developments in the design and specification of equipment, technological change in shipping and containers, all combine to make investment in equipment a high-risk activity.

Clearly, container equipment selection and procurement is a difficult matter, and it is easy to make wrong decisions. Yet the benefits to seaports of containerization will never be fully realized if an adequate stock of the right type of equipment is not provided, and if it is then not operated and maintained well. Box handling rates will be low, so that unit costs and ship's time in port will be high. Shipowners may decide to bypass the port or leave older ships on those routes, so that shippers will not be able to obtain competitive freight rates; the country's imports will be more expensive than they should be and its exports will be uncompetitive as they enter international seaborne trade.

1.2.6 Despite decades of assistance by international agencies and foreign governments, the problem of equipment management in the ports of developing countries is actually becoming more serious, threatening the ability of many ports to meet their trading obligations. Often, the wrong type of equipment has been purchased for the volume and nature of the terminal's trade, or there is an unsatisfactory mix of units, causing operating and maintenance problems. Availability of equipment is poor and Downtime high, because of poorly planned and executed preventive maintenance schemes. There is insufficient provision for spare parts and lax spare parts control. Obstructive bureaucratic and government procedures limit the ability of port authorities and terminal operators to replace equipment and obtain spares quickly. Maintenance workshops are often unsuitable or inadequately equipped, good engineering practices are not established, staff are poorly trained, so that equipment is not properly maintained and repaired and has to be scrapped prematurely. Management does not collect data regularly, and has no management information system to monitor the performance of equipment and to assist in formulating procurement policies and replacement strategies.

1.2.7 The poor standard of management of equipment procurement, operation and maintenance is the single most serious problem on container terminals in developing countries. When investment proposals for container terminals are being evaluated, these issues have to be very carefully considered, to ensure that the suggested system best meets local operating conditions, and to check that appropriate steps have been taken by the port to ensure that the equipment will be properly operated and maintained. Facilities, staff skills and working practices may all have to be reviewed and improved. To evaluate such issues effectively, a comprehensive knowledge is needed of the operating and maintenance features of the alternative container-handling systems and equipment.

1.2.8 The World Bank is a major source of funding for port and harbour development. A typical Bank lending operation for port development will have as its main components civil works, equipment, technical assistance and training, and funding for further studies or engineering. A review of the past five years' lending operations shows that there were 29 port and harbour operations with a total cost of US$3829 million, of which $1109
million (29%) was for port equipment. The average project cost is about $132 million, with an equipment component of $38 million. Knowledge of the characteristics of port equipment is vital to the staff of the Bank associated with port lending operations, and also for the staff of the Bank's borrowers - port authorities, etc. Although the Bank's borrowers will normally have consultants to advise them on the numbers and type of equipment needed, the final decision has to be made by port managers in agreement with Bank staff. The primary aim of these training materials is to present to those staff the basic information needed for making informed decisions on equipment investment.

1.3 Container Handling Systems

1.3.1 A considerable variety of equipment is used for handling containers in ports, and terminal design, layout and operations differ accordingly. At the quayside, containers can be handled to and from the ships by jib cranes, multipurpose cranes, gantry cranes and even mobile cranes. In the present context we are concerned solely with purpose-built container terminals handling specialized container ships, and in that circumstance need only consider quayside gantry cranes (also known as container cranes or by Paceco's brand name, 'Portainer'). Quay transfer may be handled by tractors towing trailers, by straddle carriers or by heavy-duty lift-trucks ('front-end loaders'). In the container yard, stacking and unstacking may be carried out by straddle carriers, yard gantry cranes or a variety of lift-truck designs, while receipt-delivery operations may also involve those equipment types, as well as tractor-trailer systems.

1.3.2 In operational terms, it is usual (and useful) to think in terms of container handling systems, each a combination of equipment types working together to perform the shoreside handling function. Six systems can be conveniently distinguished:

1. the Tractor-trailer System, in which containers are both handled and stored on 'over-the-road' chassis or terminal trailers, which are moved around the terminal by heavy-duty tractor units;

2. the Straddle Carrier Direct System, in which quay transfer, stacking and other duties are performed by straddle carriers;

3. the Straddle Carrier Relay System, in which straddle carriers are responsible for in-yard stacking and unstacking, while quay transfer and other movements are performed by tractor-trailer sets or other equipment;

4. the Yard Gantry System, where the container yard is equipped with rubber-tyred or rail-mounted gantry cranes for stacking/unstacking, with tractor-trailer units for quay transfer and other movements;

5. the Front-end Loader System, either entirely performed by heavy-duty lift-trucks of one sort or another - a 'Direct' system - or with other equipment for quay transfer, in a 'Relay' system;

6. Combination Systems, various 'hybrid' combinations of straddle carriers, yard gantry cranes and other equipment, with more than
one type of stacking equipment in use at a time, each carrying out a function to which it is best suited.

1.3.3 In the present context we are concerned with the major types of handling equipment, rather than the details of the procedures and practices of handling systems, and so, in the chapters that follow, we shall consider separately in turn the following types of equipment: quayside gantry cranes, straddle carriers, rubber-tyred yard gantry cranes, rail-mounted yard gantry cranes, terminal tractors and trailers, and lift-trucks (front-end loaders and reach-stackers).

1.4 The Terminal as a System

1.4.1 The distinctive feature of a specialized container terminal is its sheer size; very large land areas are required for the stacking of containers and their movement through the terminal. The quay wall, if the terminal is to accommodate third-generation cellular container vessels, up to 290 m in length, is normally 300 m long for a single, deep-sea 'unit', while 500 and 750 m would be the respective accepted lengths of 'two-unit' and 'three-unit' terminals. The water depth at the quay must be sufficient to accommodate the draught of these large vessels - up to 12 m when fully loaded. On the quayside is a wide area for landing import containers and marshalling export containers prior to loading; it needs to be free of obstructions, to allow the unimpeded movement of large units of equipment. Behind the marshalling area is an extensive stacking area - the Container Yard - taking up to 60 or 70% of the total space of the terminal.

1.4.2 The container yard is used primarily to stack containers awaiting onward movement. It is set out in a series of well-marked and numbered blocks, linked by access roadways and aisleways for the movement of equipment; the actual layout of the yard depends on the type of handling equipment used. Some stacking areas are set aside specifically for 'special' containers: refrigerated and controlled-atmosphere containers requiring an electricity supply; overheight and out-of-gauge containers; hazardous-cargo containers. Import and export areas are distinguished, as are areas for empties, to separate these activities as far as possible.

1.4.3 Where a high proportion of LCLs ('less than container load' boxes) pass through the terminal, a consolidation shed or Container Freight Station (CFS) is commonly provided within the terminal, although the trend in Europe is to move the CFS out of the terminal area altogether; there are good operational arguments to support this. It is in the CFS that import LCLs are unpacked and the separate consignments stacked for collection, and that export consignments are consolidated into empty containers.

1.4.4 Movement into and out of the terminal is via a gate complex, where documentary, security and container inspection procedures are undertaken. A rail reception/dispatch terminal may also be located in some suitable area of the container terminal. Good access roads and parking areas are provided, and also, in some types of terminals, designated points (interchange areas or 'grids') at which road vehicles can deliver and/or collect their containers. Finally, there are maintenance and repair workshops, offices and a control room or tower from which
operations are coordinated and controlled. Weighbridges, trailer parks and other miscellaneous facilities take up their space, too, so that the total surface area of a container terminal is very extensive indeed.

1.4.5 Handling operations within a container terminal consist of a series of distinct, inter-dependent activities, their nature depending on container status - FCL ("Full Container Load"), LCL, Empty, Transit or Transshipment - and the range of services provided on the terminal:

1. The first activity, referred to as the Ship Operation, consists of the loading and discharging of containers between the vessel and the quayside. Since all incoming and outgoing containers must pass through the Ship Operation, it ultimately determines terminal handling rates, and so it is often referred to as the 'dominant system'.

2. Movement between the quayside and the container yard (most container terminals do not load/discharge directly to/from inland transport or waterborne craft) is known as the Quay Transfer Operation; its particular significance is as a regulator of the Ship Operation - it has a direct influence on ship loading and discharging rates.

3. Containers are generally stored temporarily in the container yard while documentary, administrative and other formalities are completed; the Storage Operation provides a buffer between the Ship Operation and the fourth of the terminal's handling activities.

4. The Receipt/Delivery Operation, through which all FCL containers flow, has become a particularly important terminal activity with the growth of through-transit containers and 'intermodalism' (the direct movement of containers, with their contents intact, between different transport modes). In this activity, containers are moved between the container yard and road, rail or inland waterway interchange points, and then (in the case of road traffic) to the gate complex, where terminal formalities are completed.

In addition to these four activities, LCL containers need to be moved from the container yard to the CFS for unpacking and the empty boxes returned to the 'empties stack', while other empties are taken to the CFS for packing before moving to the container yard prior to loading aboard a vessel. Clearly, a box is handled several times during its transit through the terminal, the actual number of movements depending on its type and status. Some terminals also store empty containers returning to the port from the hinterland - 'recirculation boxes' - to await onward movement by sea as empties, or to be called for by a consignee and packed up-country.

1.4.6 Clearly, container flow through a terminal is a complex series of interconnecting activities or subsystems, together summarizable as the 'Terminal System'. The output of the whole system is dependent on the capacity of the weakest link in that chain, while the performance of each subsystem can be markedly affected by that of the others; there is a great deal of interdependence between all terminal activities. Not surprisingly, there is considerable variation in performance between terminals, even those employing the same container-handling systems - equipment specification is not the only determinant. There are differences in traffic volumes and flows (e.g. import:export ratios) and
also considerable variation in the quality of management information, control and supervisory procedures.

1.5 Validity of Data

1.5.1 The operating, performance and cost data appearing in these pages have been calculated by averaging the questionnaire responses from terminal operators. Where possible, the information has been checked against published sources and the opinions of industry experts. Some difficulty has been encountered in arriving at a consensus and in interpreting questionnaire responses, particularly where differences occur in terminal financial and operations reporting systems. Some data have had to be adjusted for uniformity and to ensure community of definitions and comparability of figures. Where significant variation occurred, a range of performance and cost data is provided. Difficulties were also experienced with certain published data, largely as a result of inconsistency in format, terminology and definitions. Where possible, such information has been adapted for comparability (see Section 1.6).

1.5.2 For consistency, metric units of measurement have been used throughout this project. Operating and performance data are expressed as container units handled or as container movements per unit of time, as appropriate to context. Storage capacity data are given in terms of TEUs ('twenty-foot equivalent units' - a 40' container counts as two TEUs). All cost data are expressed in US$ at September 1987 prices; prevailing currency exchange rates have been used to convert currencies to US$.

1.5.3 The objective of the exercise has been to gather data which are both realistic and representative of well-managed terminals, particularly with regard to operating and cost performance of container-handling equipment. Significant differences often occurred between the operating claims of respondents, equipment manufacturers and independent observers. Manufacturers tend to quote figures calculated on the basis of specifications (e.g. of travel and hoist speeds), while operators often give peak values and not average sustained performance. The data finally presented here are, in fact, intended to be indicative of sustained operations, under day-to-day operating conditions, and taking into account non-productive equipment movements, shifts within stack, movements of equipment between terminal areas, and so on. Caution must be exercised in applying the data collected from European ports to ports in other regions where operating conditions, traffic patterns, and labour and other costs are different. Given such caution, it is felt that the data provide guidance and, properly interpreted, can be applied to terminals in developing countries.

1.6 Definitions and Calculations

1.6.1 For consistency and to allow accurate comparisons to be made between equipment types, strict definitions have been applied to equipment Utilization, Availability and Downtime.
1.6.2 Equipment Utilization is a measure of the proportion of time that a machine is actually doing useful work. It is calculated by dividing the 'recorded machine hours', i.e., the number of hours the machine actually worked in a year (either calculated from workshop records or, preferably, recorded by an hour-meter fitted to the engine) by the 'possible machine hours' - the maximum number of hours that the machine could have been used in the year.

1.6.3 Equipment Availability is a measure of the proportion of time individual machines are accessible to terminal operators, and is calculated by dividing the 'available machine hours' (the number of hours that the machine is actually available for use in the year - the 'possible machine hours' less Downtime) by the 'possible machine hours'. Both Availability and Utilization are normally expressed as percentages.

1.6.4 It must be acknowledged that there is some confusion and difference of opinion over whether 'possible machine hours' should be used in such calculations or the total hours in a particular period. For example, some operators claim that a machine should be considered as theoretically 'available' for 168 hours in a working week, since it could (if it is in working order) be used at any time in the 24 hours of each working day. Others, however, take the view that it is unrealistic to include the hours when the terminal 'unit' is not at work (because of public holidays, shift changeovers, non-working periods). Instead, they use the number of hours that the terminal is scheduled to work in that period, as is the custom of the port - the maximum number of hours that the equipment could, in reality, be worked.

1.6.5 In this study we have taken as the Possible Machine Hours for all calculations the number of hours the terminal is scheduled to work. Although some terminal operators claim a possible working time of 720 hours a month (24 hour working, 7 days a week), the majority of questionnaire respondents reported a maximum of 600 hours as the basis for their equipment reliability measures, and we have used that figure in our calculations of equipment performance here (unless the respondent gave firm figures for hours actually worked). Thus, a Utilization level of 50% is taken to indicate that the machine is used 300 hours/month, and an Availability figure of 90% means that it was 'available' for operators to use for 540 hours in the month.

1.6.6 There is a danger that using the above interpretation of Possible Machine Hours may distort the collected figures for Downtime - the measure of the time when equipment is out of service and unavailable for use. Although terminal operations may only be scheduled for 600 hours a month, maintenance staff usually provide a 24-hour service so that emergency repair work (and, in some terminals at least, some preventive maintenance) is undertaken outside operating hours. Downtime figures are often expressed, then, in terms of the amount of time when equipment is unavailable for use during scheduled terminal operating time; they are not a complete measure of the total time spent in the workshop, which is the most useful comparative measure in the present context.

In this study, however, in an attempt to compensate for the many differences of interpretation of Downtime in the published and questionnaire data, we have assumed that maintenance staff work the same 600 hours a month as operations staff, and that only occasional emergency repairs are carried out outside that time. Preventive maintenance is then normally
scheduled for periods when a particular machine is not required for operations, but still within the working day. In this interpretation, Downtime is clearly the Possible Hours less Available Hours, and Downtime includes both scheduled preventive maintenance and accident and breakdown repair. To obtain reliable comparative figures for these interpretations of Utilization, Availability and Downtime, the data from the returned questionnaires, and those from published material, have been cross-checked against all the available 'internal evidence' provided by related information.

1.6.7 Average annual and hourly Operating Costs for each type of equipment covered by this survey have been calculated, to illustrate the importance of careful selection. Average annual costs per container movement (irrespective of whether it is a 20' or 40' box) have also been calculated on the basis of average sustained performance rates; container movements are a much better guide to equipment use than throughput in terms of containers or TEUs, since many boxes have to be handled several times during their journey through the terminal. In each case, an appropriate factor has been used to convert container throughput to moves: 3.5 moves per container transit with high-stacking systems, 2.5 moves per container transit for low-stacking equipment, and 3.0 moves per container transit for equipment stacking to an intermediate height.

The Total Cost of equipment is taken as the sum of the Ownership Cost (=capital cost) and Operating Cost. The Average Annual Ownership Cost has been calculated by applying a Capital Recovery Factor (at a 12% discount rate) over the assumed asset life. The Average Annual Operating Cost has been extracted from the questionnaire responses (and some previous survey data) and so relates largely to European conditions; it includes the cost of fuel, maintenance and appropriate direct labour (driver) costs — all employment costs, allowing for complete manning, including reliefs, for a three-shift day, seven days a week. The cost of maintenance also includes direct labour costs, as well as the cost of spare parts, lubricants and other consumable materials, but excludes overheads. The Total Annual Cost was finally divided by the assumed annual operating hours (based on the Utilization figures for that equipment), to produce the hourly cost, and by the average hourly sustained box handling rate to produce the average cost per box movement.

A summary of the operating and maintenance costs of individual pieces of equipment and an analysis of systems costs are presented in Chapter 8.
Chapter 2

QUAYSIDE GANTRY CRANES

2.1 Introduction

2.1.1 Although portal, jib, multipurpose and even mobile cranes continue to be used in seaports to transfer containers between ship and shore, specialized gantry cranes become more and more necessary as box throughput increases and larger cellular ships are handled. The massive quayside gantry crane, with its typical 'A'-frame, box-girder framework from which the (usually) lattice-structure boom is suspended, is the most distinctive feature of a dedicated container terminal. Whereas surface mobile handling systems offer considerable variety and choice, the gantry crane remains the one constant element in lift-on-lift-off container operations.

2.1.2 The gantry crane's function on the terminal is a pivotal one. The speed with which it loads and discharges containers determines the ship handling rate and sets an upper limit to the overall throughput of the terminal. The crane cycle has to run smoothly and as nearly continuously as possible while the ship is being worked; (in the loading cycle) pick up the export container from the quay transfer equipment or the quay surface beneath the crane legs; transfer it smoothly to the designated 'slot' on or below deck; land it carefully in the slot; and return without delay for the next container. The driver, in his cab below the trolley, expertly controls the hoist, the travel to the cell guide or box position (his cab following the box's movement along the boom rails), the lowering into the slot and the return, empty, to the quayside. The discharging cycle is, of course, the reverse of this sequence.

2.1.3 Quayside gantry cranes had their origins in the mid 1950s, but the first purpose-built container crane was installed in 1959 by Paceco. This crane, the design of which was based on its earlier box girder, hammerhead crane, was introduced for handling containers on the Pacific service then being pioneered by the Matson Navigation Company. The 'A'-frame, box-girder construction of this first gantry crane provided the basis for subsequent generations of cranes. In the mid-1960s, containerization spread rapidly and international services opened up, particularly the North Atlantic service of Sealand, and there was a considerable increase in the number of container cranes purchased by ports. By today, there are over 1100 gantry cranes or 'portainers' in service in the world's ports. Although initial development was in the USA, much of current manufacturing capacity is in Europe and Asia (often under licence from US firms) and there is now strong international competition for the supply of the 200 or so cranes expected to be purchased over the next three or
The development of gantry cranes has reflected the increasingly stringent demands of seaport terminals and ship operators and the rapid technological and size development of container ships. Cranes have become steadily bigger, faster and more reliable. In their engineering design, much attention has been given to stiffness and to metal fatigue. They require less maintenance and have become increasingly automated. They have also become more expensive, with prices currently in the range of US$3 million to $6 million, depending on specification. The selection, operation and maintenance of these assets have assumed increasing importance for senior port and terminal managers and are of critical significance in terminal development.

The typical mid-1960s crane has a capacity of about 30 tonnes under the spreader, a wheelspan of about 15 metres and an outreach of 35 metres; these parameters matched the dimensions of the largest container ships then operating. Those early cranes were designed for a working life of about 600,000 container moves. During the 1970s, as container ships increased significantly in size, so did the demand for cranes with larger capacity and greater efficiency and reliability. The latest generation of gantry cranes has been constructed to handle post-Panamax-sized vessels (i.e. ships with a beam of over 32.2 m) and to meet terminal requirements into the 21st Century. They have a greater life expectancy than the earliest cranes (up to 40 years - two to five million moves), with higher resistance to metal fatigue (particularly from the effects of shock loading) built into the structure. The actual length of life of a current generation crane will, however, still depend on the environment (particularly climatic) in which it operates, the quality of maintenance it receives, the skills of its drivers, the intensity of its use and the details of its design and construction (e.g. the ability of its drive systems to withstand high accelerations and speeds, the quality of its electronic components). To maximize working life, current models incorporate the latest in electronic and automated control systems, fault diagnosis and condition reporting, and effective safety systems. The timespan between routine maintenance and major overhauls has appreciably increased in recent years.

The most significant recent developments have been designed to improve operating performance - crane cycle times have been speeded up and lift capacities have been increased. A relatively early attempt at this allowed two 20' containers to be lifted simultaneously from adjacent cells - the process of 'twin lifting'. A more recent (and more successful) development has been the introduction of the 'second trolley system', which splits the crane cycle into a ship cycle and a shore cycle; while the boom trolley handles containers to and from the shipboard cells in the usual way a second trolley system, situated between the legs of the gantry, transfers containers between the terminal surface and a platform, which then moves the box to the ships side of the portal, to await lifting by the ship cycle. The second trolley, operating either manually or fully automatically, provides a buffer to keep the boom trolley continuously active, and reduces the distance of travel within the primary crane cycle. Second trolley systems are expensive, but their introduction is expected to be cost-effective in high-throughput terminals. Combined with increases in trolley travel and hoist speeds, such developments have greatly reduced crane cycle times and have permitted handling rates of up
to 40 or even 50 boxes per hour under good operating conditions.

2.1.7 Other significant developments have taken place in spreader design, reliability and life expectancy. Features of new spreaders include reduced weight of major components, the provision of a 180° rotation ability, and a more rigid design. Vulnerable electric/electronic and hydraulic components are now fully enclosed for protection and the system is shock-mounted. Spreader lifespans of 2 million moves are now commonly predicted, and some manufacturers claim an expected lifespan of 3.5 million moves.

2.2 Specifications

2.2.1 The basic structure of a gantry crane is not greatly different from that of the first Portainers. The 'A'-frame is usually still of single box-girder construction, for its high strength-to-weight ratio, though many cranes have been built with tubular, rather than square-section, legs, and both single-plate-girder and lattice-frame booms are now in use in various individual designs. Most quayside gantry cranes are electrically powered, either from the grid or from a local generator, and only 15% of the present population are diesel-powered.

2.2.2 The main changes that have taken place are in size and lifting capacity, as container loads and ship sizes have increased. Since a working life of 40 years or more is now envisaged for a ship-to-shore crane, it is clearly vital to ensure that cranes purchased now are capable of meeting any future increases in ship and container dimensions. Already, some container terminals have had to refurbish and 'stretch' their gantry cranes (e.g. by 'giraffing' their legs) to meet such changes, and many major terminals have guarded against premature obsolescence by 'oversizing' their most recently purchased gantry cranes, i.e. buying bigger than was immediately needed.

The three critical dimensions of a gantry crane from the operational point of view are its lifting or hoisting capacity, its outreach and its air height. We shall consider these in turn, together with the other dimensions that need to be looked at when preparing crane specifications: backreach, wheelspan, clearance between the legs, overall length and clearance under the portal.

2.2.3 Lifting Capacity is expressed in either 'tonnes under the crane head' or 'tonnes under the spreader'; the latter is more useful for operating purposes since it takes account of the spreader beam itself, which can weigh up to ten tonnes and thus reduces the rated capacity of the crane. Surveys by Containerisation International in 1985 and 1987 (publications that we shall refer to repeatedly) clearly indicate that the popularity of cranes with capacities up to 30 tonnes is on the wane and that the most popular size is already the 31-40 tonne range, with a clear trend towards equipment rated at 35-40 tonne Safe Working Load (SWL). 85% of recent orders have been for cranes in the 31-40 tonne range, but the proportion of orders for cranes of SWL above 40 tonnes has been increasing steadily. There have been recent orders and commissionings for cranes up to 55 tonnes capacity, particularly at new major terminals.
Although under current ISO conventions the maximum permitted payload of a 40' container is 30,480 kg (approximately 30 tonnes), it is prudent to anticipate that this will be increased during the life of a new crane, particularly if the ISO endorses the 45', 48' and greater container lengths currently being discussed and if 'high-cube' boxes of 9' or 9'6" height become more common. Pressure from ship operators to increase container lengths, widths and heights beyond ISO dimensions is high. Operators also have to take account of overweight boxes and the need to lift very heavy hatch covers with their quayside cranes (individual covers weigh 30 tonnes or more). Cranes may also need to cope with the occasional heavy lifts, with volumes and weights in excess of loaded containers, and to allow 'twinning' - handling two loaded 20' boxes as one lift. Since 20' boxes have a maximum permitted ISO weight of 24 tonnes, a lifting capacity under the spreader of 48 tonnes is needed for the safe handling of twin lifts. There is, of course, a cost penalty for over-capacity, and the extra cost has to be balanced in each case against the hoped-for (but difficult to quantify) return.

2.2.4 Outreach is normally measured from the waterside crane rail to the outermost point to which containers can be handled. This critically important dimension is, of course, related to ship's beam, and it is much more useful to be given a figure for the true 'reach over water' or Operational Outreach, derived by deducting from the given 'outreach' figure the distance between the waterside rail and the quay wall, plus any allowance necessary for fendering.

The objective must be to select an operational outreach that ensures that containers can be handled to and from the outermost cell of the largest vessel to call at the port (unless port policy is to turn the ship around at the berth or to move containers from the outer cells by other means, e.g. shipboard cranes or roller hatch covers). Until recently, nearly all ship-to-shore gantry cranes had outreaches of below 40 metres, with the majority below 35 metres; all third generation cellular container ships have beams within the Panamax limits of 32.2 metres. However, major changes in the geography of liner trades and ship routing, and in the size of vessels, have prompted the commissioning by selected terminal operators of post-Panamax size cranes. The majority (65%) of recent orders have been for cranes with outreaches of over 36 metres, with a third of them having outreaches of over 40 metres. Recent installations by European Container Terminus, Rotterdam, (ECT) and orders by other terminals are for an outreach of up to 50 metres and an operational outreach of 40 metres; such cranes are capable of handling vessels carrying 16 boxes athwartships on deck (39.6 metres beam), which are expected to be used on major trade routes in the 1990s and beyond. American President Lines (APL) has announced the construction of five of such vessels.

2.2.5 Air Height is the height of the spreader beam, in its highest lifting position, above the waterline (more strictly above the level of High Water of Spring Tides). A more practically useful measure, to operators particularly, is Total Effective Lift, the vertical distance over which the trolley and spreader unit can actually handle and stow containers in the vessel. The crane must be able to lift containers carried up to five (and possibly six) high on deck and to handle containers safely into and out of the bottom position of the cell guide system, often nine deep below deck.

Although Air Height and Total Effective Lift are the dimensions that are
of major importance operationally, they both depend on factors other than
the dimensions of the crane itself - height of the quay above high water
of spring tides, the tidal range, the size and loading of the ships calling
at the port. The related manufacturers' specification measure is **Lift
Height Above the Quay**, which is not dependent on those 'extrinsic'
factors. When specifying Lift Height Above the Quay for a new crane,
those physical conditions must be taken into account by the planning
team. Typical values for this dimension have been until recently in the
range 20-30 metres, and 54% of the present crane population have Lift
Heights of up to 25 metres, 42% between 26 and 30 metres, with only 4%
with Lift Heights over 30 metres. However, there is a clear trend
towards greater Lift Heights and 60% of recent orders have been for
cranes with Lift Heights Above the Quay of 26-30 metres and 14% for over
30 metres, with 5% for over 35 metres. A Lift Height Above the Quay of
30 metres, with a total Effective Lift of 47m allows stacking up to 5 high
on deck and 8 or 9 boxes under the deck in post-Panamax vessels. Ports
handling short-sea feeder services obviously will not need such massive
cranes; in each case, the Air Height and Lift Height selected will depend
on the service draught (and hence freeboard) of the vessels expected and
the height to which containers will be carried on and under deck.

2.2.6 Manufacturers also quote the related specification, **Boom Clearance**, which
gives the height of the boom above High Water of Spring Tides when in its
horizontal position. This is of concern when moving the crane between
loading/discharging positions, determining whether the boom has to be
raised to pass over ship's masts, superstructure or funnel.

2.2.7 The **Backreach** is the distance between the inboard crane rail and the
maximum landward position of the trolley and spreader. It varies between
8 and 30 metres, depending on operational needs; backreach must at least
be sufficient to allow hatch covers to be landed clear of the container
pickup and delivery area between the legs, and some terminals use the
Backreach area to land boxes that are being shifted prior to re-loading.

2.2.8 The operational significance of **Wheelspan** or **Rail Gauge** is that it must be
wide enough to allow uninterrupted movement of mobile equipment
delivering and picking up containers between the rail legs. From the
point of view of terminal development, wheelspan is also significant in
that it determines the intensity of the wheel loading on the quay.
Wheelspans used to be in the range 15 to 20 metres, but newer cranes
(particularly those serving tractor-trailer trains) have spans of up to 35
metres, allowing delivery/receipt from several trains at a time, and space
for through routes to other cranes working the same ship. A wheelspan of
30.5 metres seems to be common in recently installed quayside gantry
cranes.

2.2.9 **Clearance Between the Legs** has assumed greater importance with the
increasing use of non-ISO-standard boxes. Containers are normally carried
on board in the fore-and-aft orientation, so the distance between the
shipside legs must be sufficient to enable 45', 48' and possibly longer
containers to pass between them as they move between the quay and the
ship; Clearance of 16 metres would be sensible for future orders, to
accommodate the next generation of containers, as well as large hatch
covers. This dimension does, of course, affect the overall length of the
crane.

2.2.10 **Overall Length** is important when working a vessel with two or more
gantry cranes, as it determines how closely together the cranes can work and whether adjacent bays can be loaded or discharged at the same time. Lengths over the buffers vary between 22 and 35 metres; the smaller the overall length, the more flexible ship planning and crane deployment become.

2.2.11 Clearance Under the Portal, the vertical clearance beneath the legs, is particularly significant in Straddle Carrier Direct operations. Clearly, portal clearance must be great enough to allow straddle carriers to pass under, to drop or pick up containers. The earliest gantry cranes had quite low portals, and rising-arch straddle carriers (see Chapter 3) were used to work below them. In Japan, low-portal gantries are still common, and low or rising-arch straddle carriers are still in demand there. Clearance under the portal of current gantry cranes ranges from 8 to 13.5 metres, sufficient to accommodate one-over-one and one-over-two straddle carriers respectively.

2.2.12 Selecting a suitable gantry crane is not, of course, simply a matter of choosing the largest available. Cost considerations, and return on investment, are crucial, and there are also significant civil engineering implications: the latest gantry cranes, capable of handling Fourth Generation vessels, and incorporating second trolley systems, weigh up to 1250 tonnes (compared with 400 tonnes for the earliest types), and impose static loadings of about 80 tonnes per wheel on the quay surface. Very special and extremely expensive construction methods are needed to support such cranes, often with load-spreading concrete and steel structures within the ground below the rails and in the quay wall, to disperse the load as much as possible.

2.3 Operations

2.3.1 Gantry cranes serving the Ship Operation are in many ways the key element of the Terminal System. The Crane Cycle is carried out in four stages: for exports, the container is picked up by the spreader from between the crane legs (either from a tractor-trailer set or from the quay surface, where it has been placed by a straddle carrier or lift-truck), is conveyed over the ship's rail to the appropriate cell guide or slot position, and is lowered into that position, leaving the spreader (after release) to be returned to the quay, where the next box is waiting. For imports, the first stage is the attachment of the spreader to the box in its stowed position, followed by its transfer to the quay and its lowering onto a trailer or onto the quay surface; the spreader is then returned over the ship's rail to the position of the next box to be discharged. In 'double-lift' operations, after depositing the export box the spreader moves to the slot of an import container in a cell in the same bay, and lifts that out of the ship on the return leg of the cycle; an even more rapid and efficient mode of operation but one which, for operational reasons, is not widely practiced.

The crane is also frequently used to lift the heavy hatch covers over the ship's side and to place them on the marshalling area below the backreach of the crane - and in, due course, to replace them when the Ship Operation has been completed.
2.3.2 The other movement of the crane is the traverse along its rails, from one loading/discharging position to another. As a cable-powered gantry crane travels, it picks up (ahead of it) or lays down (behind it) its power-supply cable, which lies in a trough alongside the crane rails. Other types pick up their power supply from an underground bar system.

2.3.3 **Operating Costs** of quayside gantry cranes in Europe are of the order of $400,000/annum (about 10% of purchase price), of which about 65% ($260,000) is accounted for by labour costs, and 25% by maintenance (excluding major overhauls and refurbishment), while power and lubricants contribute about 10% of the costs. In developing countries, although local labour costs might be lower, annual operating costs are much the same because manning levels are higher, the cost of spare parts is much higher, and there is a frequent need to import maintenance technicians from overseas.

2.3.4 Although some terminal operators allocate one driver per shift to each crane, the more common Manning practice is to provide two drivers and allow them to interchange. About 58% of terminals transfer drivers between quay cranes and other duties during a shift; a common practice is to alternate between crane driving and checking, providing variety in the work programme and reducing the periods of deep concentration. Typically, drivers spend a maximum of two hours in the cab at a time during a 7.5-8 hour shift, with one refreshment break of about 30 minutes; breaks should be staggered to keep operations going.

2.3.5 Careful selection of gantry crane drivers is extremely important, and there is a crucial inventory of necessary skills, aptitudes and physical attributes. Apart from good general health and fitness, high visual acuity and depth (distance) perception are essential; the cab is situated some 20-30 metres above the quay surface, and the driver must be able to position containers accurately on quay transfer equipment and into the ship's cell guides. Excellent powers of concentration are needed, as driving is a demanding job in itself, apart from the strain of continuous communication with other operators and supervisory staff and the absorption of a great deal of information from voice and data links. A high level of hand-eye coordination and psychomotor skill is needed to handle the controls effectively, particularly in conditions of high wind and swell. It is sometimes claimed that the driver's ability is a better solution to control of sway of the spreader beam and container at high operating speeds than the fitting of expensive and complex anti-sway devices. Drivers also have to be able to work alone at height and to be highly motivated and well trained. Although the 1985 Containerisation International survey indicated that 17% of terminals do not provide training for gantry crane drivers, specialized training is generally agreed to be essential. Typical programmes include classroom, on-the-job and in-service training of about three months' duration, with strict assessment and certification a regular feature.

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2.4 Performance

2.4.1 There is considerable disparity between manufacturers' claims and operators' experience in gantry crane operating performance and utilization. Manufacturers' claims on performance rates are based on the
theoretical cycle time, calculated from hoist and trolley speeds, etc. These figures will be much higher than those achievable under operating conditions. Even operators tend to exaggerate performance (for commercial and promotional purposes) by quoting rates achieved at peak periods or under ideal conditions. What should be quoted are average rates that can be sustained consistently under normal conditions. Terminal operators are interested in two primary indicators of gantry crane performance: the total number of container moves a crane can make per annum and the Hourly Handling Rate, which is clearly a function of the crane cycle time. The latter is of particular interest to the ship operator.

2.4.2 Early cranes were designed for 2000 operating hours a year and an assumed life of 15 years. At an assumed working rate of 25 crane cycles per working hour, this amounted to an expected 750,000 cycles over the crane's working life. In the 1970s, these design parameters were increased to an assumed lifespan of 25 years and 4000 hours of use per year, a possible lifetime total of 2.5 million crane cycles (given major overhauls and refurbishment every 10 or 15 years). Post-Panamax cranes, built to higher specifications and with more rigid structures, are assumed to have a life of 30-40 years and, with their second-trolley systems and with hoist and trolley speeds some 100% higher than earlier generations of cranes, can achieve 55 moves/hour. This could amount to 6.5 million crane cycles over their lifetimes, given regular refurbishment.

2.4.3 The evidence from leading European operators is that, although their terminals operate on a three-shift system, seven days a week, most of their cranes record between 200 and 350 operating hours a month (in North America as few as 130 hours a month) — a Utilization level of 30-60%. Containerisation International's 1987 survey endorses those figures, revealing a worldwide gantry crane Utilization of about 25% of their available working lives. These low figures are not surprising when it is remembered that Berth Occupancy at a container terminal should not, for operational reasons, exceed about 50%. One of the problems of container terminals is the extent of peaking — on some days, every berthing point might be occupied and all cranes in operation. On other days, the berth may be empty. Ship operators demand two conditions before entering into an agreement to use a terminal: that a minimum number of cranes will be allocated to each of their vessels on each call (usually two for a second or third generation vessel, three for the largest ships) and that a minimum daily handling rate will be guaranteed (typically 700 moves/day). To meet these obligations, it is often necessary for the terminal operator to build-in excess capacity, and so cranes will inevitably be idle for much of the time.

2.4.4 Although (perhaps because) Utilization is low, the maintenance record of quayside gantry cranes has been very good and Availability is extremely high. Figures are consistently in the range 95-98% (based on possible machine hours of 600 a month). Downtime is very low, at 2-5%, with most preventive maintenance (which accounts for about 50% of Downtime) being undertaken when the crane is not required for operations; only 60-100 operational hours are lost per year through unplanned maintenance and repair. Breakdown repair accounts for 40% of Downtime, and equipment damage just 10%. Some terminals in the Far East report Downtime of 25 days a year, while 80% of quayside gantry cranes are 'down' for fewer than 15 days. The 1985 Containerisation International survey concluded that Downtime amounts to about 14.5 days per year on average — 4%.
2.4.5 The causes of breakdowns/repairs are mechanical, electrical and hydraulic. The major site of mechanical failure is the spreader beam, responsible on average for about 50 hours of Downtime per year - a third of total Downtime. At Felixstowe, between 80% and 85% of operational Downtime is caused by spreader beam damage and defects, and the 1987 Containerisation International survey quotes the spreader as giving rise to about 30% of total Downtime. The main reason seems to be a lack of robustness in the engineering and the resulting damage to hydraulic connections and electromechanical switches when spreaders come into contact with ships, vehicles, etc. Such risk of damage is particularly severe when handling non-cellular vessels and when ships have a list. Because of such vulnerability, telescopic spreaders were not popular in the past, but they are increasingly common now, particularly where the mix of box sizes and types makes them almost essential. Considerable research and development effort has gone into improving spreader beam reliability and robustness, in fact, though terminal operators still maintain several spare sets for replacement in the event of damage; worldwide, about 1,750 spreaders are owned for every crane. Other prominent and frequent causes of mechanical failure are damage to drive motors, crane travel mechanisms (including trolley wheels and rails), sheaves and sheave bearings, hoist cables, and trolley electrical cables (due to the continuous looping and the effects of wind).

The major causes of electrical breakdowns (which cause about 40% of total Downtime) are failures of limit switches, relays and interlockings (these present major maintenance diagnostic problems) and for hydraulics it is hydraulic couplings and ruptured hoses (particularly in the spreader).

2.4.6 Deciding precisely how many cranes to acquire for a specific throughput is thus a vital problem for terminal planners. Although some terminals claim handling rates of 90,000 moves a year per crane, it is clear from the collected and published data that 50,000 moves per year is a more realistic estimate. Containerisation International's 1985 survey revealed that 61% of the world's ship-to-shore gantry cranes handled fewer than 1,000 TEU per week (approximately 830 moves/week), i.e. about 40,000 moves/per crane/year, though major ports in the Far East handled up to 1,500 TEU per week per crane. In fact, independent evidence suggests that some Far East terminals are now achieving about 70,000 moves/year/crane, and the new post-Panamax cranes could exceed such figures, provided the demand was there.

The actual rate achieved depends, of course, not just on demand but also on the type of ships handled; not only are rates inevitably lower with conventional, multipurpose and other non-cellular vessels than for cellular ships, but first, second and third generation container ships also handle at different rates. Other factors include the mobile container-handling ('back-up') system used and the quality of terminal management. In many African countries, handling a high proportion of multipurpose ships, annual handling rates of 40,000 moves per crane may be good.

All of these factors must be considered when determining the number of cranes to acquire, and it is wise to accept more realistic throughputs than manufacturers might claim. There is, however, obviously a physical limitation to the number of cranes or service points that can be placed on a berth; there must be a minimum distance between cranes when they are working. In 35.6% of terminals (Containerisation International, 1985)
the average length of quay per crane is 150 metres, while a further 28.7% allocate one crane per 150-200 metres.

The number of cranes is not just determined on the basis of annual throughput but also by the level of service guaranteed to ship operators. Despite the present alleged overcapacity, many ports are still ordering new cranes to guarantee rapid turnarounds to win business at a time of intense competition - a vicious circle.

2.4.7 Considerable differences exist between claimed hourly handling rates. Although many terminal operators claim handling rates of 40-50 moves an hour (even as high as 60 moves per hour), it is the average sustained performance which is of greatest relevance, taking into account handling containers from different types of vessels, different stowage locations, hatch cover handling and other non-productive movements, operational delays, crane shifts etc. Average sustained handling rates at most major terminals seem to be in the range of 18-20 moves per crane working hour; this accords well with Containerisation International's survey figures of 20-25 TEU per hour. In the most extensive published survey, covering 7 million crane cycles recorded over seven years, the average sustained handling rate was 17.7 moves per working hour. So, for daily planning purposes, it would be sensible to apply rates of 20 moves/hour, to allow for variations in demand, non-productive periods, delays and Idle Time, and the limitations of the back-up container-handling system.

2.4.8 Of greater interest to ship operators are the handling rate per Ship Hour in Port and the Daily Transfer Rate between ship and terminal. Available data from ship operators show wide regional differences; average gross hourly handling rates/ship for Second and Third Generation ships at major terminals in the far East are in the 40-60 range (depending on whether two or three cranes are allocated per ship) and Daily Transfer Rates range between 300 and 1200 containers, typically 800-1200. In Europe, the corresponding figures are 35-45 per hour, 600-800 per day, whereas in Africa and the Indian sub-continent, with a high proportion of non-cellular tonnage, average rates are 5-15 per hour, 100-250 per day.

2.4.9 There has been considerable emphasis recently on improving gantry crane handling rates, and trolley travel and hoisting speeds have been increased significantly. Trolley travel speeds have risen from about 125 metres/minute in the early 1960s to over 200 metres/minute in the 1980s, while hoist speeds have gone up from 30 metres/minute to 80 metres/minute under maximum load and as high as 125 metres/minute under low loads. These changes have been aimed at speeding up the crane cycle, particularly with the cranes of 40-50 metres outreach, where trolley travel distances can exceed 112 metres. At these high speeds it has been essential to install systems to suppress acceleration/deceleration effects and to reduce load-swinging.

2.4.10 We can now analyse further the costs of the ship operation with a gantry crane. For a relatively modest-sized gantry crane, taking a purchase price as $3,500,000 and a working life of 25 years, we can work out its Annual Capital Recovery (at a Discount Factor of 12%) as $450,000. Its operating cost (Section 2.3) is about $400,000, which gives an annual total cost of about $850,000. Assuming further that it is operational for 3500 hours in the year, its hourly cost is about $245 and, at a handling rate of 20 moves/hour, that gives a handling cost of about $12 per box.

If the handling rate is only 15 moves/hour (more typical of the Third
World), the handling cost would be about $16 per box.

For a 'post-Panamax' gantry crane, costing about $6,000,000, and with a life expectancy of about 35 years, the Annual Capital Recovery is about $735,000 which, with an operating cost again of $400,000 a year, gives a total annual cost of $1,135,000. Assuming the crane works 3500 hours, that gives a total cost of about $329 an hour. At an average handling rate of 30 moves an hour, the cost per container works out at about $11 and at 20 moves/hour it would be $16 per box.

2.5 Maintenance

2.5.1 In Europe, maintenance accounts for 25% of total operating costs (about $100,000 per year), made up of about 75% labour costs, 20% spare parts costs and 5% consumable materials. In developing countries, labour costs can be as low as 40% of total maintenance costs, and spare parts can account for nearly 60% of total costs. Between 30 and 50 hours of preventive maintenance are carried out on each crane per month (about 50-200 man-hours).

2.5.2 To achieve cost-effective use of these extremely expensive port assets, the maintenance function must be very efficient, and great dependence must be placed on preventive maintenance checks. Most terminals employ a specialist team to maintain quayside cranes, equipped with a mobile workshop/repair van, and preventive maintenance is carried out outside operating hours. The major components of the preventive maintenance scheme are weekly and monthly (rather than daily checks, as in the case of mobile plant), paying particular attention to hoist cables, brakes, wheel and sheave bearings, limit switches and all safety devices. Electric motors are checked annually. At 10,000 hours, close inspection is given to brushes and tachometers, and at 50,000 hours and 100,000 hours extensive inspections are carried out to such components as the hoist gear box, trolley rails, wheels etc. The crane is repainted every 5-7 years (at a cost of about $65,000) to keep the structure in good condition. Refurbishment by the manufacturer is commonly required after about ten years of operation, and currently costs about $1 million.

2.5.3 Although much maintenance is carried out on site, extensive workshops are essential, with specialized facilities for testing spreaders and electronic gear. Ports recruit maintenance staff with the standard mechanical and electrical skills. Increasing use of solid state drives and electronic control equipment means that additional skills are required, especially to deal with automation and with radio and data communication systems. Training is provided largely on-the-job, though the necessary specialized training may either be arranged at the ports themselves or at manufacturers' premises (often lasting several months). A few ports run apprenticeship schemes.

2.5.4 Spare parts management is a critical element of a good maintenance system. The cost of replacement parts varies between $10,000 and $30,000 per annum per crane, and some $60,000-70,000 worth of stocks are kept (1-2% of the purchase price of the crane), the majority of them (70%) engine/transmission parts and about 20% electrical components. Some spares have a strategic value (i.e. are kept in stock, even though they
are not likely to be needed, because without them the crane would be immobilized, including main hoist gear box, couplings, gantry and trolley wheels, electrical regulators, electric motors and armatures. Many spare parts are, in fact, purpose-built. The recommended policy for stocking is to maintain a stock for at least two years, and perhaps longer if lead times are long; the procurement contract should attempt to secure supplies for a minimum of 25 years.

2.5.5 Spreader Beams The high incidence of damage to and breakdowns of spreader beams, and the high proportion of total Downtime due to that, warrants a brief section on this critical part of the lifting unit, the part that comes into direct contact with the container.

Early designs, particularly of telescopic spreaders, were very unreliable, and were prone to damage (especially to the telescoping drive mechanism) when they came into contact with the ship, containers or vehicles. Since the mid-1970s, considerable research and development have been devoted to improving the robustness and reliability of spreaders, often through collaboration between manufacturers and terminal operators. The result is a new generation of spreaders of better design and reliability. The manufacturers' aim has been to balance the need for robustness and rigidity with the desire to minimize weight, since the weight of the spreader beam directly reduces the lifting capacity of the equipment and adds to the power needed to lift.

There are many types of spreader beam on the market. The simplest and cheapest is a fixed frame, with twistlocks operated manually or mechanically activated by the raising and lowering of the spreader sling. The fixed frame is robust and almost maintenance-free and can, in the event of damage, be manually operated. However, it is more likely to be found on conventional or multipurpose terminals and those with low throughputs. At the other extreme is the modern telescopic spreader beam, with automatic twistlocks and possibly trim, list and slewing features, designed to reduce delays when coupling the container and so to improve handling rates. Such a spreader beam costs between $50,000 and $100,000, depending on complexity. This is the type normally found on the quayside gantry cranes of large, dedicated terminals, and also on yard gantry cranes. Indeed, spreaders may be interchangeable between quayside and yard gantry cranes, though spreaders for lift trucks and straddle carriers are of rather different design.

The automatic fixed frame or telescopic spreaders used on quayside gantry cranes are normally constructed of section beams. All motions, including telescoping, twistlock operation and corner guide activation, are hydraulically powered. Today, twistlock assemblies are built in modular form to allow quick replacement and easy maintenance. Recent developments include the use of solid-state controls, which are more reliable than electromechanical types, and the containment of hydraulic mechanisms and electric motors in protective cases. Additional protection against shock loadings have also been incorporated.

A particularly complex spreader design is the rotary spreader, with the facility for rotating the container during the lift. Its application is largely restricted to handling containers onto RoRo vessels, where they might be stowed athwartships; it is not widely used.
2.6 Features to look out for

2.6.1 The crane must be prevented from being moved along the rails in high winds, by securing pins. In parts of the world subject to cyclones, additional securing devices, such as tie-downs, will be required. The power and braking systems must be sufficient to drive the crane into high winds and to control its movement when running downwind. Early cranes were operationally restricted to maximum windspeeds of 45-55 kph, but the stronger and more rigid current types permit operation at windspeeds of 67-77 kph (Beaufort force 9). A wind gauge and strict operating rules for high wind conditions are essential.

2.6.2 Anti-collision devices are desirable, to ensure that cranes working on the same quay do not come into contact with one another - or effective gantry buffers must be fitted, at the very least.

2.6.3 For driver comfort and safety, trolley drive acceleration/deceleration must be restricted to a maximum of 0.6 metre/second; this is particularly important for cranes with long outreach and high trolley speeds. Developments are taking place to separate the movements of trolley and cab, to avoid that restriction.

2.6.4 European terminal operators place great emphasis on cab design, control layout and driver comfort when preparing their procurement specifications. Good all-round vision is essential, with (in temperate climates) double-glazing and heated windows to prevent condensation. A high level of sound insulation is important, particularly eliminating irritating noises from fittings and components. The amount of light entering the cab from the terminal (e.g. from ship's lights) needs to be controlled, to prevent glare and to ensure that digital displays are easily and accurately read. Adequate heating and ventilation (or, in warmer climates, air conditioning) must be provided for driver comfort, together with well designed seating and ergonomically designed and laid out controls. Particularly where driver interchange is practiced, it is important that control and instrument layout should be standardized between machines on the terminal.

2.6.5 Access stairways (at an angle not exceeding 45°) or (preferably) lifts should be provided for cab access, not ladders.

2.6.6 Overload warning systems and limit switches must be fitted to prevent lifting of overweight, damaged or trapped containers.

2.6.7 Driver-operated or (preferably) automatic warning lights, bells and/or sirens should be fitted to indicate when the crane is moving along its rails.

2.6.8 There should be a strict observance of management rules preventing crane movement and container handling without authorization.

2.6.9 Strictly enforced operating procedures, particularly traffic separation schemes, must be laid down, to prevent damage to containers and equipment and injury to staff.
2.7 Future developments and trends

2.7.1 As has been the case over the past 20 years, future gantry crane development will be dictated by increases in vessel size (notably of beam and freeboard) and container dimensions. These will affect crane lifting capacity, outreach and lift height.

2.7.2 Second trolley systems, introduced in the last three years, are likely to spread steadily, in spite of the additional 25-50% construction costs, as part of the drive (linked with higher trolley travel speeds) for ever shorter crane cycle times. Routine handling of 45-55 containers per hour remains the target.

2.7.3 There might be further development of twin-lift systems, to improve handling rates, but the system does present operational difficulties.

2.7.4 Self-propelled trolleys, already used extensively (particularly with rotating spreaders), might replace rope-driven systems. However, the rope-driven trolley can be accelerated and braked using less power than the heavier self-driven trolley, and traction is also a problem with that type.

2.7.5 The steady increase of working life is likely to continue.

2.7.6 The extent of automation of gantry crane operation is likely to be greatly increased, though industry opinion favours driver-assisted, rather than full, automation. The system will be fully linked to the terminal information system.

2.7.7 Electrical and electromechanical control systems will be increasingly replaced by electronic systems, with an accompanying trend away from analogue to digital control. For example, there has already been a distinct move away from Ward Leonard electromechanical speed control to electronic (thyristor) control, to increase hoist and trolley speeds. However, it is sometimes argued that in developing countries the simpler, more robust and more easily maintained electromechanical systems have advantages.

2.7.8 Diagnostic sensing systems will be introduced to monitor crane operations, to reduce maintenance costs, and condition monitoring of cranes and spreaders will become common.

2.7.9 Research and development will result in improved construction materials for spreader beams, improving reliability and lifespan, even with more intensive use.

2.7.10 Better design will lead to improved access for maintenance.

2.7.11 More complete enclosure or encapsulation of electronic and other components, with air-conditioning where moisture control is necessary, will greatly extend their life and reliability, particularly in regions of high humidity; they will be given guaranteed lifespans.
2.7.12 Intervals between maintenance checks, services and overhauls will be increased.

2.7.13 The continued drive for improved operational efficiency will put pressure on ports to refurbish and modify their existing cranes and increase their degree of automation.
Chapter 3

STRADDOLE CARRIERS

3.1 Introduction

3.1.1 The straddle carrier is a wheeled frame which lifts and transports a load within its framework. In spite of problems with the earliest generations of straddle carriers, they are still the most popular form of container-lifting device; 1600 of them had been sold by the beginning of 1985, and the current market is about 100-120 machines a year worldwide, at a price of around $500,000.

3.1.2 The popularity of the straddle carrier is undoubtedly due to its versatility; it can perform all activities within a container terminal. In an all-straddle carrier operation, known as the Straddle Carrier Direct system, the machines are used both to transfer containers between the quayside and the container yard and to stack them in the yard; they are also used for intermodal movements in receipt-delivery and for movement to and from the CFS. In the Straddle Carrier Relay and various combination systems the machines are used for stacking in the container yard and for working at the grid, while other equipment services the Quay Transfer Operation and moves containers about the terminal.

So the key to the straddle carrier's popularity is its operational flexibility, its ability to move anywhere in the terminal as needed, to perform any of a wide range of activities. It also has considerable selectivity; it can move quickly and directly to the required working position and gain rapid access to the container or storage slot.

3.1.3 The straddle carrier has a long history, but was first built for moving containers (as a 'van carrier') in 1957 by the Clark Equipment Co. Initially it was designed for carrying 24' boxes weighing up to 20 tonnes, and stacking them one-over-one, i.e. it could traverse a row of containers, carrying one under its arch, and stack that one on top of a grounded container.

Straddle carrier production really got under way in 1965, when it was built for ISO boxes and could stack 20' boxes one-over-two. By 1967, straddle carriers were also being built by Belotti, TCM and Mitsubishi, and by 1968 these manufacturers had been joined by Peiner, Demag and Rubery-Owen.

3.1.4 Early models had 6 wheels and were driven by a hydraulic system or chain drive. Both systems had deficiencies: hydraulic systems leaked, making terminal surfaces dangerous; chain-drives lost tension, posed safety
problems and were easily damaged. Early models also experienced problems with their 'rising arch' design, in which the upper part of the frame, together with the cab and the hoist mechanism, telescoped within the lower frame to allow pickup/delivery below the legs of the ship-to-shore gantry cranes existing then, which had low portal clearance. The rising arch suffered high stress on the tops of the lift-cylinder rods. Fixed frames, built to traverse up to 3-high stacks (i.e. to stack 'one-over-two') were an early improvement, but could not pass under the legs of many existing gantry cranes.

The changes, in 1975-76, to diesel-electric drive (Nelcon) and to shaft-drive (others) were both major improvements, and the increase from 6 to 8 wheels, with 2, 4 or all of them driven, was another development. Ferranti took over Clark in 1977 and Rubery-Owen in 1978, and improved the earliest of the straddle carrier designs.

3.1.5 There are now two main types of carrier: twin-engined, low-mounted types and single-engined, top-mounted ones. Almost all are now fixed-arch, shaft-driven and 8-wheeled, with ram or motor lift, usually hydraulic. 3-high stacking is still favourite (about 80% of total sales), though a range stacking from 2-high to 5-high is available. 6-wheeled and 10-wheeled alternative designs are also available.

3.2 Specifications

3.2.1 The steel framework of a straddle carrier is built of tubular or (more often now) girder or box-section steel. Current machines have the following range of principal dimensions and operational specifications:

3.2.2 Overall Height varies between about 9 metres (for rising arch and smaller fixed-arch designs) and 15 metres (for those stacking 1-over-3); 1-over-4 machines have an overall height of about 17.5 m. This dimension is important in relation to clearance under fixed equipment, e.g. the legs of a quayside gantry crane, and quayside work is restricted for practical purposes to 1-over-2 stackers.

3.2.3 Lift Height (below the spreader) determines the stacking capability of the machine. Choices of 5.5 metres, 9 metres and 11.7 metres lift height are commonly available, allowing 1-over-1, 1-over-2 and 1-over-3 stacking respectively. Lift height could be a critical feature if box dimensions increase in the future. A machine just capable of stacking 8'6" boxes 1-over-3 will not be able to stack 9' or 9'6" boxes to that height.

3.2.4 Overall Length can be as small as 9.0 - 9.5m, in which case a 40' container will project to the front and rear when being carried, but many machines now have lengths of about 12.3 metres (i.e. length of 40' box) so that the container is protected (by some sort of buffer/bumper) during transport. When considering terminal design, the length of the carrier is not likely to be the only significant factor, of course; the long dimension of the container will often determine the maneuvering space required, or the position of the cab, if it projects significantly to the front or side.

3.2.5 Inside Width is about 3.0 to 3.5 metres for general-purpose, container
yard straddle carriers, 3.5 to 4.0 metres for machines used at rail terminals (so that the carrier can traverse a train of rail wagons). This dimension could be significant if box widths increase beyond the present 8' width, as is being actively considered at the moment; spreaders for 8'6" wide boxes may not be usable within the narrower-framed machines.

3.2.6 Outside Width varies between the 4.3 to 4.5 metres of general-purpose straddle carriers and the 4.8 to 4.9 metres of machines designed for rail terminals. Clearly, this dimension largely determines row spacing in the container yard and, consequently, stacking density.

3.2.7 Minimum Outer Turning Radius varies between 9.2 and 10.9 metres. This influences access aisleway width; aisleways about 20 metres wide will allow left- and right-turning straddle carriers to move simultaneously in the same aisleway.

3.2.8 The Weight of the machine is from about 48 to about 58 tonnes unladen and up to 90 tonnes when carrying a full 40' container. The significance of this lies in the demands made on the terminal surface. The important factor is, of course, Wheel Loading: how much weight is transmitted to the pavement under each wheel. This will also depend on the number of wheels (4, 6, 8 or 10). Quoted static wheel loadings vary from 9 tonnes beneath each wheel to 12 tonnes. The number of wheels could, therefore, be an important factor when choosing equipment for a specific terminal, to suit sub-surface conditions. A 10-wheeled straddle carrier, even if more expensive than a 6-wheeled machine, might be more economical if it allows a less expensive terminal paving to be used. However, dynamic loading is just as important; the full weight of the vehicle is thrown onto fewer wheels when turning or braking, and constant subjection to such loads can cause the terminal surface to be rippled.

3.2.9 Lift Capacity is now at least 30.5 tonnes under the spreader (sufficient for current 40' loaded containers) and is commonly 35 or even 40 tonnes; it is worth considering the larger capacity machines when buying now, to prepare for possible increased ISO sizes over the next 15 to 20 years.

3.3 Operations

3.3.1 In the Straddle Carrier Direct system, the container yard is laid out in a series of blocks, each block containing 20-40 rows, 10 to 20 TEU slots long (60-120 m), with wheel-spaces between the rows of 1.5-1.8 metres (depending on drivers' skill and machine width). Between the blocks are access aisleways between 17.5 and 20 metres wide, allowing straddle carriers to pass each other safely at speed and to turn through right angles into the rows. The rows run at right angles to the quay, to reduce travel distances to a minimum, and the rows are kept relatively short for the same reason. Longer rows also tend to increase the risk of damage (as the straddle carriers travel along them to and from the target ground-slot), as well as reducing accessibility to the containers in stack. The yard surface needs to be able to bear the weight of the machines (70 to 90 tonnes when loaded) without serious wear; static loads of 20 tonnes/m² or more have to be withstood. Levelness and smoothness of the surface are equally important, to minimize wear and tear on the straddle carriers when moving at speed and to preserve their stability.
3.3.2 Export containers are normally stacked 2 or 3 high, in a block near the quayside. Imports are stacked in a block to the landside (stacked alternately one and two high within a row, for easy access without excessive shifting), while empties are stacked 3 to 4 high (often by lift-trucks, in a block well away from the operational part of the container yard). So the average stacking heights are 1.5 for imports, 2.5 for exports and 3.5 for empties. This explains why the most popular straddle carrier type is still the 3-high stacker (1-over-2) - this suits most statuses of boxes under most circumstances. There is good utilization of space with this system - up to 400 TEU per hectare is easily possible for import-export areas, and higher than that for empties stacked in their 'empties pool'.

3.3.3 The less desirable operational feature of the straddle carrier is the risk of damage to containers and equipment because of the high travel speeds, the narrowness of the wheel spaces (necessary to achieve high stacking densities) and the height of the driver's cab - some 10 to 12 metres above the yard surface. The driver's view of the box and stack is also restricted from some angles, so driver skill is obviously an important factor in this context, and cab/control design must minimize fatigue. Damage is commonly caused to boxes by misjudgement of the height of the transported box above the stack; it is usual now to lift and lower boxes while travelling, which adds to this danger.

3.3.4 For a two-crane operation, six straddle carriers are commonly used on quay transfer when discharging, four when loading, so mean equipment requirement on quay transfer is five machines. Four other straddle carriers are needed for receipt/delivery, one on CFS duties and two in maintenance/reserve. A useful equipment deployment figure, then, would be about 12 carriers per two-crane terminal 'unit'. Manning is commonly at the rate of three drivers for two straddle carriers (allowing for relief changes within shifts and continuous operation throughout a shift) - that's about 18 drivers per shift. So total manning (including the quayside gantry crane, supervision, checking, etc.) is normally 28 men per two-crane 'unit' per shift. Straddle carrier drivers need to be skilled and well trained; some three months of classroom, practical and on-the-job training are needed.

3.3.5 In the Straddle Carrier Relay system, the quay transfer operation is performed by terminal tractor-trailer sets. The straddle carriers pick up containers from an interchange point and stack them in rows, while the tractors take the empty trailers back to the quay apron, etc. Carriers also move containers between the yard and inland transport at a grid. Container yard layout is in blocks and rows, as for the Direct system, but the rows are here parallel to the quay, to provide an interchange point for the blocks, at which the tractor-trailer sets transfer their boxes.

3.3.6 The Relay operation requires fewer straddle carriers than the Direct system. For a 2-crane operation, three or four straddles are needed for stacking in the container yard, another three or four on receipt/delivery, one on CFS duties and two in reserve - say 10 machines altogether. In addition, six to eight tractor-trailer sets are needed for quay transfer, so manning for the relay operation requires 15 straddle carrier drivers and eight tractor drivers, plus the crane drivers, supervisors, etc. - about 33 men per shift altogether for a two-crane 'unit'.

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3.3.7 The Straddle Carrier Relay system is attractive where quay transfer distances are long, as tractor-trailer sets are more appropriate for long quay transfers. Another advantage, compared with the Direct system, is the slight reduction in capital outlay – two fewer straddle carriers per two-crane 'unit'. The tractor-trailer sets used instead for quay transfer are much cheaper to buy, and are also more robust and cheaper to operate and maintain, while driver skill is less demanding. There is also less wear and tear on the straddle carriers when they are not used for quay transfer, which reduces demand on maintenance.

3.4 Performance

3.4.1 The number of container moves possible per hour depends on a number of factors: travel distance, travel speed, hoist speed, ease of access and the nature of the straddle carrier activity. It is difficult, therefore, to quote a useful 'average' handling rate for a straddle carrier, when it will vary with circumstances – is the straddle carrier on quay transfer duty, stacking in the yard, handling imports, exports or empties, etc.? However, some estimates can be made, based on specifications and standard terminal layouts. For example, straddle carrier travel speeds range between 20 and 30 kph empty, 17 and 25 kph loaded; hoist speeds range between 10 and 30 metres/minute empty, 8 and 18 metres/minute loaded. Straddle carriers are certainly capable now of achieving 20 moves/hour in a Direct operation under favourable conditions, but a sustained quay transfer handling rate of between 12 and 15 moves/hour (depending on travel distance) is more realistic. This compares favourably with the figure of 8 moves/hour accepted for the earliest straddle carriers. However, handling rates for Receipt/Delivery and CFS activities will be lower, and so an overall average rate, for all terminal activities, of 12 moves/operating hour is probably a useful estimate for calculations based on throughput.

3.4.2 For planning purposes, when estimating equipment demand, a factor of one straddle carrier per 8000-10,000 box throughput was common for older machines, but for current models a figure of one per 12,000-14,000 box throughput is more appropriate. Based on a range of 2.5 to 3 moves per box transit, this amounts to between 25,000 and 40,000 lifts per machine per year.

3.4.3 Availability figures for straddle carriers are currently much better than, say, ten years ago. Based on a possible operating month of 600 hours, values of 60% (for existing older machines) to 95% (for newer designs) are quoted, with 85% as a reasonable average now. Utilization is relatively low, however; figures as low as 80 hours per month per machine are quoted, though a more usual range is between 200 and 400 hours a month. A mean figure of 300 hours a month would represent a Utilization of only about 50% of the Available Machine Hours, which indicates that ports are 'over-stocking' with these machines to cope with peak demand, and that they spend a large part of their lives unused.

3.4.4 Downtime figures quoted by ports are extremely variable and a wide variety of formulae are clearly used in calculating them. However, if an Availability value of 85% is accepted as a working average, then total Downtime must be 15% of operational time – about 90 hours per month. Of
this total, about 25% is planned Downtime (preventive maintenance) and 75% of it unplanned repair of equipment breakdown and damage.

3.4.5 Operating Costs average about $240,000 a year; this represents about 50% of the purchase price per year. Fuel, used at a rate of about 20 litres/working hour, is estimated as contributing (with lubricants) about 10% of the operating costs, while maintenance, including replacement materials such as tyres and batteries, contributes about 25%. Driver costs can amount to 65% of annual operating costs.

3.4.6 The Working Life of a new straddle carrier should be at least 15 years (say 50,000 hours) but, for calculating operating costs, we'll assume a life of 12 years and a purchase price of $500,000. At a Discount Factor of 12%, the Annual Capital Recovery is about $81,000. When this is added to the operating cost of $240,000 a year, the total annual cost amounts to about $321,000. Assuming further that the machine operates for about 3500 hours a year, we can estimate the total cost per hour as about $92. If the average handling rate is 12 moves/hour, the cost for handling each container comes to about $7.5.

3.5 Maintenance

3.5.1 Regularity of servicing is vital, but intervals vary widely from port to port, manufacturer to manufacturer. The commonest intervals are 500-1000- and 2000-hour services, but some ports carry out a 250-hour service, too. Major overhauls, including engines, are carried out at 10,000, 15,000 or even 30,000 hours; the interval depends on local operating conditions and circumstances. Service intervals certainly seem to be increasing, and 1000-hour intervals are likely to become the norm. On average, straddle carriers spend about 20 hours a month on routine servicing (about 25% of total Downtime), the other 70 hours or so being on-location or in-workshop repairs of breakdowns or accidental damage.

3.5.2 The causes of unscheduled repairs can be categorized as electrical, mechanical or hydraulic, but the commonest causes are problems with electrical components; failures involving electrical systems, alone or in combination with other faults, account for between half and two-thirds of all defects. The commonest electrical faults involve mechanical switches, microswitches and relays, which are susceptible to damage/deterioration through vibration. The solution to these problems seems to be to replace the components with proximity switches, solid state devices and printed circuit wiring. The most vulnerable part of a straddle carrier is undoubtedly the spreader, which suffers electrical, mechanical and hydraulic problems. To help to eliminate these, Valmet has removed all electrical and most electromechanical components (all junction boxes, relays and switches) from the spreader and placed them in a weatherproof box on the top platform of the machine.

3.5.3 The annual Maintenance Cost is currently estimated variously as between 8% and 15% of purchase price, i.e. $40,000 to $70,000 a year, with a mean of about 12% ($60,000 a year); this agrees well with the estimated 25% of total operating costs ascribed to maintenance. Labour contributes about 35% of maintenance costs - some 60-90 man-hours per month on average. About $35,000 (60%) are spent on replacement parts per machine per year,
including tyres and batteries, with about $20,000 worth of spares being kept in stock. Other consumables contribute the remaining 5% of maintenance costs ($3000). Tyres last anything from 2000 hours to 4000 hours, depending on manufacturer, type and operating conditions; in practice, the cause of replacement is frequently damage, not wear. Batteries last about two years in Europe, but possibly as little as one year in the tropics. The cost of replacement tyres and batteries is typically between $12,000 and $16,000 a year.

3.5.4 In addition to the normal tools and workshops, straddle carriers require specially built and expensive maintenance facilities, consisting of a tall workshop (to accommodate the largest machine owned or contemplated) fitted with fully adjustable access towers, walkways and platforms and an overhead crane. However, for some of the latest designs of straddle carrier it is claimed that the built-in ladders and platforms permit sufficient access, without the need for towers. A mobile facility, in the form of specially fitted vans, is necessary for attending to repair work on location. Each van needs to be fully equipped, including electrical test gear and welding equipment. Some form of mobile elevating platform may also be necessary.

3.5.5 Maintenance staff have to be particularly skilled and well-trained to be able to service and repair electrical, mechanical and hydraulic systems of high complexity; diagnosis of faults is the major problem. Specialist mechanical/hydraulic and electrical/electronic maintenance teams are sometimes employed. Training schemes of three years or more are considered necessary, with additional training by manufacturers when new machines are purchased. Knowledge of data-communication systems is becoming increasingly necessary.

3.6 Features to look out for

3.6.1 Shaft drive is to be preferred to hydraulics, because of the risk of fluid leaks from the latter, leading to dangerous terminal surfaces.

3.6.2 The fixed arch design is more reliable than a rising arch, which puts strain on vertical hydraulic cylinders, but rising arch straddle carriers are useful where older ship-shore gantries are in use, with low portal clearance.

3.6.3 Wheels and other external components are vulnerable to contact damage, so bogie girders, bumper plates and similar protective devices are needed. Hydraulic pipes, cables and other vulnerable components must be placed so that they cannot be damaged by impact with a container or port structure. The terminal surface must be kept free from obstacles at all times.

3.6.4 The machine's centre of gravity needs to be as low as possible, for maximum stability when cornering on full lock; figures vary between 3.3 and 4.2 metres above the ground. Good designs will have all heavy components positioned as low as possible on the frame. Safe cornering speeds on full lock are given as between 12 and 22.5 kph, but it is probably wise to keep nearer the former speed than the latter, and to enforce the terminal's maximum cornering speed strictly.
3.6.5 Cab location and structure need to be designed for maximum driver vision; closed circuit television has been tried as an aid to cover blindspots, but has not proved successful. All manufacturers claim maximum driver field of view, though cab position varies from a high, central one within the frame profile to a position on the front or side (i.e. outside the frame) of an upper support column. The proportion of cab window and floor glass has steadily increased over the years; in some 1975 models, 83% of the view below six feet above the ground was obscured from the driver's position.

3.6.6 The cab layout and design should maximize driver comfort: seat design and adjustability (some rotate through 180° to suit both directions of travel); roominess; quietness (noise is a critical factor - the engine is preferably low-mounted and distant from the cab, and good insulation is required; 65 dBA can be achieved); good instrument layout; control of ventilation, heating and cooling, as appropriate; ease of access (via a safe, protected ladder to a railed platform alongside the cab) with an emergency escape system (a hatch plus a safety rope or lowering harness).

3.6.7 Important safety features include: warning lights, horns and/or bells to indicate that a machine is moving; multiple/split braking systems with a separate parking brake; all wheels should have brakes; electronic load-limiting and overload warning devices on the hoist; emergency stop and auto-shutdown systems; handrails and non-slip surfaces for maintenance platforms; a brightly coloured paint finish.

3.6.8 Servicing and maintenance features: easy access to engines, lubrication points and check-points; simplicity of control systems for ease of maintenance; avoid high-voltage generators (as in diesel-electric systems) as they cause maintenance problems; high level of skill and training required in maintenance staff.

3.6.9 Drivers need to be carefully selected and well-trained. They should be physically fit, able to climb and work at height, have good eyesight, be able to work alone for long periods, and be able to handle complex controls under demanding circumstances while communicating through radio or data links. Technical and engineering ability and understanding are helpful, though not essential.

3.7 Future developments and trends

3.7.1 Improved information/communication systems; radio communication links are likely to become increasingly supplemented by full data links.

3.7.2 Increased automation: automatic location of containers and transfer of container information to and from a central computer.

3.7.3 Even better all-round vision for the driver, by improved siting of the cab with respect to the frame.

3.7.4 Improved maintainability, through reduced numbers of components, increased robustness and protection of parts, increased use of solid-state
controls, printed circuit wiring; improved hydraulic systems; increased intervals between services; built-in fault diagnostics and remote condition sensing.

3.7.5 Relocation of electrical and other components away from the spreader and other vulnerable areas.

3.7.6 Higher lifting power, to match increases in container weights and dimensions; 40-tonne capacity machines are already available from Ferranti, Mitsubishi, Nelcon, Peiner, TCM and Valmet.

3.7.7 Higher stacking machines are already available - up to 5-high - but stacking height is operationally determined, and 3-high stacking seems likely to remain the most popular. However, if container dimensions increase, even a one-over-three stacker will have to have increased lift height, of course, and inside width may also have to be increased.

3.7.8 Increased travel speeds are a possible development, but safety factors will probably limit further increases.
Chapter 4

RUBBER TYRED YARD GANTRY CRANES

4.1 Introduction

4.1.1 Yard Gantry Cranes or Transfer Cranes were a development of industrial overhead cranes. There are two distinct types. Rubber-tyred gantry cranes (frequently referred to by the Paceco brand name, 'Transtainer', or just as 'RTGs') run on heavy-duty tyred wheels (of straddle carrier type, in the main) while rail-mounted gantry cranes run on steel wheels over fixed rails, 100 to 125 mm wide. Although these two types of transfer cranes serve the same function, there are distinct differences between them, apart from their wheels, and they will be considered in separate chapters in this account.

4.1.2 Superficially resembling 'stretched' straddle carriers, rubber-tyred gantry cranes span several rows of containers and can stack them up to five high (one-over-four). Yard gantry cranes are essentially container yard stacking devices and are used in combination with other container-handling equipment, usually tractor-trailer sets, for the Quay Transfer Operation. Tractor-trailer sets are also needed for other duties, including movement to and from the CFS. At the CFS, the box is either left on the trailer for packing/unpacking or is lifted off the trailer by yet more equipment, usually a lift-truck.

4.1.3 Rubber-tyred gantry cranes were first built by Paceco around 1960, and Drott-built machines began to be installed in 1969. By the beginning of 1970, some 25 machines had been commissioned and in that year another 22 were installed, by several manufacturers. Deliveries then increased steadily and by 1981 over 300 were in use, two-thirds of them built by Paceco and its world-wide licencees. By 1985 nearly 500 machines had been installed, over half of them Paceco types. Hitachi, which supplied its first yard gantry crane in 1974, is now the second biggest supplier.

4.1.4 Port operators tend to suggest that rubber-tyred gantry cranes are becoming relatively more popular, at the expense of straddle carriers, but published figures indicate steady growth, paralleling that of straddle carriers which are maintaining their popularity well. The most recent orders favour rubber-tyred gantries rather more, and almost all World Bank financed container terminal projects have lately included the purchase of these machines.

4.1.5 The early rubber-tyred yard gantry cranes had a variety of spans, from 8 metres (covering just two container rows and a roadway) to over 25 metres, but the range of 20-23.5 metres soon established itself as the
most popular; such cranes span 5 or 6 rows of containers and a roadway. Indeed, although cranes spanning 7 rows and the roadway (27 metre span) are now available (and probably represent an upper limit to rubber-tyred gantry size), the 5 or 6 rows plus roadway design remains the most popular. Smaller machines are, however, still available for special purposes, e.g. a 12 metres (three rows plus roadway) by Valmet.

4.1.6 Stacking height has increased markedly. The first Paceco transtainers stacked one-over-one (8'6" boxes) and it was not until 1972 that a gantry stacking one-over-three was built, while the first one-over-four appeared in 1982. Currently, one-over-three and one-over-four designs are equally popular, though Paceco and Valmet still make one-over-two machines, too. Four-high stackers are made by Paceco, Mitsubishi and Marathon, while five-high cranes are built by Paceco, Mitsubishi, Nelcon, Morris, Valmet, MGM-IHI and Hyundai. Current models stack 9'6" boxes to their rated height.

4.1.7 As with other container-handling systems, a general trend has been the increase of lifting capacity, from 22 tonnes in early units to over 40 tonnes in current models. Box length is not a problem with rubber-tyred gantries, as boxes are not handled through the framework.

4.1.8 Early RTGs had just four wheels, but an important development has been the introduction of 8-wheeled and 16-wheeled cranes, designed to spread the weight of the crane over a larger terminal surface area; 16-wheeled cranes are available from Morris, MGM, Nelcon and Peiner. The motive power for rubber-tyred gantries is diesel or (more commonly now) diesel-electric. Their power has increased steadily, giving higher hoist and trolley speeds in current machines.

4.1.9 A major development has been the introduction and elaboration of automatic location systems, sending the crane to the correct block position and row, and even locating the individual box in the row. Steering along the block is still normally a manual operation, though fully automatic steering is foreseen.

4.2 Specifications

4.2.1 Rubber-tyred gantry cranes have a massive framework of box-section steel, with an Overall Height of about 17-19 metres and Spans generally between 19.8 and 26.5 metres. Overall Lengths of the framework vary between 9.3 metres (on 4-wheeled machines) and 11.6 metres (for 8-wheeled gantries) or more.

4.2.2 Lift Height Under the Spreader is very similar, of course, to that of equivalent straddle carriers: from 11.0 to 12.2 metres (on the four-high stackers) to 13.6 to 15.1 metres (on the five-high stackers); the larger figures in each case are for the latest machines, built to handle containers up to 9'6" high. Lift Capacity can be 30.5 tonnes, 35.5 tonnes or 40 tonnes under the spreader, according to choice.

4.2.3 The framework is, understandably, extremely heavy; the Weight of the machine and load is between 100 and 140 tonnes when carrying a loaded 40' container. The distributed load is about 50 tonnes per wheel for
four-wheeled machines but only about 13-16 tonnes per wheel for the newer 16-wheeled designs. These values are extremely significant in terms of terminal surface construction; it is common for RTGs to require special weight-bearing, narrow roadways or runways along which the wheels can run, with reinforced concrete beams or similar load-bearing systems, while the rest of the yard is surfaced with relatively light-duty pavement. However, steel turning plates may need to be embedded within the surface at the ends of blocks, so that the machines can turn their wheels through 90° to move to another block.

Because of their lower wheel loadings, the 16-wheeled gantries may not require reinforced runways and, as their wheels are carried in pairs on bogies, and rotate as the bogies turn, steel turning plates are not required, either. So 16-wheeled RTGs would appear to offer the terminal designer considerably more flexibility, when modifying the layout to meet changed traffic and other circumstances, than machines with 4 or 8 wheels.

4.3 Operations

4.3.1 Rubber-tyred yard gantries operate exclusively in the container yard. Transfer between the ship-side and the container yard is carried out (usually) by tractor-trailer sets. These drive along the roadway or 'truck lane', generally within the span of the gantry, to pick up or deliver their containers, while the gantry crane moves the containers between the trailers and the stacks and shifts the boxes within the stack. For receipt/delivery, road vehicles are allowed onto the terminal and along the roadway to the appropriate row; there is not normally an interchange point in this system as there is with straddle carrier systems.

4.3.2 The containers within the storage area are normally arranged in long rows parallel to the quayside, with about 30 TEU slots per row (which is thus about 200 metres long). There are usually five or six rows per block, plus the truck lane, giving a total block width of 22.5 to 26.5 metres. At the ends of the blocks are roadways about 20 metres wide, and an extra roadway space is provided between adjacent blocks. The wheels of the rubber-tyred gantries can turn through a right angle, so that the equipment can be moved from one storage block to another as required, to meet operational needs; while RTGs are not as operationally flexible as straddle carriers, they do offer a degree of flexibility in this way.

4.3.2 The main attraction of yard gantry systems is their economical use of land area because the machines stack high and densely; wheelspaces are not needed between container rows. Average operational stacking heights with RTGs are 2.5 for imports and 3.5 for exports; the 1985 Containerisation International survey gives a mean stacking height for all yard gantry systems as three boxes. Assuming a 50:50 import/export split, about 700 TEUs can be stacked per hectare. Not surprisingly, then, it is the larger terminals, with high throughputs, that favour yard gantries: one-third of terminals with 10,000 TEU container yard capacities use these systems. RTG systems are also attractive where land area for stacking is limited. However, the high and dense stacking means that terminal planning and container control need to be particularly efficient if delays, congestion and other operational problems are to be avoided.
4.3.4 **Operating Costs** are moderately high for rubber-tyred yard gantry cranes. The purchase price of an RTG is about $750,000-900,000, and annual operating costs amount to about $250,000 per machine, i.e. about 30% of purchase price. Of total operating costs, about 60% is accounted for by labour costs (in Europe, at least), 15% by fuel and lubricants (machines consume 18-20 litres of fuel per operating hour) and 25% by preventive maintenance and repair.

4.4 **Performance**

4.4.1 Rubber-tyred Gantry Cranes are only moderately rapid machines in operation, with travel speeds of 90-150 m/minute (5.5-9 kph) - about half the speed of straddle carriers - and transverse trolley speeds of 50-70 m/minute. Hoist speeds vary between 9 and 23 m/minute when lifting a container, 18 and 49 m/minute when empty; the higher values are available with newer, 'high-speed' machines.

4.4.2 As with other handling systems, operating performance varies with demand and distance travelled between moves, and will obviously be heavily dependent on the ability of the quay transfer equipment to 'service' the gantry cranes. The port of Felixstowe reports a performance of 30-35 moves/hour at peak and an average of 20 moves/hour. The Containerisation International (1985) survey found rates of 18/hour (Australasia) to 27/hour (North America), with an 'average' of 21 moves/hour. Krupp RTGs at Hamburg move about 18 boxes/hour. A realistic attainable average performance over a shift, including moves between blocks, would seem to be about 20 boxes/hour. Assuming an average usage of about 65 hours a week, this would represent an annual performance of about 65,000 box moves per machine.

4.4.3 For a two-quayside-crane operation, each crane handling about 25 boxes per hour, about three RTGs will be needed in the container yard handling the containers to and from the quay-transfer equipment (six to eight tractor-trailer sets per 2-crane 'unit'), with another one or two on receipt/delivery and handling to vehicles for CFS work, and one in reserve - say six machines per 2-crane 'unit'. Felixstowe has 31 RTGs altogether, serving a total of 13 quayside gantry cranes, on the basis of one RTG for every 20,000 containers handled through the terminal. At the high stacking densities of RTG container yards, it is estimated that each box has to be handled between 3 and 3.5 times during its transit through the terminal, so the performance rate is between 60,000 and 70,000 lifts per machine per year.

4.4.4 **Manning** is normally two men per RTG - one driving and one acting as checker in the ground-level cab, so that total manning for a 2-quayside crane 'unit', including drivers for the quay-transfer tractors, supervisors, etc., would be about 30-32 men. While the RTG drivers need to be very highly skilled, the tractor drivers need only moderate levels of skill. RTG drivers should be given about three months' training, including sessions on operational and safety aspects of the job and on-the-job training with an expert. Strict performance tests must be given during and after training.
4.4.5 Availability figures for RTGs are usually quoted in the range 90-95%, though one operator (Glebe Island Terminals) reports only 65-75%, saying that its RTGs "incur the greatest downtime of all their equipment, because of continuous rough usage". Figures for Utilization are generally low, e.g. about 40% (of total hours, i.e. about 250 hours per month). The Containerisation International (1985) survey confirms an 'average' usage (for all types of yard gantry crane) of about 250 hours per month, varying between 170 hours/month in North America and over 300 hours/month in Australasia. Clearly, ports are 'overstocked' with yard gantry cranes to cover peak demand, and Availability is unlikely to be a problem.

4.4.6 Downtime is said to average about 25 hours/month (about 4-5% of working hours), but varies widely, from about 7 hours per month in North America to 48 hours/month in Latin America. The 25 hour figure could well represent 'unplanned' Downtime only, since the Port of Singapore records show that 13 days each year are set aside for planned maintenance per machine - say 26 hours per month. Total Downtime is more likely, therefore, to average about 50 hours a month - say 8%.

4.4.7 The Working Life of a RTG is currently at least 15 years, at an operating rate of 3000-3500 hours per year, giving at least 45,000 working hours over its life. The latest generation of machines should, in fact, comfortably exceed this lifespan, performing perhaps a million moves in a 20-year life (provided the machine is well looked after). At a purchase price of $850,000 and an operational life of 15 years, the Annual Capital Recovery (at a discount rate of 12%) is $125,000. With operating costs at $250,000 a year, Total Annual Costs are thus about $375,000. At 3000 working hours a year, the cost works out at about $125 an hour and the handling cost, at 20 moves/hour, is about $6.25/move.

4.5 Maintenance

4.5.1 The Port of Singapore plans 13 days of preventive maintenance per year for its RTGs, and its Availability figures indicate some 30-60 hours a month of maintenance and repair time, with perhaps 15-30 hours of unplanned Downtime. The Containerisation International (1985) survey shows that 60% of repair jobs are to do with electrical faults and a further 8% with combinations of electrical and hydraulic or mechanical defects. Minor electrical faults, particularly involving electrical drives and control systems, account for most maintenance and repair jobs, but other causes of breakdowns are anti-sway system faults, hydraulic leaks and seals, and problems with hoist ropes. Accidental damage accounts for less than 1% of defects, and spreader damage probably accounts for most of this.

4.5.2 The Maintenance Cost is about 8% of purchase price per year - some $60,000-70,000 per year. Maintenance costs for RTG terminals worldwide were given in the Containerisation International (1985) survey as varying from $10,000 to over $40,000 per machine per year, with an average of about $35,000, but it seems likely that these figures did not include labour costs, which make up about 65% of total maintenance costs. Spares (including tyres and batteries) account for about 30% of the costs and consumables the remaining 5%. Tyres currently have lives of 4-5 years on
four-wheel RTGs and up to ten years on multi-wheel-axle types; they cost about $1600 each. Batteries last 4-6 years in temperate climates.

4.5.3 Maintenance is carried out according to strict schedules, out of operating hours, and two-weekly inspections of the spreader and anti-sway gear are particularly critical. Electric motors are checked every 1000 hours, with major inspections and greasing at six-monthly intervals. Greasing of wheel and sheave bearings are most important. The diesel engines are overhauled at intervals of 16,000-18,000 hours.

4.5.4 Since it is not practicable to service RTGs under cover, mobile workshops are needed, and platforms to enable easy high-level maintenance, so that maintenance and repair can be undertaken on site. However, workshop facilities are needed to test, maintain and repair the machines' subassemblies, e.g. the spreader, engines and motors. As well as normal mechanical and electrical tools, special tools and jigs are needed for some components.

4.5.5 Maintenance personnel require the usual mechanical and electrical skills, with specific knowledge of diesel engines, electric motors and of welding. As electronic and communications systems increase in importance, electronic repair skills are increasingly demanded. It is usual for maintenance staff to have, in addition to standard initial training (e.g. through apprenticeship), specialized training provided by the port, by manufacturers or by specialists.

4.6 Features to look out for

4.6.1 Components and parts of the framework at low levels need to be protected by buffers, fenders, etc. against accidental damage.

4.6.2 Electronic and other delicate components should be enclosed, sealed or encapsulated. This is particularly important in regions of high humidity.

4.6.3 Drivers need to be carefully selected for fitness and aptitude (good eyesight, distance-judgement, coordination, capable of climbing to and working at heights, to work alone and concentrate for long periods, while maintaining contact with other staff through radio and data links) and fully trained for the job. Technical/engineering knowledge and aptitude would be useful but are not essential.

4.6.4 The cab should be well designed for the driver's comfort: comfortable and fully adjustable seating, the seat rotatable through 180° for safe and convenient driving in both directions; well positioned and laid-out controls and instruments; clear vision in all directions; appropriate heating/demisting/cooling/air conditioning, to suit the climate; good sound insulation; adequate access via protected stairs, not ladders, and an emergency escape route.

4.6.5 A checker/tallyman cab should be provided at ground level, with full communication with the driver's cab.

4.6.6 Warning devices, such as flashing lights, bells and/or sirens, should be fitted to indicate when the crane is moving.
4.6.7 Clear lane marking on the terminal is essential, as tractor-trailer sets and road vehicles share space with the container-handling equipment; operating rules must be strictly observed.

4.6.8 The framework needs to be particularly rigid and 'stiff' to create a stable platform for container handling, and 'soft' tyres should be avoided, for the same reason. The frame needs to be strong enough to cope with differences in level of the yard surface without excessive distortion.

4.6.9 Access to all service points and checkpoints must be rapid, easy and full.

4.6.10 Effective communication systems need to be installed, using radio and data links with central information and control systems.

4.7 Future developments and trends

4.7.1 Radio communication links are likely to be increasingly supplemented by data links.

4.7.2 Automation is certain to become more common. Already, systems are available for automatic positioning along a block and to a slot in the row, but steering and container pickup and positioning are still normally under manual control; more complete automation, including container identification, is likely to develop and spread.

4.7.3 Dimensions are unlikely to change appreciably; it is generally thought that machines straddling seven lanes plus a roadway and stacking one over four represent the practical limit of RTG development. However, changes in container dimensions may well cause relatively small increases in height and span to continue to accommodate the same number of rows and stack height. Lift capacity is also likely to increase to match container weights.

4.7.4 Remote sensing and reporting of critical component condition is likely to be widely adopted, with accompanying automatic fault diagnostic devices.

4.7.5 Mechanical and electrical components will be improved, to reduce Downtime and extend lifespans and maintenance intervals. The use of thyristor controls will increase.

4.7.6 Increasing standardisation and interchangability of components will make maintenance easier and stocking of spares less critical and expensive.
Chapter 5

RAIL-MOUNTED YARD GANTRY CRANES

5.1 Introduction

5.1.1 Rail-mounted yard gantry cranes, like rubber-tyred gantry cranes, developed from industrial overhead cranes. They span several rows of containers and can stack them up to five high (one-over-four). They run on steel wheels over fixed rails, 100 to 125 mm wide, and are essentially container yard stacking devices. They are used in combination with tractor-trailer sets, (or, in a few cases, straddle carriers) for the Quay Transfer Operation, for CFS duties and other terminal movements.

5.1.2 Rail-mounted gantry cranes were first installed in container yards in 1968, when two Drott cranes and three others were commissioned. Eight more machines were delivered in 1969 (two more Drott, three Pacecos and three others), ten in 1970 (three of them Paceco), 15 in 1971 and 19 in 1972. By 1980, over 150 rail-mounted gantries had been installed, 46 of them by Paceco, 13 Hitachi, 11 Nelcon, 9 Krupp, 8 Mannesmann, 6 Mitsubishi and the 5 early Drott machines. By 1985, 200 rail-mounted gantries were in use. Whereas rubber-tyred gantries are fairly well distributed around the world, the majority of rail-mounted gantries are in Europe (41%), with just 23% of them in North America and 19% in the Far East (1981 data).

5.1.3 It is important to distinguish between two distinct types of rail-mounted gantry crane: those used for stacking in the container yard and those used on receipt/delivery operations at rail terminals. The latter are by far the more common type (possibly accounting for two-thirds of installed gantries); they are generally small gantries, spanning perhaps two or three rail tracks and a roadway. Container yard rail-mounted gantry cranes generally have large spans, and about 65 of these large-span gantries had been installed by 1985, about 40 of them after 1976.

5.1.4 Rail-mounted gantry cranes have become steadily larger since their introduction, as they have become more specialized. Stacking cranes with spans up to 36 metres (covering 12 or 13 rows of containers) were soon joined by larger gantries, with spans of up to 60 metres. The largest type (used at Matson terminals in Los Angeles and Richmond) has a span of over 100 metres. Stacking height seems to have stabilized from earliest days at one-over-four. As with other container-handling systems, a general trend has been the increase of lifting capacity, from 22 tonnes in early units to over 40 tonnes in current models. Rail-mounted gantries are generally electrically powered, by cable or by their own local generators.
5.1.5 The major development has been the introduction and elaboration of automatic systems. Rail-mounted cranes lend themselves to a completely automatic operation, with the driver merely acting as a back-up to the terminal's central computer system. The computer sends the crane to the correct block position and row, and even locates the individual box in the row.

5.2 Specifications

5.2.1 Like RTGs, rail-mounted gantry cranes have a massive framework of box-section steel, though the span between the legs is generally much greater than rubber-tyred machines - up to 60 metres, accommodating 20 rows between the legs. Railhead gantries have smaller spans, of about 8 metres. A major feature of rail-mounted gantry cranes, distinguishing them from RTGs, is a cantilever extension to the framework on one or both ends of the span, with outreach of from four metres up to 16 metres or so. One of these cantilevers allows up to three rows of boxes to be stacked outside the rails, in addition to those stacked between the rails while the other extension covers a service roadway. Terminal tractors and road vehicles drive along this roadway, to deliver and pick up the containers to and from the stack.

5.2.2 Overall Height and Lift Height are similar to those for rubber-tyred gantries. Heights vary between 17 and 19 metres, and lift heights are between 11 metres and 15 metres.

5.2.3 The Wheelbase is about 15 metres, and Overall Length is about 20 metres. These dimensions are important, since containers are usually handled through the framework as they are moved between the stacks and the service roadway. Current designs allow ample space (about 15 metres) between the uprights for 40' containers to pass through between the stack and the roadway - indeed, 45' containers can generally be accommodated. However, clearance needs to be checked carefully when rail-mounted cranes are being procured, as future 48' containers might pose problems.

5.2.4 The Weight of the larger rail-mounted gantries, when carrying a full 40' container, is 300-370 tonnes including the spreader (which is usually a fully rotating design). For gantries with 16 wheels (eight pairs on four bogies) the distributed static load is thus about 20-25 tonnes per wheel, but the smaller rail-mounted gantries, paradoxically, might place greater loads on their fewer wheels: e.g. those at ECT Home Terminal put loads of 40 tonnes (360 KN/m²) per wheel on the 100 mm rails. To bear such weights, the rails are mounted on massive concrete beams, and piling might be needed where the sub-surface is not strong.

5.3 Operations

5.3.1 In their container yard versions, rail-mounted yard gantry cranes operate exclusively as container stacking machines, while tractor-trailer sets are (usually) responsible for quay transfer. The tractors drive along the roadway or 'truck lane', generally outside the rail under one of the
cantilever extensions, to pick up or deliver their containers, while the gantry crane moves the containers to and from the stacks and shifts the containers within the stack. For receipt/delivery, road vehicles are allowed onto the terminal and along the roadway to the appropriate row; there is not normally a 'grid' interchange point in this system as there is with straddle carrier systems (though the system at ECT Home Terminal does use such an interchange point, and straddle carriers and tractor-trailers are used as intermediate transport devices).

5.3.2 As for RTG operations, the main attraction of the rail-mounted yard gantry system is its economical use of land area because of the machine's high and dense stacking ability (provided, of course, that the terminal's planning and control systems are efficient). The storage blocks tend to be larger in both dimensions than for rubber-tyred machines. In Hong Kong, for example, the rails are 375 metres long with a gauge of 44 metres, i.e. spanning 15 rows, with 65 TEU slots per row. Several cranes will work along the same stretch of rails - four machines in Hong Kong - each stacking one over five. With average stacking heights of 4.5, the Hong Kong terminal can accommodate 4000 containers under the gantries (a density of about 1000 per hectare). Having several gantries working speeds up operations, of course, but also allows continuation of service if one gantry is out of operation.

At Multiterminals, Rotterdam, the container yard is set out in two parallel blocks, each about 500 metres long (80 TEU slots), with 12 rows of containers between the rails and three more rows under one cantilever. The three gantries per block stack one over four; at an average stacking height of 3.5, this results in about 4200 boxes being stackable per block, at a density of about 850 per hectare. At ECT, each stacking area is some 300 metres long (50 TEU slots per row) by 60 metres wide (20 rows), giving a stacking density of about 930 TEU/hectare, when the 15 metre-wide roadways on either side of the yard (for straddle carrier access) are included.

5.3.3 Operating Costs are high for rail-mounted yard gantry cranes. The purchase price of a medium-sized rail-mounted gantry crane (with a 30 metre span and 8 metre outreach either side) is between $2.2 million and $2.5 million. Its operating cost is about 15% of its purchase price per year, i.e. $350,000 or so per year. Drivers' salaries account for about 55% of operating costs in Europe, maintenance for about 30% and power (electricity) and lubricants the remaining 15%. For a smaller rail-mounted gantry crane, as used at railheads, the purchase price is about $1 million, and annual operating costs are equivalent to about 27% of purchase price, at about $270,000. Labour contributes about 55% of this, maintenance 30% and power, lubricants, etc. 15%, as for the larger cranes.

5.4 Performance

5.4.1 Because the span of a rail-mounted gantry crane is larger than for a RTG, trolley speeds can be faster - up to 150 m/minute is achievable. Hoist speeds are also higher, at 30-60 metres/minute, and the gantry itself can move along its rails at 100-150 metres/minute. However, operating performance varies with demand, distance travelled and the quay transfer operation's ability to feed the crane, and overall performance is not
dramatically faster than that of a RTG. The reason is that, as stacking density increases, so do the number of 'unproductive' moves in accessing boxes. Travel distances are also higher in the very long blocks usual in rail-mounted systems.

In practice, ECT achieves 24 moves/hour, with a theoretical peak rate of 30 moves/hour, for its larger gantries at Home Terminal, and up to 40 boxes/hour with its smaller gantries (32 metre gantries, spanning 7 rows plus a roadway) at Delta Terminal. Almost certainly, handling rates over a shift will average at about 25 moves/hour overall, including in-stack movements and receipt/delivery, as well as movements relating to quay transfer. For planning purposes when determining equipment requirements, a factor of one rail-mounted gantry crane to 35,000 to 40,000 box throughput is used. Based on high stacking, with 3 to 3.5 moves per box transit, this represents between 105,000 and 140,000 lifts per machine per year, i.e. 25 to 32 moves per operating hour.

5.4.2 Assuming that three rail-mounted gantries are deployed per two quayside gantry cranes, and that each requires a driver and a checker, while six to eight tractor drivers are needed for quay transfer, the total Manning for a two-crane 'unit' will be about 24 men per shift. Only the crane drivers need to be particularly highly skilled, and they need to be fully trained. In some three months of training, they will have received classroom instruction on operational and safety aspects of driving, as well as practical and on-the-job training, given by experienced drivers.

5.4.3 The very special system at Matson's terminals operates on a different principle, as one cantilever of each gantry extends into the quayside operating area, containers being delivered below it via a special transport system, while the other cantilever serves the receipt/delivery area, so that the container yard and shipside operations are fully integrated. They are also fully automated, and the powerful motors allow extremely rapid transport of the boxes; the gantry drive achieves 106 metres/minute, the trolley traverses at 244 metres/minute and the hoist drive at 68.6 metres/minute. However, the operating performance of this system has been disappointing - well below its design capacity.

5.4.4 Availability figures for rail-mounted cranes as high as 96% are quoted, with Utilization of about 55-60%. There is little doubt that ports have 'overstocked' with yard gantry cranes (as they have with other equipment) to cover peak demand, and Availability is unlikely to be a problem.

5.4.5 Downtime is not very different from that for RTGs. For example, at ECT, Downtime of its rail-mounted gantries averages 24 hours per month, with 'breakdowns during operations' amounting to about 12 hours a month, while routine maintenance accounts for the other 50% of Downtime.

5.4.5 The rail-mounted gantry cranes at ECT work for about 3000 hours a year, but could do at least 4000 hours a year and could expect a working life of 25-30 years. Based on an estimated 100,000 moves a year, that amounts to about 2.5 to 3 million moves altogether. For a crane costing $2.35 million, the Annual Capital Recovery at a life of 25 years amounts to about $300,000. When the operating cost of $350,000 a year is added, the total cost adds up to about $650,000 a year. Given an operating year of 3500 hours, the cost of the crane amounts to about $185/hour. Assuming a handling rate of 25 moves/hour, the cost of handling is about $7.5/move. Circumstances can combine to make rail-mounted systems attractive,
particularly where land area is limited and where ground conditions make RTG (or, indeed, straddle carrier) operation expensive in terms of terminal pavement construction.

5.5 Maintenance

5.5.1 For rail-mounted gantry cranes, damage accounts for about 10% of maintenance and repair time, breakdown and repairs about 40%. With power being delivered by electrical cable (and consumed at about 100 KWh/operating hour), there are no batteries to be serviced and replaced, of course, and no expenses on tyres. Total Maintenance Costs are estimated at about 4% of purchase cost per year, i.e. about $100,000 a year, of which some 80% is staff salaries (for about 200 man-hours per month). For smaller cranes, maintenance (at $80,000 a year) amounts to about 8% of purchase price per year, 55% of this due to labour costs, 40% to spares and 5% to consumables.

5.5.2 Maintenance is carried out according to strict schedules, out of operating hours. As for RTGs, inspections of the spreader and anti-sway gear are particularly critical; inspections of these and other components are undertaken every two weeks at ECT, for example. Electric motors are checked every 1000 hours, with major inspections and greasing at six-monthly intervals. Greasing of wheel and sheave bearings are most important. Major overhauls of trolley wheels are carried out at 5-6 years, trolley rails at 8 years and gantry wheels at 10 years, while the main hoist gear box is overhauled at 12 years.

5.5.3 Rail-mounted gantries are obviously fixed plant, and so mobile maintenance facilities are needed. However, a workshop is required to test, maintain and repair the spreader, motors and other components. Maintenance personnel require, in addition to the usual mechanical and electrical skills, specific knowledge of electric motors, welding and electronic repairs. Specialized training, provided by the port, by manufacturers or by specialists, is needed in addition to standard initial training.

5.6 Features to look out for

5.6.1 Electronic and other delicate components should be encased, sealed or encapsulated. Special precautions, such as air conditioning, may be needed in regions of high humidity.

5.6.2 Components and parts of the framework at low levels need to be protected against accidental contact damage, by buffers, fenders, etc. Since rail-mounted gantries share the same length of rail, proximity detectors should be fitted to prevent accidental contact between gantries as they move to new loading or discharging positions. At the very least, effective buffers must be fitted.

5.6.3 Drivers should be carefully selected for fitness and aptitude for spending long periods working at heights. They need: good eyesight, distance-judgement and coordination; the ability to climb to considerable
To work alone and concentrate for long periods, while maintaining contact with other staff through radio and data links. Technical/engineering knowledge and aptitude are useful but are not essential.

5.6.4 The cab should be well designed for the driver's comfort and safety. Particular attention should be given to: seating, which should be comfortable and fully adjustable; control and instrument layout, which must be as convenient and standardized as possible; field of vision, which must be clear and unobstructed in all directions; appropriate heating/demisting/cooling/air conditioning, to suit the climate; good sound insulation; adequate access via protected stairs, not ladders, and an emergency escape route.

5.6.5 A checker/talleyman cab should be provided at ground level, with radio communication with the driver's cab.

5.6.6 Flashing lights, bells and sirens should be fitted to give unmistakable warning when the crane is moving.

5.6.7 Operating rules for work within the container yard must be clearly set out and strictly observed, and clear lane markings and direction signs for terminal tractors and road vehicles are essential.

5.6.8 Access for maintenance to all service and inspection points must be rapid, easy and full.

5.6.9 Full voice and data communication links with central information and control systems need to be installed, to ensure that operations under conditions of high stacking density are as efficient as possible.

5.7 Future developments and trends

5.7.1 Data links will increasingly supplement radio communication links between the crane driver and the rest of the terminal system.

5.7.2 Extensive or even complete automation is certain to become more common. This is likely to include container pickup and positioning, as well as identification and location.

5.7.3 Remote condition monitoring is likely to be widely adopted, to simplify fault diagnosis and to make preventive maintenance more effective.

5.7.4 Mechanical and electrical components will be improved, to reduce Downtime and to extend lifespans and maintenance intervals. The use of thyristor controls will increase.

5.7.5 Increasing component standardization and interchangability will make maintenance easier and the stocking of spares less critical and expensive.

5.7.6 For rail-mounted gantries, practical size limits are not so obvious as for RTGs, but it is likely that operational considerations will prevent the very largest container stacking cranes becoming more common. Reductions
in average Dwell Times on container terminals mean that it is not as important as it once was to be able to accommodate vast numbers of containers in the container yard; with good organization and management of operations, even relatively small-area terminals are now able to stack sufficient containers to meet quite high demand without the necessity for achieving the very high stacking densities only available with the largest rail-mounted gantry systems. It is likely that this form of container handling system will not become much more common than it is today, and that it will continue to be the hallmark of the very specialist, very high throughput terminal, with a highly automated operation and complete computer control.
6.1 Introduction

6.1.1 Terminal tractors and their trailers or chassis are among the commonest of equipment types on container terminals. There were over 4000 units in service in 1985, over 600 of them built by Ottawa, 400 Douglas 'Tugmasters' (a brand name commonly applied to all terminal tractors), and several hundred by each of the other major manufacturers, Sisu, Capacity, BT and Daf. Demand has been fairly steady since 1975 (at about 200-300 per year), apart from a peak in 1980 and 1981, to over 500 a year.

6.1.3 The tractor is basically a heavy-duty motive power unit, or 'prime mover', fitted with one of a variety of coupling devices for attaching rapidly to an over-the-road chassis or a yard trailer. The tractor-trailer set is commonly used in the various Relay and Combination types of container-handling systems, for transporting boxes between the quayside and the container yard, as well as for transport to and from a CFS and to Receipt/Delivery 'grids' in some systems. The tractor also has a prominent role in the handling of containers to and from RoRo vessels, either mounted on their over-the-road chassis or lifted (by front-end loader) from their storage position below deck onto low-bed yard trailers.

6.1.3 Tractor-trailer systems have been used for container handling since the very earliest days of this form of unitization, and Sealand (the pioneer company in container transport) remains dedicated to the principle of using over-the-road chassis for transporting containers to and from the terminal container yard, using tractors for in-terminal movement and quay transfer.

Mafi, one of the largest manufacturers, produced its first dedicated terminal tractor in 1968 (this machine was still operational in 1985) while Sisu, another major supplier, sold its first tractor in 1969, with specific RoRo designs shortly afterwards.

6.1.4 Over the years the design has evolved gradually to become more and more specialized for port work. For example, the cab has moved to an off-centre position, with easy access to the trailer coupling device, brake cable connections etc., and its seating and control layout have become modified for easy reversing, with all-round driver vision a particular feature. Air-cooled engines, with improved fuel efficiency, have become more common.
6.1.5 Two distinct types have evolved: four-wheeled tractors with drive to two wheels (used in quay transfer and yard duties) and four-wheel drive tractors specifically for RoRo work, where they are required to climb and descend ramps, often under wet and slippery conditions. The RoRo tractor generally has a manual gearbox, for maximum power, while 'level-ground' tractors normally have automatic gearboxes. Since a clean exhaust is essential for working between decks of a RoRo vessel, those tractors are fitted with catalytic exhaust cleaners, and they are also designed to produce as little noise as possible.

6.2 Specifications

6.2.1 Terminal tractors have a Length of about 5 metres, with a forward cab, positioned to one side of the chassis. The platform behind the cab carries the 'Fifth Wheel' linking device, which is designed to lock into a corresponding device on the chassis/trailer. The link can be elevated hydraulically so that, when it is fully engaged, the forward end of the chassis or trailer is lifted clear of the ground for movement. The design of the link is variable and can be complex; it is a very important component, as all traction power has to be transmitted through it. Sliding systems, 'goosenecked' designs (which allow the tractor to engage with the coupling on a low trailer) and other forms of linkage are used by various manufacturers, as well as a simple tow-bar coupling.

6.2.2 The engines (diesel powered) are now in the 160-240 bhp range, and transmission is manual or automatic, through a torque converter; hydrostatic transmission is available from BT and Mafi, who claim reduced fuel consumption (because it allows the engine to run at constant speed) and noise, increased braking efficiency and torque. However, the port of Gothenburg is the only major user of hydrostatic transmission.

6.2.3 The Capacity or 'Fifth Wheel Rating' ranges from 20t up to 50 t or more, but the most popular size (comprising 45% of the total tractor population of about 4000 in 1984) is the 21-30 t range, with 32% in the 31-50 t range and only 2% over 50 tonnes. The relative popularity of these capacities has not changed since about 1976; the demand for all sizes remains constant. However, if the practice of using tractors to pull trains of two or more trailers spreads, the proportion of tractors with fifth wheel ratings of over 50 tonnes will inevitably rise. Note that the fifth wheel capacity normally quoted by manufacturers relates to a speed of 5 kph; there is a significant de-rating at higher speeds, e.g. a 25 tonne capacity at 5 kph falls to only 14 t at 30 kph.

6.2.4 The turning circle is an important factor, determining roadway dimensions in the storage area. For the popular Sisu machines the Minimum Outer Turning Radius is about 6.1 metres, and the Terberg tractors at Bremerhaven have a turning radius of 6.3 metres, while Levy quotes the minimum inside radius for its machines - about 5.8 metres.

6.2.5 The trailer built solely for in-terminal use is a wheeled frame, with corner flanges for guiding the containers onto the trailer as they are loaded, and for securing them during quay transfer. The trailer may be designed expressly to carry 20' or 40' containers, or it may be expandable and capable of being adjusted to 20' or 40' length. Some designs of 40'
trailers have central flanges, so that they can also accommodate two 20' boxes. Current trailers for 40' containers are rated up to 40 tonnes capacity, and 45' trailers can carry 48 tonnes.

The other category of trailer is more robustly constructed and licensed for 'over-the-road' use. Such 'plated' trailers, with twist-lock fittings to secure the containers, are known as chassis (indeed, it is common to refer to all types of tractor-trailer combinations as 'chassis systems').

6.3 Operations

6.3.1 In import quay transfer, the tractor with its empty trailer (or train of two or more trailers) positions itself below the quayside gantry crane to receive a container, then transports it to the appropriate storage slot in the container yard (in the case of a yard gantry stacking system) or to an interchange point (in the case of a straddle carrier relay or lift truck relay operation). After the container has been lifted off, the tractor-trailer returns to the quayside for the next container. In chassis operations, the container remains on its chassis while in storage, and this storage system is also used in some terminals for 'specials', including refrigerated containers.

6.3.2 Tractor-trailer operations are rapid, as travel speeds of 20-60 kph are possible with current tractor units. The most popular range is 21-40 kph (46% of tractors in 1984), with 41-60 kph next (26%); these proportions have not changed significantly since the mid-1970s, though there are signs that the 41-60 kph machines are becoming slightly more popular with time. Cycle times obviously depend primarily on quay transfer distance, but it is generally taken that between four and six tractors are needed for each ship-to-shore gantry crane in a pure tractor-trailer system, three to four tractors per crane in relay operations using straddle carriers, yard gantry cranes or lift trucks.

6.3.3 Manning is one driver per tractor, which gives total manning of some 28 men per shift per two-crane terminal 'unit' in a pure tractor-trailer system (corresponding figures for relay operations are given in the relevant chapters). Only moderate skills are needed; drivers need public and company truck-driver licences, and need to be tested at the end of their company training period, which should take about two weeks, including classroom training on operational and safety procedures as well as practical and on-the-job instruction by experienced driver-instructors.

6.3.4 The purchase price of a tractor is between $50,000 and $75,000 for level-ground tractors (RoRo versions are more expensive, costing up to $90,000). Its Operating Cost is about $130,000 a year - about twice the purchase cost. Labour costs contribute about 70% of this, fuel (at 10 to 12 litres of diesel/hour) and lubricants (about 0.2 litres an hour) 15% and maintenance also about 15%. A 40' over-the-road chassis may cost as much as $20,000 and a 20' chassis some $18,000, but a yard trailer costs only about $15,000. Its operating cost is about $2500 a year (15% of purchase price), entirely accounted for by tyres and other maintenance items. Clearly, the tractor-trailer system is the cheapest type of container-handling equipment to purchase, operate and maintain.
6.4 Performance

6.4.1 Tractors are generally considered the least sophisticated and most reliable of container-handling machines, with the lowest Downtime and greatest operational flexibility. Availability is quoted as 90% and Utilization is about 350 hours a month — say 60%. Downtime is about 10%, at about 60 hours a month.

6.4.2 Used on Quay Transfer operations in a Relay operation, a tractor-trailer set performs 5 to 8 moves an hour — on average perhaps 7 moves/hour. Only about 4 moves/hour are achieved in a Chassis System operation, where the tractor has to be coupled to/uncoupled from the chassis at the beginning and end of each cycle.

6.4.3 The Working Life of a tractor is about ten years (though some 20 year-old machines are still in operation) so, at a purchase price of $105,000 for a tractor and three 40' terminal trailers, the Annual Capital Recovery will be $18,600. Assuming the set's operating cost is about $137,500 a year, the total cost is about $156,100. If the set works for 4000 hours a year in a relay operation, the cost comes to about $39/hour and, assuming an average performance of 7 moves/hour, about $5.5 per move.

For a pure chassis operation, the cost is considerably higher, because one chassis is required for every container handled and stored. Most chassis operations are proprietary systems, anyway, and the financial arrangements and ownership of the chassis are very different to (and incomparable with) the other handling operations discussed in this Manual.

6.5 Maintenance

6.5.1 Some 60% of Downtime is unplanned, 40% due to preventive maintenance. About 25% of total Downtime is caused by damage repair, 20% to repair following breakdown, and 15% is time waiting for spare parts to arrive. Of the breakdowns, 90% are mechanical, 5% electrical and 5% hydraulic; drive axles, brakes and air systems are particularly liable to problems. Collisions with other tractor-trailers, with straddle carriers or other mobile equipment when cornering are the commonest accidents, with inattentive drivers or misunderstandings the usual cause. The fifth wheel linkage is a major cause of breakdowns.

6.5.2 Preventive maintenance is straightforward with terminal tractors, as they are relatively simple mechanisms with familiar engines and transmissions. Apart from daily driver checks (on fuel and oil levels, tyres, etc.) perhaps five or six routine services per year should be scheduled; 1000-hour intervals are common, with about three days needed for each service. About 15 man-hours per month are needed on average for preventive maintenance. Major overhauls are needed every four or five years, at about 15,000 hours. Normal workshop facilities, with ramps, inspection pits and a standard range of tools, are perfectly adequate for tractors. Maintenance staff require the standard workshop skills, but
annual refresher training is recommended, amounting to about five days a year.

6.5.3 Tractor Maintenance Costs are about $15,000-$20,000 a year - equivalent to about 30% of its purchase price. Labour accounts for about 50% of this, spares (including tyres and batteries) 40% and consumables about 10%. Replacement tyres and batteries cost about $4000 a year; tyres last about 2000 hours and batteries about three years under European conditions. Spares for three months' maintenance are held, 70% relating to engines and transmissions, 20% to chassis and bodywork and 10% to lubricants and other consumables.

It costs about $2500 per year (about 20% of purchase price) to maintain a yard trailer, about 40% of this accounted for by labour costs, 55% spares (tyres cost $400 each) and 5% consumables. Clearly, the tractor-trailer combination is the cheapest type of equipment to maintain on a container terminal.

6.6 Features to look out for

6.6.1 For ease of maintenance, all check-points and service points should be readily accessible, via flaps or covers.

6.6.2 A tilting cab (now virtually standard) makes engine accessibility very easy.

6.6.3 Particular attention needs to be paid to the construction quality and reliability of axles, shock absorbers, motor and gearboxes, and the fifth wheel mechanism.

6.6.4 For driver safety, a rear-opening cab door (or one that opens onto the platform) is important, as it allows access to the cable and hose connections between tractor and trailer without stepping down onto the terminal surface; it also reduces cycle times on a chassis operation (or where 'specials' are being stored on their yard trailers), by speeding up the linking process.

6.6.5 Driver comfort is vital, and noise and temperature insulation, ventilation and heating should be paid particular attention to, as well as seat suspension and the layout of instruments and controls. In Sweden, a maximum noise level of 80 dBA is enforced, though both Mafi and Terberg now claim a noise level of only 75 dBA in their tractors.

6.6.6 For safety, a reversing seat is useful (for 'forward' vision without strain in both directions), and good all-round cab vision is essential, with large windows.

6.6.7 Flashing warning lights fitted to the top of the cab, bright paint colours and effective rear-view mirrors are other important safety features. All untrained and unauthorized personnel and equipment must be kept out of operational areas.

6.6.8 Strict adherence to planned maintenance schedules keeps Downtime to a minimum and gives good fuel and oil economy. Long maintenance intervals
should be looked for, with built-in features such as automatic greasing.

6.6.9 Automatic cutout devices, protecting against oil pressure variations etc., are very desirable.

6.6.10 Braking systems must be completely compatible with related terminal equipment, i.e. tractor and trailer braking systems must match completely. Twin-line systems are recommended.

6.7 Future developments and trends

6.7.1 Improved communication links between drivers and other terminal staff, to reduce cycle times and improve information systems.

6.7.2 As container dimensions and weights increase, tractors with greater power will become more common (though designs with over 50t capacity are already available). Wider use of trains of five or more trailers will increase the demand for even larger tractors and for trailers with coupled axles.

6.7.3 Improvements are likely in the 'fifth wheel' linking systems, such as the tilting fifth wheel introduced by Sisu to cope with damaged or badly positioned trailers and containers.

6.7.4 Engines and drives with greater robustness will be developed, to increase maintenance intervals and operational reliability.
Chapter 7

LIFT TRUCKS

7.1 Introduction

7.1.1 Lift Trucks (commonly and misleadingly referred to as Fork-lift Trucks) have become a prominent and universal means of handling containers in terminals. Their familiarity, versatility and reliability have made them a popular choice for terminal operators; there are over 1750 units of 15 tonnes capacity or more in operation in the world's seaports. In the present context, we are concerned with lift trucks of capacities of 12 tonnes and over; most of these are exclusively employed in handling containers at dedicated, multipurpose or conventional facilities.

7.1.2 Lift trucks can be used in two principal ways. In some terminals, particularly where the layout and configuration of quays dictate or where small and expanding throughput is experienced, they are the primary back-up system in what is a dedicated lift-truck operation. In such cases they can be used in a 'direct' system, where quayside jib, multipurpose or gantry cranes permit lifting/loading of containers under the crane legs, or in a 'relay' system using tractor-trailer sets for the quay transfer operation. Alternatively, and more commonly, they are used in combination with other primary systems; in this secondary, supporting role - handling and stacking empty containers and performing intermodal transfers, especially to rail - they are particularly efficient.

7.1.3 In 'front-end loader' configuration, lift trucks can employ top, bottom or side-lift spreaders to lift containers, and can also use a fork attachment which engages with 'fork pockets' on the base of some containers (forklift attachments are only suitable for lightweight or empty containers). Higher capacity trucks are usually fitted with a frame which attaches at 2 or 4 points to the side or top of the container; the frame can be either of fixed length or telescopic. The top-lift attachment (a 'spreader' similar to those used on straddle carriers and gantry cranes) is preferred for better load distribution.

7.1.4 Other machines comparable to front-end loaders and often included in the same family, but employing very different designs and lifting principles, are the Side-Loader and the Reach Stacker. The side-loader is a truck with a mounted lifting device which lifts a container onto the side of the chassis, in which position the box is carried to its storage position or pickup point. This design of lift truck has, to all intents and purposes, disappeared as a primary means of handling containers in dedicated terminals, as it is slow in operation, it cannot stack high and can only stack in two-wide rows; it is now only to be found in a supporting role.
in a very few multipurpose facilities.

In contrast with side-loaders, reach stackers are becoming more popular because of their greater space efficiency, and they are increasingly found in a supporting role on small and multipurpose terminals. Reach stackers are tractor-like vehicles having a lifting boom located within the wheelbase; they resemble mobile cranes, from which they have been largely developed. They are marketed by five major manufacturers under such names as Port Packer, Piggy Packer, Constacker and Yard King, but use basically the same principles.

7.1.5 Lift trucks were initially developed for military purposes during the second World War. The early designs had poor manoeuvring characteristics, were mechanically unreliable and had relatively low capacities (in the 3-tonne range). In the 1950s and, particularly, the 1960s, they began to be more widely introduced into port work, initially in developed countries and eventually into developing countries. Today, they are the workhorse of the port transport industry; their versatility has improved with the parallel development of a wide range of specialized attachments and they are now to be found handling many cargo and commodity types and undertaking a variety of different port activities. They are basically simple machines to operate.

7.1.6 Lift trucks had a poor maintenance record in the 1960s, particularly the high-capacity machines, designed to carry heavy loads. This was primarily because of torsional loadings imposed on the truck, and unreliable components. However, further development work improved the design and there was considerable increase in capacity. Of these heavy-duty machines, models in the 20-30 tonne capacity range were most popular, being used primarily to handle logs, timber, steel and machinery. They began to be used (as front-end loaders) for handling containers and other unit loads in the 1960s, though early problems were experienced over stability and obstruction of the driver’s view by the load. Under intense competition between manufacturers, major improvements were made in the strength of the frame, mast and carriages, and in transmission, drive, braking and steering systems. The number of lift trucks grew appreciably in the late 1970s and early 1980s with the introduction of machines of up to 52 tonnes capacity, and their wider application in a supporting role on dedicated terminals.

7.1.7 The mid-1970s saw the introduction by Belotti of the reach stacker, which was developed from the mobile crane and lift truck. The popularity of the machine has grown and there is now a worldwide demand of about 90 machines a year, particularly in the USA and Australasia. This design is clearly seen as an alternative to or replacement for the lift truck and can be used for all the routine tasks of container terminals, including intermodal handling operations. The distinctive difference between them is the telescopic or fixed boom, hydraulically activated, which allows the reach stacker to stack containers in rows up to three deep. The boom also results in the machine being more stable when moving with a load, because it can bring the load back to just within the wheelbase. When stacking containers, however, reach stackers are no more stable than front-end loaders. Reach stackers are also more complicated and expensive, particularly if a telescopic boom is fitted to permit block stacking in two or three rows.

7.1.8 The reach stacker is, nevertheless, a very useful and versatile machine.
Like the front-end loader, it can be fitted with grapple arms or clamps for picking up a container still attached to its chassis, for placing on railwagons ('piggy-back' handling or TOFC - 'Trailer On Freight Car'). Reach stackers are also useful in handling 'swap-bodies'. Unlike the front-end loader, the reach stacker gives driver vision unimpaired by a mast when moving forwards.

7.2 Specifications

7.2.1 The principal specifications to be considered when selecting lift trucks for container handling are the lifting capacity, stacking height, wheel loading and overall dimensions. We shall deal with these in turn, first for front-end loaders and then for reach stackers.

7.2.2 The most popular front-end loaders in the late 1970s and early 1980s were in the 20-29 tonne Lifting Capacity range, but the more recent trend is for machines with 30 to 40 tonne capacities or more, reflecting the need to handle full 40' and longer boxes. Over 60% of all heavy-duty machines in operation have capacities of over 20 tonnes. Note that the quoted capacities are the maximum permitted load, including the weight of the spreader beam. If fully laden 40' containers are to be handled, a lifting capacity of at least 30 tonnes will be required under the spreader - a total lift of about 36-37 tonnes. Alternatively, if only empty containers are handled, of about 2-3 tonnes weight (or 4-5 tonnes for empty refrigerated containers), a smaller capacity machine will be sufficient; a 12 tonne lift truck is sufficient for standard empties.

7.2.3 Today, front-end loaders to be found on container terminals range from 8 tonnes up to 52 tonnes in capacity, although container-handling machines are normally considered as being those in the 12-52 tonne range. In selecting an appropriate capacity, terminal managers must consider the range of tasks to be performed by the lift truck, and possible evolution in container dimensions and weights. Prices vary considerably between capacities, e.g. a standard 12 tonne machine, as used to stack empty containers, currently costs about $100,000, while a 42-tonne machine costs about $300,000 - spreader included in each case - so correct choice is very important.

7.2.4 Care must be taken in interpreting a manufacturer's quoted lifting capacity since this relates to specific operating conditions; it is expressed at a given 'load centre' and on the assumption that the weight of the container being lifted is uniformly distributed on each side of that point. The load centre is measured from the heel of the spreader carriage and, on lift trucks used for handling containers, is typically quoted as 1200 to 1250 mm, although, since the container itself is 2.44 metres wide, 1220 should be considered the bare minimum value, and many critics claim that it should be greater. The tilt mechanism of the mast (usually +/-5°) allows containers to be tilted back while being moved about the terminal, which ensures that they are carried within the permitted load centre. Even so, stability problems may occur when stacking fully laden boxes, particularly at height, and when braking with the container elevated.

7.2.5 If the container is carried outside the load centre or is itself unevenly
loaded, the lifting capacity of the truck must be de-rated. For example, a machine with a quoted 35-tonne capacity at 1200 mm load centre would be de-rated to 30 tonnes at 1600 mm and about 26 tonnes at 2000 mm. A major de-rating also takes place when stacking containers at height, particularly in the fourth or fifth tiers, and so it is necessary to build-in a considerable safety margin if three-high or greater stacking is to be used. For example, a lift truck with an under-spreader capacity of 32 tonnes is de-rated to 30 tonnes at four-high stacking and to only 20 tonnes when stacking five-high. This is a particularly important consideration at the time of equipment procurement.

7.2.6 The second major selection consideration is Stacking Height. At the top end of the range, front-end loaders are now available which can stack containers six-high safely and efficiently, even in winds of up to 47 kph (Beaufort 7). There is a small but growing interest in such high stackers - and it is worth remembering that new purchases should be capable of handling 'high-cube' boxes (9'6" high) to the required height, which means a lift height of 9 metres for three-high stacking, 11.8 metres for four-high and 13.4 metres for five-high stacking.

This high-stacking can be achieved with a fixed, one-section mast, but it is frequently made possible by a duplex or triplex mast, an extending mast of two or three sections. Extending masts have the advantage of low overall height when the mast is retracted, which allows use in areas of restricted height, such as aboard RoRo vessels. For such applications, the important specification is the 'free-lift height', i.e. the height to which the carriage can be raised without the mast having to be extended. Single-section masts suffer far less wear and tear than the more complicated duplex and triplex masts, however, and are to be preferred whenever possible. Indeed, in spite of the current interest in five-high and six-high stackers, machines with the more modest capability of stacking three high are increasingly popular, with about 60% of all units in operation currently in this category.

7.2.7 A very important consideration is the Weight of the truck and consequential Terminal Surface Loading, which is accepted as a major problem with the front-end loader. When a lift truck is loaded, virtually the whole all-up weight is transferred to the drive axle and, with big machines, this imposes high ground loadings. For a 25-tonne truck, a ground loading of 60 tonnes/m² may be exerted, with even higher figures (up to 90 tonnes/m²) for the top-of-the-range models. Not surprisingly, terminal surfaces have to be built to a high specification for this type of equipment, and even then damage and repair costs are high.

To help overcome these problems, manufacturers have reduced the unladen weight of their machines as much as possible - often to as little as 50-55 tonnes unladen (about 80 tonnes with a box) - and have increased the number of wheels on the front (drive) axle. Although six-wheeled machines are still most common (a pair on each side of the front axle and two on the back), the latest designs reduce terminal surface loadings by having eight wheels, three on either side at the front. On some models, two of these wheels can be extended as outriggers, which is claimed to aid stability (although this slows down operating performance considerably). Other developments have been the introduction of large diameter wheels and wide profile, low-pressure and high flotation tyres. Even so, careful consideration must be given to terminal surface factors, particularly if lift trucks are being deployed in a direct system,
involving long travel distances and constant braking.

7.2.8 Other principal specifications to consider are the overall dimensions of the machine, typically 10.4 m length with spreader attached and 4.15 m width (spreader not extended) for a 42-tonne machine. Outer Turning Radius is also important in terminal layout, with 7.0-7.4 m possible with the high capacity but more manoeuvrable machines that have been recently developed. Except for the low profile machines intended particularly for work aboard RoRo vessels and in sheds, Overall Height to the top of the unextended mast ranges from 6.5 m to 9.6 m; RoRo machines can have overall heights as low as 3 m.

7.2.9 Reach stackers have a typical maximum rated Lifting Capacity of 55 tonnes (with the boom retracted) to about 40 tonnes (at a load centre of 1200 mm) - though machines that can lift higher weights at greater load centres are available. Once again, however, the rated capacity varies with lift height. Reach stackers at the top of the range can typically stack containers five-high in the front row of a container stack, four-high in the second row and three-high in the third. However, their lifting capacity is very much reduced when stacking in these inner rows. For example, a reach stacker rated at 40 tonnes at a 2000 mm load centre can achieve this when stacking to the top tier of the first row but can only lift 10 tonnes to that height in the second row and a mere 7 tonnes at the top tier of the third row (though these capacities can be increased if auxiliary counterweights are fitted). A Kalmar '35-tonne' machine can lift 35 tonne boxes, 9'6" high, up to four-high in the front row but only a maximum of 18 tonnes to that height in the second row. If such de-rating limits are acceptable, then reach-stackers can be useful, but for full flexibility when planning operations, terminal operators really need them to be able to lift boxes of at least 24 tonnes (i.e. a full 20' unit) to full height (and certainly to three-high) in the second row.

7.2.10 A reach stacker is classed as a mobile crane, and as such one of its specifications has to be its 'Tipping Load', the load at which the machine will topple over. Its rated lifting capacity has to be no more than 75% of the tipping load, providing a safety margin factor of 1.33. For a Valmet machine, the tipping load is 45 tonnes at the front row.

7.2.11 The Overall Length of a typical four-high reach stacker is 10.65 m, with a Width of 4.5 m and an Outer Turning Radius of 8 m. The Overall Height of the machine is 4.8 m with the boom lowered and retracted, and 14.0 m with boom in the fully extended position. Maximum Stacking Height under the spreader is 12.2 m. Typically, unladen weights are 55 tonnes, and the same problems of Wheel Loading apply as for front-end loaders.

7.2.12 The purchase price of reach stackers depends on the specification and attachments required, but is typically of the order of $400,000 to $450,000, including the spreader. This is significantly higher than for an equivalent capacity front-end loader, costing about $300,000, while an empties stacker (12 tonne) can cost as little as $100,000. In common with front-end loaders, reach stackers have the comparatively short lifespan of ten years, though working lives are now being extended, and front-end loaders can be refurbished, replacing the mast, to prolong their lives.
7.3 Operations

7.3.1 The lift truck is attractive to users because it is considered a simple machine with relatively low initial cost, compared with other types of container-lifting equipment, has relatively low operating cost and good maintenance features. Most terminals today deploy a small fleet of lift trucks to support the main handling equipment and to block-stack empty containers. Machines capable of stacking five-high are commonly used on this task, and are particularly cost-effective. Lift trucks can also be used for intermodal transfers, to and from road and rail vehicles (provided there is sufficient space between the rail tracks and the rails are fitted flush with the terminal surface) and, if of low-profile design, in RoRo operations. Fitted with other attachments, the machine can be used to handle timber, steel, unit loads and other large, indivisible loads and, consequently, they have been widely used on multipurpose and conventional berths/terminals.

7.3.2 However, the front-end loader is not very effective at picking up or landing containers on the quayside; containers are normally carried aboard vessels in the fore-and-aft mode, and are loaded and discharged in this direction, and so, unless the crane swivels the container through 90° or lends it in the backreach area, it is in many cases impossible for the truck to approach the container (between the gantry crane legs) at right angles to engage the spreader. Another problem is that the quay construction might not withstand the high wheel loadings. Furthermore, lift trucks generally cannot be used to move containers to and from 'reefer points' (for plugging-in of refrigerated boxes) on the terminal.

7.3.3 However, in spite of these problems, front-end loaders are used on some terminals as the principal back-up system. Opinion in the industry suggests that they can be cost-effective at comparatively low throughput - up to 120,000 containers/year - where space permits or where terminal design makes it difficult to employ other systems, e.g. where container terminals have been developed by converting general cargo berths and where it would be difficult to move rubber-tyred gantry cranes, for example, from one quay to another. Where jib cranes are used (so that there is no need to pick up or drop boxes between the crane legs), the lift truck can be deployed for all terminal activities, including the quay transfer operation - but even here they should not be used over long quay transfer distances, because of their low safe travel speeds.

7.3.4 As the principal system, four or five lift trucks are needed per crane on Quay Transfer and stacking, a total of nine for a two-crane 'unit'. Four are needed on Receipt/Delivery, two on CFS duties and one in reserve - a total of about 16 machines. At one driver per machine per shift, total Manning for such an operation would be about 26 men per shift. Although drivers need not be as highly skilled as for gantry cranes or straddle carriers, training is still a vital factor. About three weeks of instruction (classroom sessions on operational and safety factors, practical instruction and on-the-job training) are needed.

7.3.5 More appropriate, perhaps, than a Lift Truck Direct operation is to use the machines in combination with tractor-trailer units, allowing the latter to perform the high-speed quay transfer part of the operation and
leaving the lift trucks to serve the stacking/unstacking and receipt/delivery functions and the block-stacking of empty containers, to which they are well suited. In such a Lift Truck Relay operation, two or three lift trucks will be required on stacking for each ship-to-shore gantry crane working - that's about five per two-crane 'unit'. In the receipt/delivery operation, one lift truck at the interchange point places containers on trailers, on which they are then transferred to the yard, where a second truck stacks them. Another machine or two will be on 'empties', CFS and other duties, with one or two in reserve and maintenance. That's a total of nine or ten per two-crane 'unit', plus the tractor-trailer sets. Manning would be about ten lift truck drivers and six to eight tractor drivers - about 26 to 28 men per shift altogether per two-crane 'unit'.

7.3.6 The major disadvantage of the front-end loader operation is its poor space utilization. Containers are normally stacked in rows two boxes wide, to permit access from either side (though empty containers can be stacked in rows four boxes wide or even block-stacked by owner, by size and type). The large turning circle required means that, to permit access at right angles to the container, aisles 18 m wide have to be provided, even with specially designed compact units. Stacked one-high, this would permit an average stacking density of about 125 TEUs per hectare. However, export containers can be stacked three high and import boxes 1.5 high on average, so an overall stacking density of about 275 TEUs per hectare is possible in a 50:50 import/export terminal. Higher stacking heights (subject to lifting capacity) would improve space utilization, but at the expense of reduced accessibility - an important consideration for imports. The front-end loader also has a poor storage and performance level when used in selective yard operations, with long distances from one target slot to another, and is not recommended for use on terminals handling more than, say, 120,000 TEUs a year. The machine's relatively low operational (i.e. safe) travel speed (compared with, say, a tractor-trailer set) also limits performance in the quay transfer operation, particularly with long cycle distances.

7.3.7 The poor space utilization of the front-end loader is partially overcome in the reach stacker design, although it must be said that there are very few terminals that depend on reach stackers as the primary means of transporting and stacking containers - and even those are terminals with relatively small throughputs. In common with front-loaders, the reach stacker is used as a secondary system, supporting the main handling equipment. Aisle widths can be as small as 11 m in normal operations with 20' boxes when reach stackers are deployed (but must be 15 m if 40' boxes are to be handled). They can be even narrower if rotating spreader frames are used. Such spreaders are able to rotate up to 120° and allow boxes up to 10 tonnes in weight to be carried in line with the chassis, thus reducing the overall width of the laden machine. They also allow the stack to be approached at an angle of up to 30° (whereas front loaders have to approach stacks almost end-on); both factors contribute to the reduced need for manoeuvring space between stacks.

7.3.8 The container yard layout in a reach stacker operation normally consists of rows 15-20 containers long and, provided the machine has the necessary lifting capacity, up to four boxes wide (allowing access to two rows from each side). Rows six boxes wide are possible, but with only light containers (under ten tonnes) stacked in the inner rows; this is particularly realistic for empties. Reach stackers are less efficient on
terminals handling a high proportion of loaded 40' boxes because of their inability to stack them two or three rows wide. Assuming an aisle width of 15 metres and one-high stacking, the stacking density is about 200 TEUs/hectare - a 60% improvement on a front-end loader system. Even if an average stacking height lower than for front-end loaders is assumed (because of the de-rating for stacking to the second and third rows of a block, in practice restricting those rows to empty boxes) - perhaps an average stacking height of two - with a balanced import-export trade a stacking density of 400 TEUs/hectare would be possible - a 45% improvement on the front-loader.

7.3.9 The annual Operating Cost of a high-capacity front-end loader is about $210,000 - equivalent to about 70% of the purchase price. Of this total, labour costs account for 70%, maintenance and repair costs 20%, and cost of fuel and lubricants 10%. Fuel is consumed at a rate of about 15-18 litres/hour by 40 tonne capacity machines and 10-13 litres/hour by 12 tonne units. Reach stacker operating costs are similar, though their maintenance costs are claimed to be lower, largely because the boom is more reliable and less damage-prone than the mast; it is the mast of a front-end loader that causes the high maintenance costs.

7.4 Performance

7.4.1 The number of container moves achieved per hour shows considerable variation and reflects the different roles that lift trucks perform on container terminals. A unit being employed solely for stacking containers in the container yard in a Relay system could be expected to achieve high handling rates, but when used on the quay transfer operation, particularly over long distances, the handling rate is lower; application is the major determinant of performance levels.

7.4.2 When used as the primary handling system in a Direct operation on a relatively small dedicated terminal, lift trucks have a target of 15 moves/hour, though under normal operating conditions average sustained handling rates of 6-8 moves/hour are more common. Factors affecting performance are travel distance and operating speed; manufacturers' figures for the latter are in the range 20-30 kph, which suggests that the designed vehicle speed is unlikely to be a limiting factor (though safe operating speed could well be). Used for stacking in a relay system, with three tractor-trailer sets serving each working crane, hourly handling rates of 10-12 boxes/machine can be achieved. It is extremely difficult to determine handling rates when front-end loaders and reach stackers are used in a supporting role because of the intermittent nature of this work, but rates of 20 moves/hour are certainly possible when stacking empties in one block. Intermodal handling rates are likely to be lower, because of the need to position containers and the generally longer travel distances involved.

7.4.3 In common with other container-handling equipment, lift trucks have a relatively low Utilization level. The Containerisation International survey of 1985 showed that just over 72% of lift trucks are used for 50 hours or less in a week and a further 16.7% for 50-70 hours a week, with an average Utilization of about 40 hours - about 25%. This amounts to an operating performance of about 2000 hours/year - entirely consistent with
figures for the lift truck fleet at the port of Bremen, which averages 1800-2000 hours/year; more highly utilized terminals employ their lift trucks for 2500-3000 hours/year. One explanation for this comparatively low level of Utilization is that, when they are used in a secondary handling system, the demand for lift trucks is intermittent.

When used in a direct, primary system, assuming an average of 7 moves/hour for quay transfer, stacking and intermodal movements, this amounts to about 20,000 moves/year. In contrast, when used exclusively for handling empties, the annual number of movements could be as high as 30,000. With a machine life of about ten years, that's about 200,000 - 300,000 moves altogether.

7.4.4 For planning purposes, a factor of one lift truck to between 6000 and 8000 box throughput is reasonable. Based on an average of three moves per box transit, each lift truck in a Direct operation should achieve between 18,000 and 24,000 moves per annum.

7.4.5 Assuming a purchase price of $300,000 and a working life of 10 years, the Annual Capital Recovery of a typical lift truck would be about $57,000. When an average operating cost of $210,000/year is added, the total cost of owning and operating a lift truck amounts to about $263,000/year. At a performance of 3000 hours/year, the cost works out at about $88/hour and, at a handling rate of 7 moves/hour, a cost of $12.5/move.

7.4.6 The reliability of front loaders and reach stackers is extremely good, with Availability regularly in the 90-95% range. Average monthly Downtime is about 30 hours/machine, although the regional variations show much higher extremes, particularly in Africa, where shortage of spare parts is frequently cited as the major cause of maintenance delays. The Containerisation International (1985) survey also revealed that Downtime did not necessarily increase with age; on the contrary, many newer machines had Downtimes greater than 30 hours/month (though many of these were probably in African ports); over 65% of machines having Downtimes in excess of 50 hours/month were delivered after 1980. The average time spent per month in preventive maintenance is 30 hours, so total Downtime is about 60 hours a month - about 10%.

7.5 Maintenance

7.5.1 Little information is available on the major causes of Downtime or the proportion of time lost from each cause. Lift trucks had a particularly poor reputation for reliability in the 1960s, because of torsional loadings imposed on the truck, leading to stress fatigue, particularly in the mast and its mounting. Manufacturers did not recognize the extent of torsional loadings imposed on the truck by containers swaying while being transported; frequent checks for cracks are still needed. Early problems were also encountered with stability and mechanical defects, with hydraulic failures a frequent complaint. Problems were regularly encountered with masts (particularly with duplex and triplex systems) and spreader beams, and tyre wear and damage were recurring problems. Significant improvements have been made since then in design and maintainability, and today's machines are far more reliable and less expensive to maintain. Manufacturers have paid particular attention to
the question of maintenance in recent models.

7.5.2 One of the most attractive features of lift trucks, particularly for developing countries, is their ease of maintenance. Maintenance staff are familiar with the machine and its components, through years of experience with conventional forklift trucks, and highly specialized maintenance facilities are not required. This, coupled with the simplicity of operation, makes them particularly suited to the needs of developing countries.

7.5.3 The annual *Maintenance Cost* for a large front-end loader is equivalent to about 15% of the purchase price of the machine. For a top-of-the-range 42-tonne machine, this is about $40,000 per annum. Of this, some 35% is for labour, 60% for spare parts (including tyres and batteries) and 5% for consumable materials. Approximately 90 man-hours/month are spent on maintenance. European port managers maintain about $40,000 worth of spare parts in stock per machine. Tyre life is two to three years or 4000-7000 operating hours, but depends on the quality of terminal surface and other conditions of use. The cost of a high-quality, wide profile tyre is about $1000.

7.5.4 The maintenance problems and costs of reach stackers are rather less severe than those of front-end loaders, largely because the incidents of damage and repair to the robustly built boom are lower than those for the front-end loader's mast; reach stackers do not have the problems associated with mast structures, mast chains and rollers. The total annual *Maintenance Cost* is about 8% of the (rather higher) purchase price—about $35,000. Labour accounts for 60% of this cost, spare parts 35% (much lower than for front-end loaders) and consumables 5%.

7.5.5 Major changes that have taken place in the design of lift trucks in recent years include improved access for maintenance and greater system protection. For example, lift-out floor plates reveal all pneumatic control circuits, while one manufacturer has located all primary and secondary hydraulic valves together in an easily accessible place. Attention has also been given to attachments, such as a telescopic side-shift attachment for fine positioning in the corner castings of the container, slew mechanisms for lifting containers which are positioned at an angle, and more load-adjustment controls. Some of the larger machines have now been fitted with a 'soft-touch', precise inching control, and a number of safety devices (such as restricted tilt) have been fitted to reduce the risk of the machine becoming unstable. Alarm or warning systems should be specified to indicate failures which may reduce stability, such as pressure drops in hydraulic fluid in the tilt cylinder.

7.5.6 Major improvements have also been made in the mechanical specification to improve reliability. Braking systems have had to be improved to meet performance levels in all climates, particularly with the high-capacity machines. Many manufacturers already 'over-dimension' their braking capacity. Hydraulically operated brakes have replaced conventional air compressors, and disc brakes, with an anticipated lifespan of 10,000-15,000 hours, have replaced the earlier drum systems for large units. Recently, one manufacturer has introduced hydrostatic drive (comprising hydraulic motors which power some or all of the wheels) to reduce the turning radius and improve manoeuvrability of large machines. Power-assisted, finger-light controls have been supplied by other manufacturers.
7.5.7 Improvements have also been made in the quality of transmission and drive axles, and higher-capacity engines (including turbo-charged diesel engines) have been introduced to improve speed and grade-climbing ability. Users still prefer cross-ply to radial tyres, because the latter require more steering effort. Tyre 'scrub' is a constant problem, particularly when the machine is manoeuvring in the unloaded condition. Pneumatic tyres are preferred to solids, and the trend is towards large, low-pressure, high-flotation tyres to spread ground loads. Finally, improvements have been made in the design of spreaders - a major source of equipment Downtime. More robust spreaders are now in use, and the spreader beam can be moved sideways and slewed, independently of the mast, to achieve precise registration with the container's corner castings, making pickup and stacking much easier.

7.6 Features to look out for

7.6.1 Despite considerable improvements in design, many users still express doubts about the inherent safety of lift trucks. Because their load is not carried within the wheelbase, stability is a major problem, particularly when stacking containers in the higher tiers or moving over uneven surfaces - a notable problem on terminals experiencing uneven settlement. High winds also cause difficulties, particularly when handling empties. Mechanisms which restrict forward tilt help to reduce the risk of instability. Tilt cylinders designed to reduce twisting moments on the mast when carrying a container at height are essential if machines are to travel over uneven surfaces or operate where there are potholes.

7.6.2 Some manufacturers fit electronic limit switches which operate when the load is lifted above a certain height. Cut-outs on all mechanisms would be better for developing countries. International safety standards (adopted by the Federation Europeene de la Manutention - FEM) have been introduced to deal with the stability problem and some manufacturers are now equipped with tilting platforms to test their machines for stability. Users should ensure that new lift trucks are designed and tested to meet these standards.

7.6.3 Poor front vision, caused by the machine's mast and load, is the single most important safety factor from the driver's point of view, and is the principal cause of collision damage to machines. The driver's vision is in any case restricted by the lifting arrangement at the front of the truck and this is worse when lifting and carrying a container. So manufacturers have tried several ways to overcome this problem. Some favour an elevated driving position, located to the left of the centre line of the truck; e.g. TCM have cabs up to 4.75 metres above the ground. The high cab allows the driver to see over the container as he travels, and he is not tempted to lift the container to an unsafe, unstable height to see beneath it. Others have introduced 'free visibility', 'high visibility' or 'thin profile' masts, in which hoist cylinders, the cross-beam and other structures are so positioned that they do not obscure the driver's view.

7.6.4 The control console should be rotatable through 180°: the cab, steering wheel, controls and instruments rotate with the seat so that the driver faces and drives backwards, his view unobscured by the mast. Alternatively, the seat alone could rotate, to face two duplicate sets of
controls.

7.6.5 Cab design needs particular attention, for driver comfort and safety. Adjustable swivel seats, adjustable steering columns and a large glass area to provide all-round vision are examples of desirable features. Air-conditioning, noise insulation and anti-glare glass must be considered, depending on climatic conditions, and exhaust emission control is demanded in many countries and under certain operating conditions. The industry now talks of 'driver-friendly' cabs, incorporating seats fitted with shock absorbers and other driver-comfort features.

7.6.6 There is a growing demand for standardization in the positioning and layout of controls and the console, to improve driver interchangeability and safety.

7.6.7 Emphasis on good driver training is essential and on the establishing of good operating procedures throughout the terminal.

7.7 Future developments and trends

7.7.1 The general consensus among manufacturers is that there are unlikely to be major technological developments applied to lift trucks in the near future. The industry envisages continual modification and steady improvement to existing technology.

7.7.2 Safety will remain a major priority. Lift-height control devices and lift limiting systems will be incorporated more widely, to ensure that machines are not dangerously operated. However, the intense market competition between manufacturers (and the fact that it is currently a buyers' market), may mean that less research and development are put into this area and that specifications will not change dramatically because of cost constraints.

7.7.3 Microprocessors are likely to be introduced (as in other heavy-lifting equipment) to monitor equipment performance and maintenance and for fault-finding in hydraulic and electrical systems - though some manufacturers have specifically excluded such developments, to keep the machine simple and to make it attractive to developing countries.

7.7.4 The trend will be towards increasing numbers of machines with lifting capacity of 45 tonnes and more under the spreader, to meet changing ISO standards and the needs of non-ISO standard and special containers. There could well be development of 'double-decked' lifting, with boxes picked up and stacked in pairs.

7.7.5 Greater efforts will be made to reduce noise and pollution emission, to improve driver comfort.

7.7.6 The competition between lift trucks and reach stackers is expected to intensify, prompting improvements in manoeuvrability and 'un-de-rated' stacking heights. We can expect improvements in design of the drive mechanism (engine, transmission) and of the hydraulic operating system.

7.7.7 Increased attention will be given to improving maintainability and the
reliability of components (increasing overload margins, improving the robustness of control systems) to increase the life of the unit and reduce the time intervals between overhauls.

7.7.8 Finally, refinements in lift controls are expected to continue—such developments as lift height control devices (microprocessor-based), which allow the driver to input the desired height of lift via a touch-pad, to stop the mast at a predetermined height.
8.1 Variations in equipment choice

8.1.1 World-wide surveys of maritime container terminals reveal that there is considerable variation in the choice of back-up systems, even among terminals of similar capacity and location. Available evidence suggests that the straddle carrier, used in Direct and Relay mode, is the most popular stacking unit and is used by about 30% of terminals. A further 30% use the straddle carrier in combination with yard gantry cranes, 23% claiming that the straddle carrier is the predominant unit for handling containers. By comparison, the yard gantry crane is used with tractor-trailer sets in only 18% of terminals, but in various combinations with the straddle carrier it is to be found in nearly 50% of terminals. The lift truck is used as a primary handling unit in nearly 25% of terminals, although these are heavily concentrated in Europe, Australasia and North America and are (surprisingly) not as popular in developing countries. They are generally found on smaller terminals, with comparatively low throughputs.

8.1.2 Geographical analysis reveals some interesting differences. Lift trucks are used for handling containers in about 50% of terminals in Australasia, including some with moderate throughputs. However, they tend to be used elsewhere in terminals where stacking capacities are below 4000 TEUs. By contrast, the straddle carrier is still considered the 'European solution', with the large majority of terminals using them in pure or combination systems. They are, however, found on terminals in all geographical regions, with a surprisingly high level of use in the Far East, North America and Africa. Although yard gantry cranes are not as widely used as straddle carriers, they are becoming more popular in Europe, the Far East and North America, particularly on large terminals with stacking capacities in excess of 10,000 TEUs.

8.1.3 The trend is clearly towards further concentration on the straddle carrier and yard gantry crane as the two principal means of stacking containers in medium to large terminals. Combination systems using these machines are likely to remain the most common global solution, although there is a noticeable trend to the wider use of pure yard gantry crane systems in developing countries in Asia and Africa. Currently, this trend applies largely to rubber tyred yard gantry cranes. Rail-mounted gantry cranes provide a more stable platform for automated operations, but are captive to the storage block; there could be advantages in adopting a mixed system, with rail-mounted gantry cranes for exports and rubber-tyred machines for imports - a more flexible arrangement that
retains the benefits of high stacking and automation. The lift truck is expected to remain a popular means of handling containers in smaller terminals, and reach stackers are expected to gain in favour with the growth of intermodalism.

8.1.4 It is evident that the choice of system, whether for a new terminal or as replacement machines, is not an easy one for senior management to make or for World Bank staff to advise on. In this Chapter we shall examine the principal operating and maintenance features that affect equipment choice, beginning with what could be expected to be one of the most important features, the total annual cost of operating the individual equipment types and the systems of which they form components.

8.2 A comparison of operating costs

8.2.1 The operating costs for the equipment types considered in this paper are summarized in the following tables. The data have been calculated on the basis of representative purchase prices (at September 1987 prices and exchange rates) and the operating and maintenance performance and costs that were developed in Chapters 2 to 7. It must be remembered that the figures are based on the operating conditions, manning levels and salaries in Western European ports, using the typical asset lives experienced there. Capital Recovery Costs are based on a 12% discount rate.

TABLE 8.2a

Annual Equipment Operating Costs

A. Quayside Gantry Cranes

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase price:</td>
<td>$3-6 million</td>
<td></td>
</tr>
<tr>
<td>Annual operating cost:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>$260,000 (65%)</td>
<td></td>
</tr>
<tr>
<td>Fuel/power</td>
<td>40,000 (10%)</td>
<td></td>
</tr>
<tr>
<td>Maintenance:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>$75,000 (75%)</td>
<td></td>
</tr>
<tr>
<td>Spares</td>
<td>20,000 (20%)</td>
<td></td>
</tr>
<tr>
<td>Consumables</td>
<td>5,000 (5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total maintenance $100,000 (25%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total operating cost (%age purchase price) $400,000 (7-13%)</td>
<td></td>
</tr>
</tbody>
</table>

(cont.)
TABLE 8.2a (cont.)

B. Straddle Carriers

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$500,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$150,000 (65%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>30,000 (10%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$22,000 (35%)</td>
</tr>
<tr>
<td>spares</td>
<td>35,000 (60%)</td>
</tr>
<tr>
<td>consumables</td>
<td>3,000 (5%)</td>
</tr>
<tr>
<td>Total maintenance</td>
<td>60,000 (25%)</td>
</tr>
<tr>
<td>Total operating cost (p% age purchase price)</td>
<td>240,000 (48%)</td>
</tr>
</tbody>
</table>

C. Rubber-tyred Gantry Cranes

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$750,000-900,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$150,000 (60%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>35,000 (15%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$42,000 (65%)</td>
</tr>
<tr>
<td>spares</td>
<td>20,000 (30%)</td>
</tr>
<tr>
<td>consumables</td>
<td>3,000 (5%)</td>
</tr>
<tr>
<td>Total maintenance</td>
<td>65,000 (25%)</td>
</tr>
<tr>
<td>Total operating cost (% age purchase price)</td>
<td>250,000 (28-33%)</td>
</tr>
</tbody>
</table>

D. Medium-sized Rail-mounted Gantry Cranes

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$2.2-2.5 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$192,000 (55%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>58,000 (15%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$80,000 (80%)</td>
</tr>
<tr>
<td>spares</td>
<td>18,000 (18%)</td>
</tr>
<tr>
<td>consumables</td>
<td>2,000 (2%)</td>
</tr>
<tr>
<td>Total maintenance</td>
<td>100,000 (30%)</td>
</tr>
<tr>
<td>Total operating cost (% age purchase price)</td>
<td>350,000 (14-16%)</td>
</tr>
</tbody>
</table>
### E. Small Rail-mounted Gantry Cranes

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$1 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$150,000 (55%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>40,000 (15%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$44,000 (55%)</td>
</tr>
</tbody>
</table>
sporxes | 32,000 (40%) |
|consumables | 4,000 (5%) |
|Total maintenance | 80,000 (30%) |
|Total operating cost (%age purchase price) | 270,000 (27%) |

### F. Terminal Tractors

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$50,000-75,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$90,000 (70%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>20,000 (15%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$10,000 (50%)</td>
</tr>
</tbody>
</table>
sporxes | 8,000 (40%) |
|consumables | 2,000 (10%) |
|Total maintenance | 20,000 (15%) |
|Total operating cost (%age purchase price) | 130,000 (175-260%) |

### G. Terminal Tractor + 3 40' trailers

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$90,000 (65%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>20,000 (15%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$13,000 (47%)</td>
</tr>
</tbody>
</table>
sporxes | 12,000 (44%) |
|consumables | 2,500 (9%) |
|Total maintenance | 27,500 (20%) |
|Total operating cost (%age purchase price) | 137,500 (137%) |
### TABLE 8.2a (cont.)

#### H. Front-end Loaders (42t)

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$300,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$150,000 (70%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>20,000 (10%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$14,000 (35%)</td>
</tr>
<tr>
<td>spares</td>
<td>24,000 (60%)</td>
</tr>
<tr>
<td>consumables</td>
<td>2,000 (5%)</td>
</tr>
<tr>
<td><strong>Total maintenance</strong></td>
<td>40,000 (20%)</td>
</tr>
<tr>
<td><strong>Total operating cost (%age purchase price)</strong></td>
<td>210,000 (70%)</td>
</tr>
</tbody>
</table>

#### I. Reach Stackers

<table>
<thead>
<tr>
<th>Purchase price:</th>
<th>$400,000-450,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual operating cost:</td>
<td></td>
</tr>
<tr>
<td>Labour -</td>
<td>$150,000 (73%)</td>
</tr>
<tr>
<td>Fuel/power -</td>
<td>20,000 (10%)</td>
</tr>
<tr>
<td>Maintenance: labour</td>
<td>$20,000 (60%)</td>
</tr>
<tr>
<td>spares</td>
<td>13,000 (35%)</td>
</tr>
<tr>
<td>consumables</td>
<td>2,000 (5%)</td>
</tr>
<tr>
<td><strong>Total maintenance</strong></td>
<td>35,000 (17%)</td>
</tr>
<tr>
<td><strong>Total operating cost (%age purchase price)</strong></td>
<td>205,000 (45-50%)</td>
</tr>
</tbody>
</table>

### TABLE 8.2b

**Comparative Summary of Annual Operating Costs**

<table>
<thead>
<tr>
<th>Operating cost</th>
<th>%age purchase price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quayside gantry cranes</td>
<td>$400,000</td>
</tr>
<tr>
<td>Straddle carriers</td>
<td>$240,000</td>
</tr>
<tr>
<td>Rubber-tyred gantry cranes</td>
<td>$250,000</td>
</tr>
<tr>
<td>Medium rail-mounted gantries</td>
<td>$350,000</td>
</tr>
<tr>
<td>Small rail-mounted gantries</td>
<td>$270,000</td>
</tr>
<tr>
<td>Terminal tractor + 3 trailers</td>
<td>$137,500</td>
</tr>
<tr>
<td>Front-end loaders (42t)</td>
<td>$210,000</td>
</tr>
<tr>
<td>Reach stackers</td>
<td>$205,000</td>
</tr>
</tbody>
</table>
8.2.2 Tables 8.2a and 8.2b demonstrate striking differences in annual costs between the different equipment types, both in absolute values and as proportions of the purchase price. However, to take such figures in isolation could be very misleading. When evaluating container equipment it is much more appropriate to compare 'system' costs, which take into account the number and mix of units to be purchased. For example, all systems must include quayside gantry cranes, and most employ a mixture of handling equipment types, each of which adds its contribution to total operating costs. We shall consider system costs in the next Section.

8.3 Container handling system costs

8.3.1 The tables below summarize the total system cost and the unit cost (per container handled) for each of the major Direct and Relay handling systems. The figures have been calculated on the basis of two throughputs: 100,000 and 250,000 containers per annum; these correspond to the handling capability of single-'unit' (i.e. two gantry crane) and double-'unit' (four gantry crane) terminals respectively. The costs are based on the figures presented in Section 8.2 and the ratios of equipment unit numbers:throughput discussed in the relevant Chapters.

8.3.2 In developing the figures presented in the tables, the following assumptions were made:
- Availability of the equipment will be good;
- Utilization will be at the average rates discussed in earlier Chapters;
- there will be a balanced trade of imports/exports;
- operating performance will be at the levels achieved in European ports.

It must be made clear that the costs specifically exclude the purchase price of the land, the construction, paving and all other terminal development costs, and the Annual Capital Recovery arising from those costs. Since these factors are enormously variable, it is not realistic to take them into account here - but clearly they will make significant contributions to the initial and subsequent annual operating costs for a particular terminal.

It should also be noted that the 'combination system' analysed here is just one sample system, a combination of rubber tyred yard gantry cranes (used for exports) and straddle carriers (for imports). Chassis/trailer and lift truck systems costs are only calculated for the single-unit terminal, as it would be unrealistic to consider such systems for a terminal handling 250,000 containers a year.
<table>
<thead>
<tr>
<th>System</th>
<th>No. of units</th>
<th>Capital Recovery Cost</th>
<th>Capital Cost</th>
<th>Annual Operating Cost</th>
<th>Total Annual Costs</th>
<th>Cost per container handled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Chassis System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
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<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractors</td>
<td>20</td>
<td>1.5</td>
<td>0.265</td>
<td>2.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chassis</td>
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<td>50.0</td>
<td>8.850</td>
<td>6.25</td>
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<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td>58.5</td>
<td>10.007</td>
<td>9.65</td>
<td>19.66</td>
</tr>
<tr>
<td><strong>B. Tractor-trailer System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
<td>2</td>
<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractors</td>
<td>20</td>
<td>1.5</td>
<td>0.265</td>
<td>2.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailers</td>
<td>2500</td>
<td>37.5</td>
<td>6.634</td>
<td>6.25</td>
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<td></td>
</tr>
<tr>
<td>Lift trucks</td>
<td>6</td>
<td>1.8</td>
<td>0.318</td>
<td>1.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td>47.8</td>
<td>8.109</td>
<td>10.91</td>
<td>19.02</td>
</tr>
<tr>
<td><strong>C. Straddle Carrier Direct System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
<td>2</td>
<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straddle carriers</td>
<td>12</td>
<td>6.0</td>
<td>0.968</td>
<td>2.88</td>
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<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td>13.0</td>
<td>1.869</td>
<td>3.68</td>
<td>5.54</td>
</tr>
<tr>
<td><strong>D. Straddle Carrier Relay System</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
<td>2</td>
<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straddle carriers</td>
<td>10</td>
<td>5.0</td>
<td>0.807</td>
<td>2.40</td>
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<td>Tractors</td>
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<td>0.9</td>
<td>0.159</td>
<td>1.56</td>
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<td></td>
</tr>
<tr>
<td>Trailers</td>
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<td>0.5</td>
<td>0.080</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
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<td>13.4</td>
<td>1.938</td>
<td>4.84</td>
<td>6.78</td>
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</table>

(cont.)
TABLE 8.3a (cont.)

<table>
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<tr>
<th></th>
<th>No. of units</th>
<th>Capital cost</th>
<th>Annual Capital Recovery Cost</th>
<th>Annual Operating Costs</th>
<th>Total Annual Costs</th>
<th>Cost per container handled</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E. Rubber-tyred Gantry Crane System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
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<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTGs</td>
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<td>5.1</td>
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<td>1.50</td>
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<td></td>
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<td>0.9</td>
<td>0.159</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailers</td>
<td>30</td>
<td>0.5</td>
<td>0.080</td>
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</tr>
<tr>
<td><strong>Totals</strong></td>
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<td><strong>F. Rail-mounted Gantry Crane System</strong></td>
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<td></td>
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</tr>
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<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
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<td></td>
</tr>
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<td>Rail-mounted GCs</td>
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<td>7.0</td>
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<td>1.4</td>
<td>0.239</td>
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<tr>
<td>Trailers</td>
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<td>0.106</td>
<td>0.10</td>
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</tr>
<tr>
<td><strong>Totals</strong></td>
<td>16.0</td>
<td>2.136</td>
<td>4.29</td>
<td>6.43</td>
<td>$64</td>
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<tr>
<td><strong>G. Lift-truck Direct System</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
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<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lift trucks</td>
<td>16</td>
<td>4.8</td>
<td>0.849</td>
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</tr>
<tr>
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<td>11.8</td>
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<td>5.90</td>
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<tr>
<td><strong>H. Lift-truck Relay System</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quayside cranes</td>
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<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
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<td></td>
</tr>
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<td>Lift trucks</td>
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<td></td>
</tr>
<tr>
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<td>0.159</td>
<td>1.56</td>
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</tr>
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<td>Trailers</td>
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<td>0.080</td>
<td>0.08</td>
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<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>11.4</td>
<td>1.619</td>
<td>4.54</td>
<td>6.16</td>
<td>$62</td>
<td>(cont.)</td>
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</tbody>
</table>
### TABLE 8.3a (cont.)

<table>
<thead>
<tr>
<th>No. of Capital</th>
<th>Annual Capital</th>
<th>Annual Operating</th>
<th>Total Annual</th>
<th>Cost per container handled</th>
</tr>
</thead>
<tbody>
<tr>
<td>units</td>
<td>cost</td>
<td>Recovery</td>
<td>Cost</td>
<td>Costs</td>
</tr>
<tr>
<td>Quayside cranes</td>
<td>2</td>
<td>7.0</td>
<td>0.892</td>
<td>0.80</td>
</tr>
<tr>
<td>Straddle carriers</td>
<td>6</td>
<td>3.0</td>
<td>0.484</td>
<td>1.44</td>
</tr>
<tr>
<td>RTGs</td>
<td>4</td>
<td>3.6</td>
<td>0.528</td>
<td>1.00</td>
</tr>
<tr>
<td>Tractors</td>
<td>12</td>
<td>0.9</td>
<td>0.159</td>
<td>1.56</td>
</tr>
<tr>
<td>Trailers</td>
<td>30</td>
<td>0.5</td>
<td>0.080</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>15.0</td>
<td>2.143</td>
<td>4.88</td>
<td>7.02</td>
</tr>
</tbody>
</table>

### TABLE 8.3b

Annual Costs of Container Equipment Systems
for terminal of annual throughput 250,000 containers
(total costs in $millions, cost/container in $)

<table>
<thead>
<tr>
<th>No. of Capital</th>
<th>Annual Capital</th>
<th>Annual Operating</th>
<th>Total Annual</th>
<th>Cost per container handled</th>
</tr>
</thead>
<tbody>
<tr>
<td>units</td>
<td>cost</td>
<td>Recovery</td>
<td>Cost</td>
<td>Costs</td>
</tr>
</tbody>
</table>

#### A. Straddle Carrier Direct System

| Quayside cranes | 4   | 14.0  | 1.784 | 1.60  |
| Straddle carriers | 25  | 12.5  | 2.020 | 6.00  |
| **Totals**    | 26.5| 3.804 | 7.60  | 11.40 | **$46**                       |

#### B. Straddle Carrier Relay System

| Quayside cranes | 4   | 14.0  | 1.784 | 1.60  |
| Straddle carriers | 18  | 9.0   | 1.453 | 4.32  |
| Tractors        | 24  | 1.8   | 0.318 | 3.12  |
| Trailers        | 50  | 1.0   | 0.133 | 0.13  |
| **Totals**    | 25.8| 3.688 | 9.17  | 12.86 | **$51**                       |

(cont.)
<table>
<thead>
<tr>
<th>No. of units</th>
<th>Capital cost</th>
<th>Annual Capital Operating Recovery</th>
<th>Total Annual Costs</th>
<th>Cost per container handled</th>
</tr>
</thead>
</table>

### C. Rubber-tyred Gantry Crane System

- **Quayside cranes**: 4 units at $14.0, annual capital recovery cost $1.784, operating cost $1.60
- **RTGs**: 12 units at $10.2, annual capital recovery cost $1.497, operating cost $3.00
- **Tractors**: 24 units at $1.8, annual capital recovery cost $0.318, operating cost $3.12
- **Trailers**: 50 units at $1.0, annual capital recovery cost $0.133, operating cost $0.13

**Totals**: $27.0, capital recovery cost $3.732, operating cost $7.85, total annual costs $11.58, $46 per container handled

### D. Rail-mounted Gantry Crane System

- **Quayside cranes**: 4 units at $14.0, annual capital recovery cost $1.784, operating cost $1.60
- **Rail-mounted GCs**: 6 units at $14.1, annual capital recovery cost $1.798, operating cost $2.10
- **Tractors**: 24 units at $1.8, annual capital recovery cost $0.318, operating cost $3.12
- **Trailers**: 50 units at $1.0, annual capital recovery cost $0.133, operating cost $0.13

**Totals**: $30.9, capital recovery cost $4.033, operating cost $6.95, total annual costs $10.98, $44 per container handled

### E. Combination System

- **Quayside cranes**: 4 units at $14.0, annual capital recovery cost $1.784, operating cost $1.60
- **Straddle carriers**: 12 units at $6.0, annual capital recovery cost $0.968, operating cost $2.88
- **RTGs**: 6 units at $5.4, annual capital recovery cost $0.749, operating cost $1.50
- **Tractors**: 24 units at $1.8, annual capital recovery cost $0.318, operating cost $3.12
- **Trailers**: 50 units at $1.0, annual capital recovery cost $0.133, operating cost $0.13

**Totals**: $28.2, capital recovery cost $3.952, operating cost $9.23, total annual costs $13.18, $53 per container handled

8.3.3 Examination of the tables above raises a number of interesting issues. The first of these is the significantly higher cost of the chassis operation when compared with stacking systems. Based on the purchase of 2500 chassis for transport and storage, the total cost of a chassis operation, for an annual terminal throughput of 100,000 containers, is $19.65 million per annum. This is about three times the cost of competing systems. However, the costs are not strictly comparable, since chassis also provide the means of inland transport and are normally the choice of a 'total transport' operator and proprietary ownership of the terminal. Perhaps a fairer comparison would be with a terminal trailer system, which is why those figures have also been calculated. They show that, although trailers are less expensive to purchase than chassis, total annual costs are very similar, at $19.02 million per annum. This is because means have to be provided of lifting containers to and from the terminal.
trailers and inland transport; lift trucks have been included for this in our example. When land costs are added, it makes a chassis/trailer system very costly, in spite of the apparently low equipment operating costs shown in Table 8.2a, and prohibitively expensive for high throughputs (which is why no figures were calculated for the 250,000 container throughput).

8.3.4 A second feature to emerge from the tables is the fact that the annual operating costs of the different stacking systems (i.e. container handling systems other than Chassis and Trailer Systems) are of the same order of magnitude - there are no striking differences between them. In the case of the 100,000 container throughput figures, the highest cost system (the Combination System) is about 30% more expensive than the lowest (the Straddle Carrier Direct System). The differences that do exist appear in both the Annual Capital Recovery costs and the Annual Operating Costs.

For throughputs of 250,000 containers a year, the differences are even less marked (and certainly well within the margins of error in the assumptions made). This applies to the Capital Costs, the Annual Capital Recovery rate and the Total Annual Costs. Again, the Combination System is the most expensive, but at this throughput the least expensive system is the Rail-mounted Gantry Crane System.

If these analyses are accepted, and the differences in system costs are far less significant than might have been expected, it throws much greater significance on the other factors involved in equipment selection, particularly operating and maintenance features, land availability and other terminal development factors. We shall consider a variety of such factors in the next Section.

8.4 Factors in equipment choice

8.4.1 Since operating and other costs are not likely to be the deciding factors, the complicated decision on which equipment system to select must be based on a broad range of factors of which operating and maintenance features are (and will continue to be) of great importance. What is essential is that senior management undertake a thorough and comprehensive evaluation of the alternative back-up systems and their component equipment types before making their investment decision. No two investment decisions will be exactly the same. The choice of equipment must be based on what will best suit local conditions, trading and traffic requirements, operating practices and manpower and maintenance skills, etc. It is a vital terminal planning activity. The many factors that have to be taken into account in evaluating equipment investment decisions and in the terminal planning process can be grouped under five major headings:

1. Terminal development factors
2. Equipment costs
3. Equipment maintenance
4. Manning requirements
5. Operating factors.

In this final Section we shall bring together in summary form, under those five headings, the principal features of each type of handling equipment and provide guidelines to the appropriate handling systems for various circumstances. In this context, 'low throughput' is taken to be under 100,000 TEU per annum, 'medium throughput' between 100,000 and 200,000 TEU per annum, and 'high throughput' anything over 200,000 TEU/annum.

8.4.2 Straddle carriers

A. Terminal development factors

1. Medium to good land utilization (400 TEUs/hectare).
2. Moderate to high terminal surface loads (20 tonnes/m²).
3. Moderate machine weight (48-58 tonnes unladen, 90 tonnes when carrying a 40' container loaded to ISO limits).
4. Wheel loadings typically 9-12 tonnes (but vary with number of wheels and their configuration).
5. Expensive, hard-wearing paving, resistant to surface scrub and dynamic wheel loadings, required for complete terminal, to permit movement of equipment to all operations areas.
6. Terminal paving prone to contamination and damage from hydraulic fluid and oil leaks.
7. Unsuitable for terminals prone to differential settlement - a smooth, level surface is essential.
8. Moderate to high initial terminal development cost, basically similar for both Direct and Relay Operations - but reduced weight-bearing capacity may be permissible on the quay apron and marshalling area in the Relay Operation.
9. Suitable for terminals with medium to high container throughputs.
10. Average stacking heights 1.5 for imports, 2.5 for exports, 3.5 for empties.

B. Equipment costs

1. One machine required for each 12,000-14,000 (Direct System) or 14,500-17,000 (Relay System) container throughput.
2. Purchase price for 1-over-2 stacker about $500,000.
3. Moderate asset life; working life at least 12 years, and can exceed 15 years if well maintained.
4. High fuel consumption (20 litres/hour).
5. Moderate operating costs ($240,000 per annum per machine).
6. Low hourly operating cost ($92/hour at 3500 operating hours/year).
7. Low box handling cost ($7.5/box).

C. Equipment maintenance

1. Shaft-drive preferred to hydraulic or chain drive.
2. Fixed-arch preferred to rising-arch machines.
3. Relay Operation results in less wear-and-tear on machines than Direct Operation.
4. Poor Downtime record (average 15% of operational time - 90 hours/month); particularly poor record in hot and dusty climates.
5. 25% of Downtime is planned, preventive maintenance (20 hours/month), 75% due to equipment breakdown and damage repair;
6. Failures involving electrical systems account for 50-66% of all breakdowns.
7. Tyre wear is high; tyres last 2000-4000 hours and cost $12,000-16000 per machine per year.
8. Batteries last 2 years on average.
9. High quality, specialized maintenance facilities needed, with access towers, walkways, platforms and overhead cranes, and a mobile facility to repair machines on site.
10. Specialized mechanical/hydraulic and electrical/electronic skills essential for maintenance staff; knowledge of communication and computer equipment will be needed more and more.
11. In Direct system, only one type of equipment needs to be maintained, reducing range of spare parts to be stocked (among other benefits); but high spares stockholding needed.
12. Average Availability of 85% achievable with good maintenance.
13. Maintenance costs about $60,000/year, 35% accounted for by labour, 60% spares, 5% consumables.

D. Manning requirements

1. High driver skill requirement.
2. Driver's cab is located 10 to 12 metres above the terminal surface, so excellent depth perception needed.
3. Aptitude tests should be applied to ensure suitability for training.
4. Minimum of 3 months' training must be provided, most of it practical.
5. Good cab layout and control design needed to maximize comfort and minimize fatigue.

6. Cab must be provided with good ventilation, heating and cooling systems.

7. Driver's field of vision tends to be restricted, unless cab design of high quality.

8. High engine noise levels, unless careful attention is given to mounting position and noise insulation.

9. Manning is commonly 3 drivers for 2 straddle carriers per shift, allowing relief changes.

10. Total manning for a two-crane 'unit' is 28 men (Direct Operation) or 33 men (Relay Operation).

E. Operating factors

1. Versatile equipment, capable of transfer, stacking and intermodal movements.

2. Suitable for use in Direct or Relay Operation.

3. High degree of container selectivity, so suitable for handling imports and exports for ships with many ports of call.

4. Is easily deployed to different terminal activities - operationally flexible.

5. Can be used in combination with other transfer and stacking equipment.

6. Good inter-modal capability, to both road and rail.

7. Suitable for common-user terminals at which many ship operators call.

8. Unsuitable for long quay transfer distances (use Relay system then).

9. Good stacking ability (1-over-3 and 1-over-4 machines available).

10. Lift capacity under the spreader at least 30.5 tonnes, commonly 35 or even 40 tonnes.

11. Hoist speeds 10-30 metres/minute empty, 6-18 metres/minute loaded.


13. Dangerous operating environment; high risk of damage to machine, personnel and containers.

14. Utilization 200-400 hours/month (c.3500/year) in Europe, i.e. c.50%.

15. Sustained quay transfer handling rates 12-15 moves/hour in Direct Operation.

17. System involves 2.5-3.0 movements per box transit.
18. Very effective when dealing with peak demands on any terminal activity.
19. Relatively little scope for automation.

8.4.3 Rubber-tyred Yard Gantry Cranes

A. Terminal development factors
1. Good land utilization (700 TEUs/hectare).
2. High stacking capability (5 high).
3. Average stacking heights 2.5 for imports, 3.5 for exports, 4.5 for empties.
4. Suitable for high-throughput terminals.
5. Suitable where land is scarce or expensive to purchase or reclaim.
6. Moderately heavy machines (140 tonnes laden).
8. Wheel tracks and turning points need to be strengthened, but rest of terminal surface carries only average loadings; container stacking area requires only low quality surfacing, e.g. gravel bed.
9. Low terminal development costs.
10. Capable of being used in combination system.

B. Equipment cost
1. Moderate asset life (minimum 15 years, 1 million moves).
2. Moderate initial purchase cost ($750,000-900,000).
3. High fuel consumption (18-20 litres/hour) and cost ($35,000/year).
4. Moderate annual operating cost ($250,000).
5. Moderate hourly operating cost ($125).
7. One RTG required per 20,000 container throughput.

C. Equipment maintenance
1. Good Availability (90-95%), provided well maintained, and low Downtime record (average 8%).
2. Electrical and electronic components susceptible to failure, but good record on breakdowns.
3. Preventive maintenance accounts for 50% of Downtime.

4. Low maintenance cost.

5. Good maintenance capability needed, with specialized and well trained maintenance staff.


D. Manning requirements

1. Highly skilled drivers needed (but tractor drivers used on quay transfer and other terminal movements need only moderate skills).

2. Three months' training programme required for RTG drivers.

3. Manning is normally 2 men/machine/shift.

4. Total manning for a two-crane 'unit' is 30-32 men/shift.

5. Driver costs account for 60% of operating costs (c.$150,000/annum).

6. Good cab design is required to maximize driver comfort, safety and field of view and to minimize fatigue.

7. A checker/talleyman cab is needed at ground level.

E. Operating factors

1. Utilization moderate (2500-3000 hours/year).

2. High trolley speeds.

3. Low travel speeds (5.5-9 kph), significant when travelling between storage areas and blocks.

4. Liable to high proportion of unproductive moves.

5. Good average hourly handling rates (20 moves/hour).

6. Annual performance of 65,000-70,000 moves/machine.

7. High lifting capacity (30.5, 35.5 or 40t in current models).

8. Average of 3.0-3.5 movements per box transit.

9. Poor container accessibility and selectivity.

10. Usable only for container stacking; must be supported by tractor-trailer sets or other equipment for in-terminal transfers.

11. Requires good terminal planning system and high management efficiency.

12. Good intermodal capability to road vehicles.

13. Good machine for transshipment traffic.

15. Good safety record.

16. Warning devices essential, and clear marking on terminal surface, for safety and to optimize flow patterns.

8.4.4 Rail-mounted Yard Gantry Cranes

A. Terminal development factors

1. Excellent land utilization (1000 TEUs/hectare).

2. High stacking capability (5 high).

3. Good average stacking heights (3.5) for imports and exports.

4. Wide-span machines (up to 60 metres) give dense block stacking.

5. Suitable for high throughput terminals.

6. Suitable choice where land is in short supply or expensive to purchase or reclaim.

7. Very heavy machine (300-370 tonnes), requiring special civil engineering structures under crane rails; elsewhere, terminal pavement need not be heavy-duty, and container stacking area requires only low-grade paving or gravel bed.

8. Moderate-high wheel loadings (20-25 tonnes per wheel).

9. Low terminal development costs.

B. Equipment costs

1. Very high initial investment cost ($2.2-2.5 million per machine)

2. High power (electricity) cost (15% of operating cost).

3. High annual operating cost ($350,000).

4. Long asset life (25 years, 2.5-3.0 million moves).

5. High hourly operating cost ($185 at 3500 hours utilization).

6. Moderate cost per box movement ($7.5 per move).

C. Equipment maintenance

1. Excellent Availability (96%), providing maintenance capability is good.

2. Moderate breakdown record.

3. Preventive maintenance accounts for 50% of Downtime.
4. High maintenance costs (c.$100,000/year).
5. Good maintenance facilities needed; mobile workshop essential.
6. Specialized and highly trained maintenance staff required, particularly in electrical/electronic fields.

D. Manning requirements
1. Highly skilled drivers required, with three months' minimum training.
3. Total manning 24 men per single-'unit' terminal per shift.
4. Manning costs high ($192,000/year - 55% of operating costs).
5. Good cab design required, for driver safety and comfort.
6. Checker/talleyman cab required at ground level.

E. Operating factors
1. Good Utilization (3000-4000 hours/year).
2. High trolley speeds (150 metres/minute) and hoist speeds (30-60 metres/minute).
3. Moderate-slow travelling speed between storage locations (100-150 metres/minute).
5. Each machine makes 105,000-140,000 lifts/year.
6. High proportion of unproductive moves, particularly in import stack.
7. High stacking results in 3.0-3.5 moves per box transit.
8. One machine needed per 35,000-40,000 box throughput.
9. Usable only for stacking; dependent on tractor-trailer sets or other equipment for quay transfer and in-terminal movements.
10. Poor selectivity, and least flexible of operating systems.
11. Excellent safety record, though warning devices are essential.
12. Capable of being used in combination systems.
13. Good intermodal capability to road vehicles.
14. Good machine for transshipment traffic.
15. Highly suited to automation.
16. Requires good terminal planning system and high management efficiency.
8.4.5 Tractor-trailer Systems

A. Terminal development factors

1. Extensive land area requirement.
2. System investment is very high.
4. Normally used in a pure operation on proprietary terminals.
5. Suitable for small terminals in start-up or early growth conditions.
6. Low wheel loadings on terminal surface.

B. Equipment costs

1. Low initial purchase price per unit (tractors, $50,000-75,000, trailers $15,000-20,000).
2. Trailer for exclusively in-terminal use is 25% cheaper than 'plated' chassis licensed for road use.
3. Moderate fuel consumption - 12 litres/hour (15% of operating cost).
4. Low operating cost ($39/hour at 4000 operating hours/year).
5. Cheapest type of container-handling equipment to purchase, operate and maintain.
6. Very expensive initial system investment cost (one chassis/trailer for every container in storage).
7. Low asset life (10 years).

C. Equipment maintenance

1. Availability good (90%).
2. High proportion of Downtime is for breakdowns (60%).
3. 90% of breakdowns are from a mechanical cause.
4. Fifth-wheel linking device is prone to maintenance problems.
5. Tyres last about 2000 operating hours.
6. Most reliable container-handling machines, with good maintenance record.
7. Low maintenance cost for tractor (30% of purchase price/year) and trailers (20% of purchase price/year).
8. Standard maintenance facilities required.
9. No specialist skills required by maintenance staff.

D. Manning requirements

1. Manning is one driver/tractor.
2. Total manning is 28 men/shift on a two-crane, single-'unit' terminal.
3. Only moderate skills are needed by tractor drivers.
4. Drivers need public driving licence, as well as terminal training.
5. High manning costs (70% of operating cost).

E. Operating factors

1. Good Utilization (3500-4000 hours/year).
2. High travel speeds (20-60 kph).
3. Low handling rate (5-8 moves/hour on quay transfer).
4. Usable in pure or relay system, and in combination systems.
5. Excellent for inter-modal operations to road.
6. High-capacity tractors available to pull trains of two or more trailers.
7. Low operating cost ($130,000/year).
8. Prone to accidents, particularly collisions with other plant.
9. Clean exhaust essential for working RoRo vessels.

8.4.5 Lift Trucks

A. Terminal development factors

1. Low land utilization (275 TEUs/hectare).
2. Wide aisleway spaces needed.
3. Extensive land area requirements.
4. Moderate-poor stacking capability of full 40' containers, though excellent stacking height for empties (up to 6 high).
5. Poor stacking in second and third rows of stack.
6. Export boxes stacked 3 high and imports 1.5 high on average.
7. High wheel loadings on terminal surface (up to 90 tonnes/m²).
8. High specification terminal surface and paving required.
9. High terminal development costs.
11. Not suitable for terminals prone to differential settlement.
12. Suitable for low-medium throughputs (up to 120,000 boxes/year).
13. Can be used in pure (Direct), Relay and Combination systems.

B. Equipment costs
   1. Low initial cost/machine ($300,000-400,000).
   2. Low equipment system cost.
   3. Comparatively short asset life (10 years).
   4. Low maintenance cost (15% of purchase price/year).
   5. Fuel consumption 15-18 litres/hour for large machines.
   6. Low operating cost ($88/hour).
   7. High cost per box handled ($12.5).

C. Equipment maintenance
   1. Good Availability (90-95%).
   2. Very good maintenance features and record.
   3. Very reliable machines.
   4. No specialized maintenance facilities required.
   5. Prone to accidental damage, particularly to masts and spreaders.
   6. High demand for spare parts.
   7. High tyre wear; tyre life 2-3 years.

D. Manning requirements
   1. Manning is one driver/machine/shift.
   2. Total manning for a two-crane, single-'unit' terminal is 26 men/shift in a Direct operation.
   3. Only moderate driver skills are required, and a training course of three weeks' duration is adequate.
   4. Cab design needs careful attention for driver comfort and safety; poor driver field of view is a danger.
E. Operating factors

1. Low Utilization (2500-3000 hours/year).


3. Poor manoeuvring characteristics.

4. Low handling rate (6-8 moves/hour in Direct operation, 10-12 moves/hour in a Relay operation).

5. Each machine performs 18,000-24,000 moves/year (200,000-300,000 moves in its working life).

6. One lift truck needed per 6000-8000 box throughput in Direct operation.

7. Moderate annual operating cost ($210,000/year - 60% of purchase price/year).

8. Versatile, multipurpose machine, easy to move between operating areas.

9. Excellent machine for handling empty containers.

10. Good machine for intermodal operations to road and rail.

11. Simple machine to operate.

12. Suitable for LoLo and RoRo operations.

13. Good in supporting role in high-throughput terminals.

14. Unsuitable for long transfer distances.

15. Poor stability, particularly on uneven surfaces and when stacking loaded boxes above 3-high.

16. Significant de-rating of lifting capacity when stacking high or beyond standard load centre.

17. Difficulty in picking up container from between the legs of gantry cranes.
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Other series referred to:

