Contributions to Management Science

Seaside Operations Planning in Container Terminals

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Chapter 2
Maritime Container Transport

This chapter provides an introduction to the maritime container transport industry. Section 2.1 briefly describes the development of maritime container transport and the observed trends within the last decades. The organization of container transports is explained in sect. 2.2. In sect. 2.3 the layout of a container terminal and the available equipment are described.

2.1 A Brief History

In 1956 a freight forwarder named Malcolm McLean transported 58 specially designed containers on the vessel *Ideal-X*. This event is commonly seen as the birth of the civil maritime container transport industry. While earlier attempts at containerization have been made in the military and in the civil sector, McLean's achievement is the first implementation of a whole transport system completely aligned to the purpose of fast container transport and handling, see Levinson (2006). A substantial decrease in the handling time of the vessel and in the amount of laborers required for the transshipment process proved his concept to be far more profitable than conventional cargo handling. Soon regular liner services were established. The first services connected ports of the US east coast with ports in the Caribbean and in Central America. Later, services where established connecting ports all around the world. The port of Hamburg (Germany), for example, served its first container vessel in 1967, see HHLA (2008).

To control the development of different container systems, an international standardization of container measures was achieved in 1964, yielding a set of container sizes that were to be used from there on. The basic container unit today is of size $20' \times 8' \times 8'6''$ (length $\times$ width $\times$ height), also referred to as a TEU (Twenty-foot equivalent unit). The containers prevailing in maritime, road, and rail transport have a length of $40'$ feet, represented by two TEU, but also referred to as FEU (Forty-foot equivalent unit). Special purpose containers, such as "High Cube" containers

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for cargo that overshoots a height of 8′6″, can differ in size. The container used in maritime, road, and rail transport can, however, not be used in air transport. The air transport industry has developed specialized container systems called ULDs (Unit Load Devices), adapted to the needs of aircraft, see IATA (2007).

Several trends can be identified in the maritime container transport industry. Within a few decades, containerization of general cargo became predominant. For example, in 2006 the degree of containerization was 97.2% in the Port of Hamburg, see Fig. 2.1. This change was accompanied by a growth of the world's container vessel fleet in terms of the number of vessels as well as in the size of vessels. In recent years this growth still continues due to the strong increase in international trade. For example, the number of container vessels with a gross tonnage of at least 300 tons grew from less than 2,500 in the year 2000 to more than 4,200 vessels in the year 2008, see ISL (2008). At the same time the total transport capacity grew from 4.4 million TEU to about 11 million TEU. According to their size, container vessels are classified into so-called generations. Although the vessel size of a particular generation is not standardized, approximate dimensions are shown in Fig. 2.2. The largest vessels in use today have a capacity of about 11,000 TEU.

The trend of increasing vessel size still continues but the application of so-called Ultra-Large Container Ships (ULCSs) seems to be limited for several reasons. First, a proper travel speed of a ULCS requires major constructional changes, e.g., the

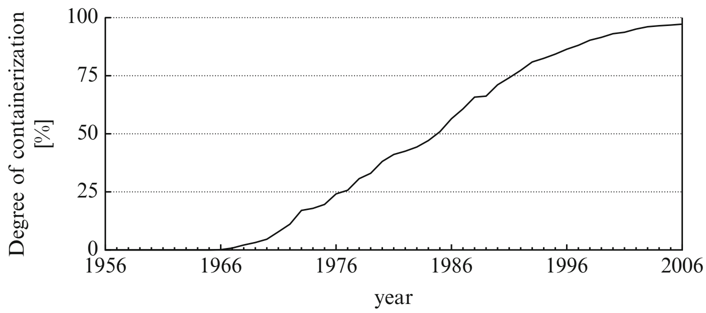
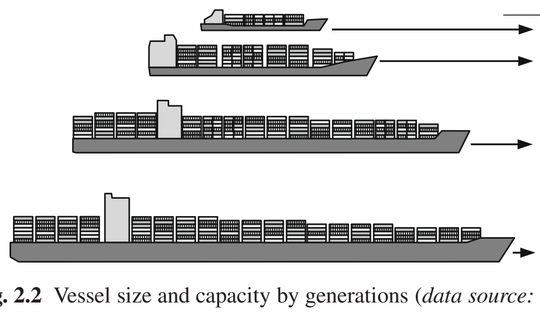


Fig. 2.1 Degree of containerization in the port of Hamburg (*data source:* Port of Hamburg Marketing, 2008)



Generation	Capacity [in TEU]	Length [in m]	Beam [in m]	Draft [in m]
-	< 760	< 120	< 16	< 8
1.	760-1000	120-190	16.0-28.0	8.0-10.0
2.	2000-2800	210-240	28.0	11.5
3.	3000-4000	260-290	32.2	12.5
4.	4000-5000	280-295	32.2	13.5
5.	5000-6000	285-318	39.2-40.8	13.5
6.	6000-6400	295-318	40.0-42.8	14.2
7.	6400-7500	318-348	42.8-45.0	14.8-15.0
8.	7500-8400	348-365	~48.0	14.8-15.2

Fig. 2.2 Vessel size and capacity by generations (*data source:* Brinkmann, 2005, p. 67)

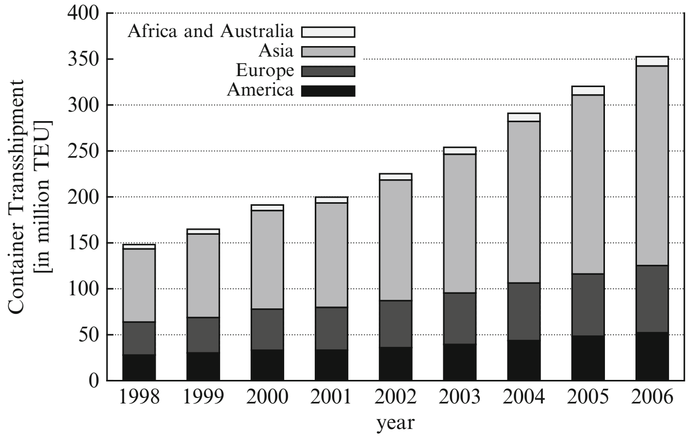


Fig. 2.3 Container transshipment by continents (*data source:* Port of Hamburg Marketing, 2008)

installation of a second engine, which result in a considerable jump in the construction cost, see Tozer and Penfold (2001). A decrease in travel speed is unacceptable because the advantage of the capacity increase may be canceled out by a reduced number of trips per year. Second, the larger the vessel is, the smaller is the number of ports and canals it can pass through. Such restrictions already exist for vessels with a beam exceeding 32.2 m. They are unable to pass the Panama Canal and are therefore also named Post-Panamax vessels, see Brinkmann (2005). Third, the number of routes where ULCS can be profitably applied is further limited to those that show a sufficiently large transport demand. According to Tozer and Penfold (2001), a most promising trade route for the application of ULCS is the one between East Asia and Europe.

A further trend in maritime container transport is the high growth in the volume of transshipped containers in ports. Figure 2.3 shows the container transshipment by continents within the years 1998–2006. It can be seen that the total number of transshipped container units has more than doubled within this time span, showing a total of 350 million TEU in 2006. This growth reflects the increasing transshipment demand caused by the attractiveness of containerized cargo transport.

2.2 Organization of Container Transports

Container transport takes place within road, rail, inland waterway, and maritime traffic networks. A transshipment node in a container transport network is referred to as a *container terminal* (CT). Usually traffic networks overlay with each other and terminals can be part of more than one network. In such terminals, containers can be transshipped between different modes of transport. Forwarding a container from a shipper to a recipient requires the use of transport relations of one or more traffic networks and a transshipment of the container in a CT whenever different transport vehicles are involved. Regarding this issue, the role of seaport terminals and the organization of the vessel traffic are of particular relevance for this thesis.

Container terminals of the maritime traffic network are located in seaports, where more than one terminal can be located in a port. The main purpose of seaport container terminals is to serve container vessels. Besides the large ocean-going container vessels, terminals also serve barges and feeder vessels. Barges are used for the container transport on inland waterways. Feeder vessels connect ports with low transport volume or insufficient accessibility for large vessels to so-called hub ports. The hubs are connected by large ocean-going vessels because of the high transport volume on these relations. The decision which ports become hubs are a subject of the strategic network design, see, e.g., Baird (2006) for a study concerning this matter.

Serving vessels in a terminal means loading and unloading containers. Containers to load on a vessel are commonly referred to as *export containers*. Containers to unload from a vessel are referred to as *import containers*. The export containers are delivered from the shippers to the terminal ahead of the sea trip. The import containers have to be delivered to the recipients after their arrival at the terminal. These two types of transports constitute the pre- and post-carriage for the transport by an ocean-going vessel. The pre- and post-carriage can be executed using different combinations of transport means, as there are trucks, trains, barges, or feeder vessels, see Fig. 2.4. Since most shippers and recipients are not directly connected to a railway network or to a port, truck transport is typically involved in a practical transport chain. Next to container transshipment, terminals also intermediately store containers. This allows delivery of export containers from the hinterland before the arrival of the dedicated vessel and pickup of import containers for further transport after the delivering vessel has already departed. In other words, a temporal decoupling of the transport links is enabled.

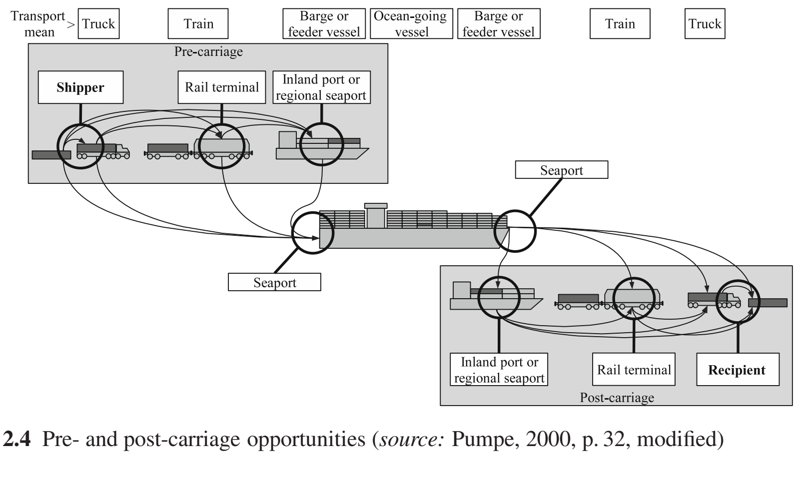


Fig. 2.4 Pre- and post-carriage opportunities (*source:* Pumpe, 2000, p. 32, modified)

The region made up of the origins of export containers and of the destinations of import containers is called the *hinterland* of a terminal. Since terminals closely located to each other show different reachability in terms of transport distances, transport times, and transport connections, the hinterland of a specific terminal cannot be defined exactly and may reach into the hinterland of neighboring terminals, see Lemper (1996). In such a situation, terminals compete with each other in attracting container shipments. An example constitutes the so-called North Range in Europe, where major CTs are located in Le Havre, Rotterdam, Antwerp, Bremerhaven, and Hamburg.

For connecting the seaport terminals, *liner services* are established on which container vessels operate. In a liner service, vessels follow a fixed schedule that gives the order of ports to visit and the calling times, see Ronen (1983). For a liner service it has to be decided on the ports to connect and on the size of the vessels to deploy. Furthermore, by deciding on the frequency of visiting a port within a schedule (e.g., on a weekly call basis) the number of vessels to deploy is determined. Liner services can be performed in round-the-world tours, where the sequence of ports lets the vessels go around the globe, or on a pendulum tour between two or three important trade regions. On a pendulum tour a vessel visits its ports in a given order and, at the last port, reverses this order to end up in the port where the tour began.

The described organization of transport networks and transport operations coincides with the (economic) advantages that make the transport of containerized goods so attractive. The shippers take advantage of the regular transport opportunity offered by the liner service schedules. The various ways of realizing pre- and post-carriage enable shippers to flexibly align transport operations to their individual requirements. A further important aspect is that vessel capacity can be booked on the basis of single TEU, providing a flexible transport opportunity almost independent of the actual volume of a shipment. A large variety of container types enables shippers to use container transport not only for general cargo but also for liquid, bulk, frozen, and other types of goods, see Hapag-Lloyd (2008). Finally, the fast transshipments decrease the overall transport time and thus, reduce the shippers' cost of capital tied up in the transported goods.

The vessel operators benefit from *economies of scale*, which motivate to establish hub terminals in order to utilize large-sized container vessels. Port related and travel related economies of scale are observed. The first stems from the fact that a relative increase in the size of a vessel leads to an underproportional increase in its port cost. For example, according to Stopford (1997), port cost per call (without cargo handling cost) has been 22,000 USD for a 1,200 TEU vessel but only 43,000 USD for a 6,500 TEU vessel in the year 1996. The economies of scale related to the travel of a vessel are based on similar observations regarding an underproportional increase in operational cost, capital cost, and bunker cost per day, leading to costs per TEU per day of 16.6 USD for a 1,200 TEU vessel and 7.5 USD for a 6,500 TEU vessel, see Stopford (1997).

Containerization also leads to *economies of speed*. From the point of view of vessel operators only the travel time of a vessel is economically productive. The speedup of cargo transshipment as enabled by containerization reduces the handling times of vessels in ports from days or even weeks down to hours. Reductions in vessel handling times increase the proportion of travel time allowing for more trips per year and the generation of revenue for additionally transported containers. This revenue can basically be obtained by an increase in the travel speed, too. However, the speed up of cargo handling seems to be more profitable compared to the increase in travel speed, see Laine and Vepslinen (1994). Consequently, the performance of terminal operations is crucial for the profitability of liner services.

2.3 Layout and Technical Equipment of a Container Terminal

The layout of a seaport container terminal consists of different areas each one serving a specific functional purpose. The four major area types are:

- *Quay area* for mooring the container vessels
- *Transport area* for the transport of containers within the terminal
- *Yard area* for the storage of containers
- *Truck and train area* for serving the external trucks and the trains

Various technical equipment is used for the terminal operations. Cranes are employed at the quay and in the yard. Yard trucks or Automated Guided Vehicles (AGVs) perform the transport of containers between the terminal areas. Alternatively, so-called straddle carriers or Automated Lifting Vehicles (ALVs) can perform the transport as well as the stacking operations in the yard. Figure 2.5 sketches the functional areas and the equipment alternatives. In the following, a brief description of the areas and the equipment is provided. More detailed descriptions are given by Brinkmann (2005).

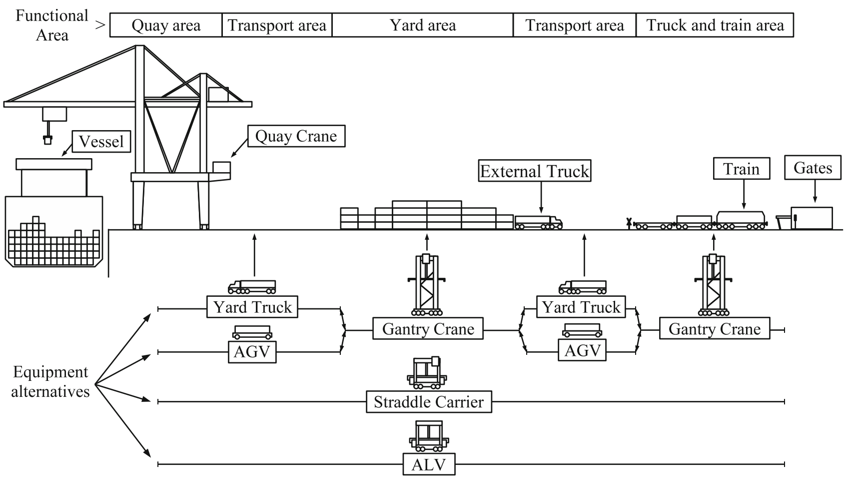


Fig. 2.5 Schematic cross sectional view of a container terminal

2.3.1 Quay Area and Quay Cranes

The seaside functional area of a CT is the quay, where ocean-going vessels, feeder vessels, and barges moor. The loading and unloading operations of containers are performed by *quay cranes* (QCs), see Fig. 2.6. Some container vessels are self-equipped with cranes in order to enable transshipment operations independent of the equipment offered at a terminal. However, nowadays vessel operators usually abstain from this option because a sufficient standard of equipment is offered at most terminals. Depending on their size, vessels may be served by up to six QCs simultaneously. Large vessels can have up to 22 container stacks side by side in a bay requiring properly dimensioned cranes with an outreach of 60 m, see Tozer and Penfold (2001). Due to the difficulties of accessing the containers within a vessel, a skilled crane driver is needed to operate a QC.

A loading or unloading operation of a container is referred to as a *move*. To unload a container, the QC's spreader is placed on it, fixed by twistlocks, and then lifted by a hoist. The crane's trolley moves to the quay where the spreader is lowered and the container is either put on the ground or put on a transport vehicle. The container is released by unlocking the twistlocks, and the spreader is hoisted again. The loading of a container uses the same crane operations in the opposite direction.

The productivity of a QC is measured by the number of moves per hour. This is a key indicator for the productivity of a terminal. In practice a QC currently realizes about 30 moves per hour, see Chu and Huang (2002). However, technological

Fig. 2.6 Quay cranes serving a container vessel (*source:* Port of Hamburg Marketing / D. Hasenpusch, 2008)

improvements aim at increasing crane productivity. Vessels can be equipped with cell guides to ease the positioning of containers within the hold, see Goedhart (2002). QCs can be equipped with two trolleys. One trolley serves the vessel and the other trolley serves the horizontal transport vehicles. Containers are handed over from one trolley to the other at a platform between the crane's uprights. While the landside trolley can be automated, an operator is still needed for the seaside trolley, see Jordan (2002). These so-called Dual Trolley QCs are applied, for example, in the Container Terminal Altenwerder in Hamburg.

2.3.2 Transport Area and Transport Vehicles

The horizontal transport system of a CT moves containers between the functional areas. The most often used equipment types are yard trucks and straddle carriers. Yard trucks are manned vehicles that pull chassis carrying the containers, see Fig. 2.7a. They are unable to lift containers and thus, demand a crane for loading and unloading operations. This requires a careful synchronization of cranes and trucks to avoid crane waiting. Dual Trolley QCs can be used to reduce such idle times because they enable a temporal decoupling of (un-)loading operations of the vessel and of the trucks. Yard trucks represent the technologically modest way of the container transport. Nevertheless, this can be economically attractive because of low purchase and maintenance costs as well as high flexibility regarding the workload of a terminal. However, labor costs for drivers lead to high operational costs.

An alternative to the use of yard trucks are straddle carriers, see Fig. 2.7b, also referred to as van carriers. Next to moving containers they are also able to lift and stack containers. This allows for the decoupling of QC operations and transport operations. If straddle carriers are used, a QC can put an unloaded container on the quay and continue the service process. This avoids crane waiting and leads to increased crane productivity in terms of moves per hour. The only prerequisite for unloading operations without crane waiting is that a free ground position is available to drop a container. Loading operations without crane waiting are enabled if straddle

(a) (b)

Fig. 2.7 Yard truck (**a**) and straddle carrier (**b**) (*source:* Kalmar Industries, 2008)

(a) (b)

Fig. 2.8 AGV at the port of Hamburg (**a**) and ALVs at the port of Brisbane (**b**) (*source:* Gottwald Port Technology, 2008; Kalmar Industries, 2008)

carriers deliver containers before the QC is ready for the pick up. The carriers can move away after a delivery without having to wait for the QC. Compared to yard trucks higher purchase, maintenance, and operational costs come along with the employment of straddle carriers.

Yard trucks and straddle carriers can be replaced by fully automated alternatives, namely Automated Guided Vehicles (AGVs) and Automated Lifting Vehicles (ALVs), see Fig. 2.8. The movement of automated vehicles is guided by induction coils installed in the pavement. AGVs are able to carry one $40'$ container or two $20'$ containers. ALVs transport a single container but can lift it like straddle carriers. Automated transport systems in CTs do currently not reach high transport productivity. One reason is that automated vehicles usually show a comparable low average speed. Another reason is that a breakdown of an automated vehicle may lead to downtime of the entire transport system. Nevertheless, the promised advantages of automated vehicles are the reduction of labor cost at the terminal and the reliable execution of work plans resulting from the elimination of human failure. Since the investment in automation needs to pay off, it is especially attractive for terminals with a high labor cost level, see Nam and Ha (2001). Currently AGVs are employed at Container Terminal Altenwerder (Hamburg, Germany), at European Combined Terminals (Rotterdam, Netherlands), and at Pusan Eastern Container Terminal (Pusan, South Korea). ALVs are a relatively new development used at the CT of Brisbane (Australia).

The functional area for executing horizontal transport is typically divided into one or more traffic lanes. The seaside transport area, also referred to as the apron, usually contains three traffic lanes, two for the flowing traffic and one for vehicles waiting at QCs to be served. The width of the traffic lanes depends on the equipment used. Yard trucks pulling several chassis at a time require a larger turn radius compared to straddle carriers. AGVs and ALVs require less traffic space because of the low speed and the precise guidance. While manned vehicles can flexibly use the available traffic lanes, the movement of automated vehicles is restricted to the network of designated travel routes. In the simplest case a single unidirectional loop design is used. Here, vehicles move along the quay in one direction and along the yard in the other direction. The vehicles can temporarily exit the loop to pickup and deliver containers at a vessel or at the yard. More complex network designs allow, for example, for bidirectional usage of traffic lanes or for more flexible routings of vehicles in order to shorten the travel distances, see Schrecker (2000).

2.3.3 Yard Area and Yard Cranes

The yard is used for the intermediate storage of containers. Import containers are stored until the hinterland transport is initiated. Export containers are stored until they are loaded onto the dedicated vessels. Areas for the storage of empty and reefer containers exist as well. A yard is usually divided into a set of yard blocks, which are separated by traffic lanes. A block consists of several parallel container rows, each of them providing a number of lengthwise arranged storage positions, see Fig. 2.9a. Multiple tiers of containers can be stacked at each position.

In Fig. 2.9a a yard is shown where the stacking and retrieval operations are performed by gantry cranes. These cranes can be rail mounted gantry cranes (RMGCs) or rubber tired gantry cranes (RTGCs). Depending on its design a RMGC spans up to 13 container rows, see Linn et al. (2003). A RTGC spans up to 8 container rows only, but it can be repositioned to other yard blocks, see Kalmar Industries (2008). Both crane types stack containers up to six tiers high. Usually the upmost tier of each stack remains empty in order to allow a crane passing over the stack with a container. One of the rows may be reserved for the service of transport vehicles, see Fig. 2.9a. Alternatively, vehicles are served at a front side of a block, which allows for a higher storage capacity but requires additional movement of the gantry cranes. Advanced technological solutions increase the transshipment capability of a crane operated yard. Double Rail Mounted Gantry Cranes possess two cranes of different size operating within the same block. The different sizes enable the cranes to pass each other, allowing for more flexible operations. Gantry cranes can be automated to a large extent. Such automated Double Rail Mounted Gantry Cranes are used at the CT Altenwerder in Hamburg. If straddle carriers are used for yard operations, the block structure is broken up by additional clearance between the container rows, see Fig. 2.9b. This enables straddle carriers to enter each row and access the desired

(a) (b)

Fig. 2.9 Container storage within the yard (*source:* Kalmar Industries, 2008)

storage position. Straddle carriers can stack containers up to a height of four tiers. Again, the upmost tier usually remains empty. If yard trucks are used at the CT, containers can be stored on the transport chassis in the yard. Obviously, little investment and operational costs as well as direct access to every container is possible, but storage capacity is wasted at the same time. Storage capacity is a key performance indicator for terminals where storage space is scarce. In general, the best storage capacity is achieved if gantry cranes are used. The usage of straddle carriers leads to a lower storage capacity which, however, is still much higher than the capacity enabled by storing containers on chassis.

2.3.4 Truck and Train Area

A seaport terminal provides the interface to the hinterland by serving trains and external trucks. Trucks have to pass gate houses, where containers are checked and transport documents are processed. If straddle carriers are used for the yard operations, trucks move to a parking area in order to be served. If gantry cranes are used, trucks are sent directly to the dedicated yard blocks in order to be served. Self-service of trucks is possible if containers are stored on chassis in the yard. For the service of trains, railway tracks lead into the terminal. If the yard is operated by gantry cranes, trains are served by gantry cranes too, where horizontal transport of containers is required again. Otherwise, straddle carriers or ALVs are used.

As can be seen above, a CT can be operated either by straddle carriers (ALVs) alone or by a combination of gantry cranes and yard trucks (AGVs). Since every equipment type shows its own strengths and weaknesses, there exists no overall best equipment selection. The selection decision basically aims at a high transshipment capability and at an economic balance of the investments to make and the expected operational costs. But also local conditions, such as a limitation of space or the labor education level, may enforce a certain decision. The particular equipment selection that is implemented in a terminal constitutes a set of requirements for the management of terminal operations.