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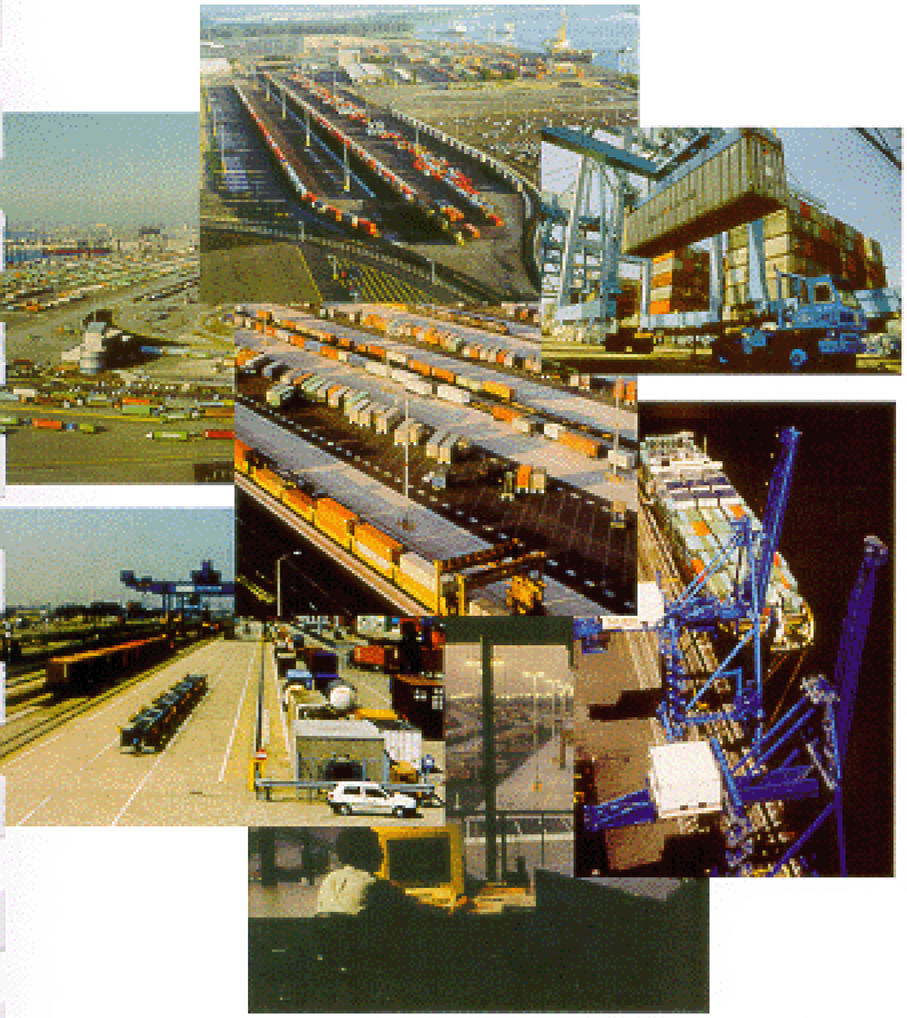

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MARINE TERMINAL PRODUCTIVITY MEASURES

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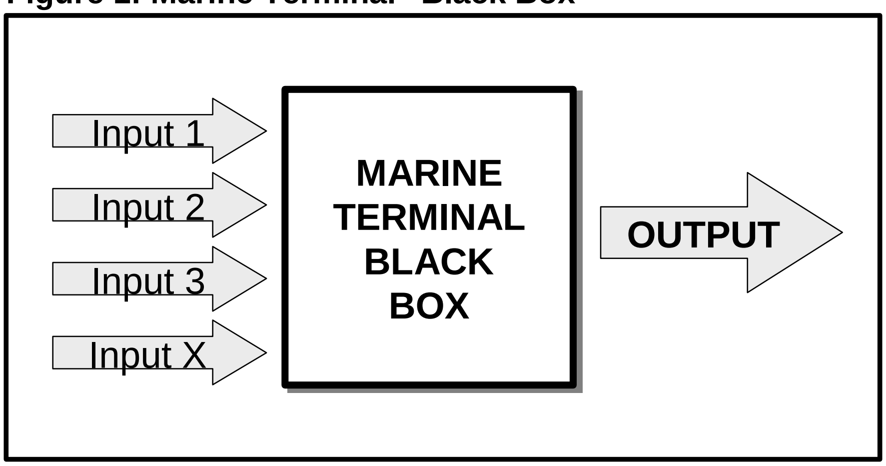
INTRODUCTION

Port productivity is an elusive measurement which has been subject to a variety of essays, presentations, papers and publications. The difficulty in defining port productivity stems as much from the variation found in world wide port operations as it does from evaluating the specific units of productivity to be measured. In addition, multiple marine terminals are often included in a single port. This can exacerbate the difficulties in port evaluation when multiple terminals share common resources such as berths, cranes or gates. This paper takes an operations engineering approach to the question of productivity measurement and will attempt to normalize the various units to be evaluated. It will also address the differences found between the discreet types of marine terminals.

In general, two approaches can be taken to quantifying a marine terminal operation. The first approach is a micro-analysis of each step in the cargo handling process over a day-to-day or even hour-to-hour time frame. The second approach is a more global or macro-analysis of major terminal components, taken on an annual basis. Generally, the micro-analysis approach is used to evaluate and improve specific terminal components or processes. The macro-analysis in more often used for evaluation of the overall effectiveness of an entire terminal or port complex. For this paper, the second or macro approach will be used (refer to Figure 1).

Figure 1: Marine Terminal "Black Box"



The most general operations engineering characterization of a marine terminal is a "black box" approach with a specific *output* for given *inputs*. Productivity can then be evaluated as the rate of output as a function of a fixed level of input. This function can be quantified as a ratio: OUTPUT/INPUT, for each different measure of input. *Output,* in all cases, will be expressed as annualized throughput, or units of cargo imported and exported through the terminal per year. *Input* will be measured in units which are specific to characteristics of the types of cargo handled at the terminal.

MARINE TERMINAL CATEGORIES

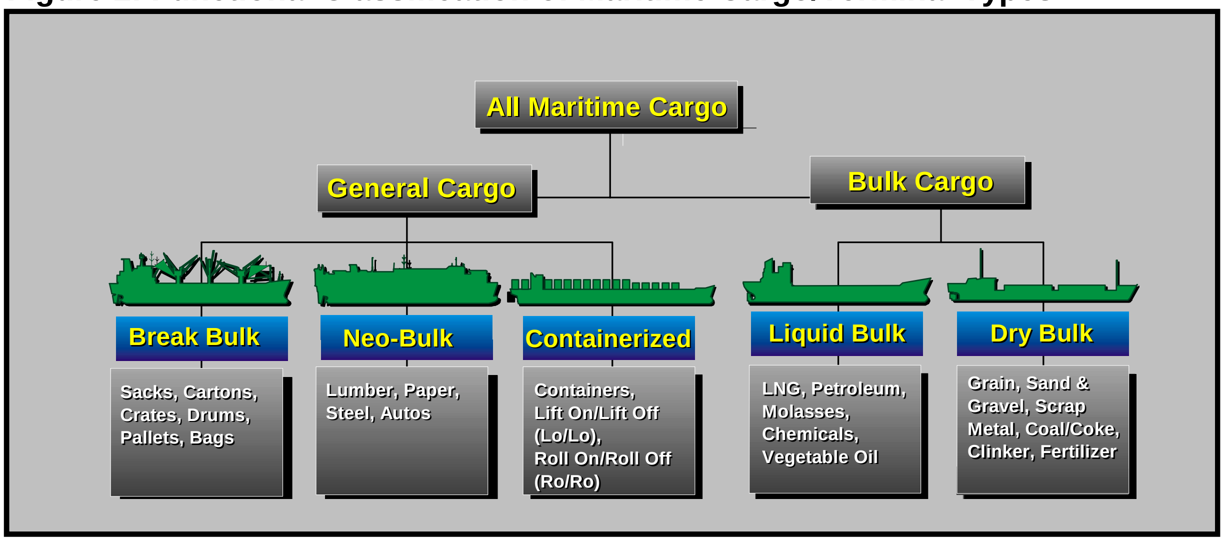
Introduction

Marine terminals can be categorized into five fundamental terminal types (refer to Figure 2). These terminal types are described as follows:

1) Break bulk cargo; includes palletized, bagged and loose-stowed cargo.
2) Neo bulk cargo; generally steel, lumber and autos.
3) Containerized cargo; includes containers and ro-ro truck trailers.
4) Liquid bulk cargo; includes crude petroleum, petroleum products and chemicals.
5) Dry bulk cargo; generally consists of grain or coal, includes other dry cargo.

Each terminal type has multiple variations of operations depending on the location of the port and on the type of cargo under consideration. In this section, each of the five terminal types will be discussed by internal component and operating method.

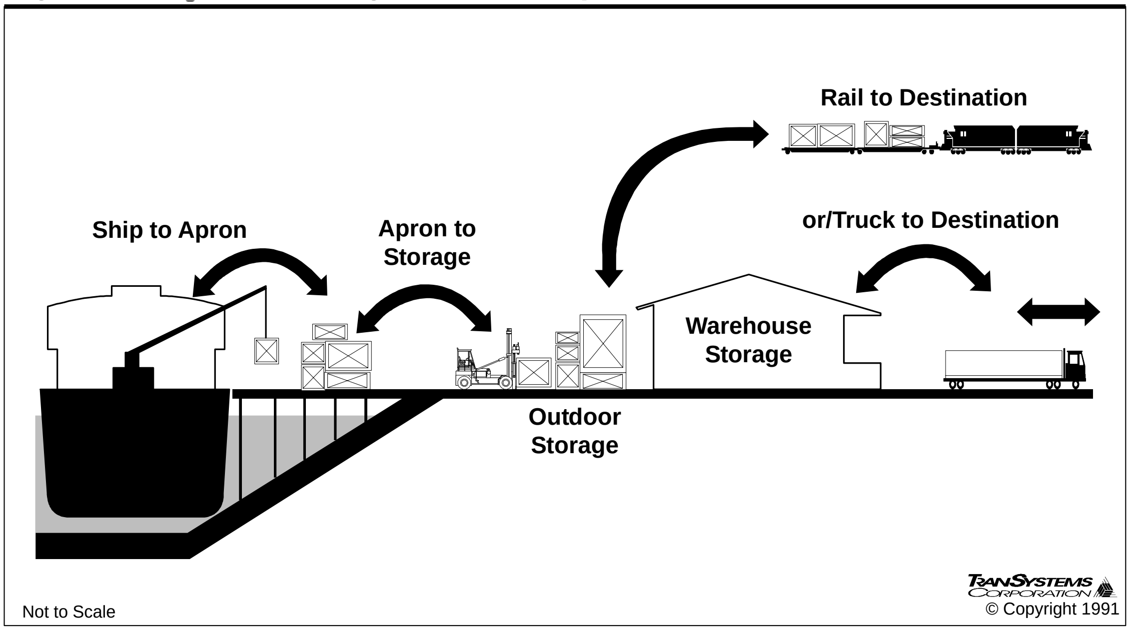
Figure 2: Functional Classification of Maritime Cargo/Terminal Types



Break Bulk (Conventional) Cargo Terminal

A conventional cargo terminal varies from the container terminal in that the cargo is usually handled by ships gear and stored within a warehouse. Documentation is generally performed at the warehouse and any gate in use is typically for security only. The following diagram illustrates a typical breakbulk terminal (refer to Figure 3):

Figure 3: Breakbulk Cargo Terminal Operations



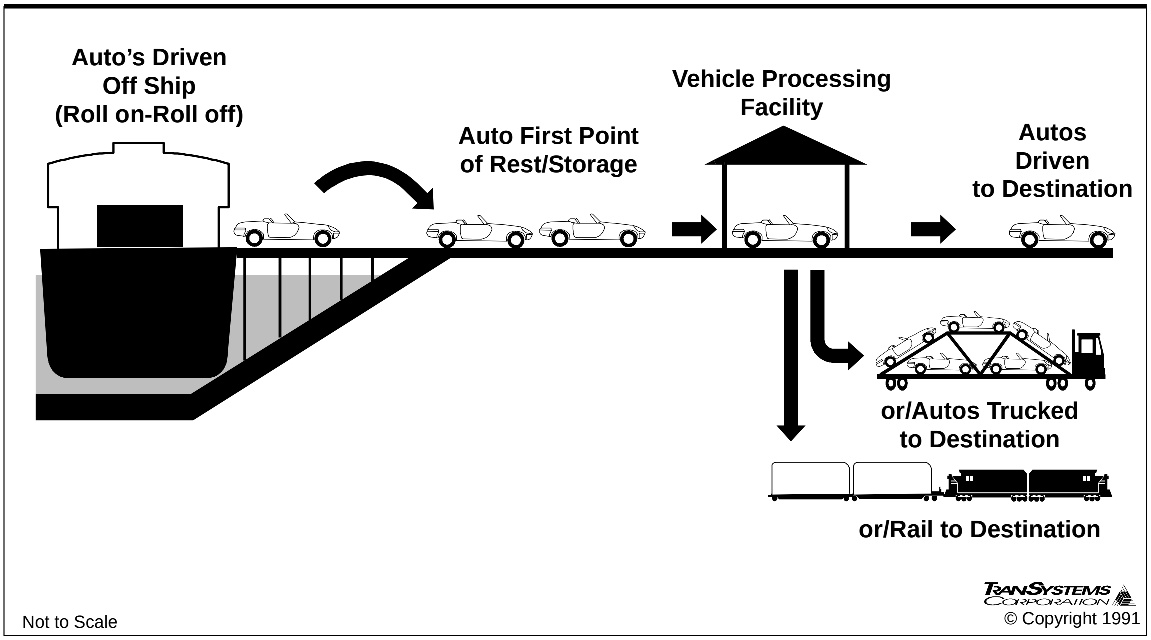
This type of terminal has four principal components which can be evaluated for productivity. These four include:

1. Vessel and Berth Activities: These activities comprise the berth availability and berth limitations on vessel capacity.
2. Ship to Apron Transfer: Cargo discharge and loading is generally carried out by ship-board cranes.
3. Apron to Storage Transfer: Cargo is transferred from the wharf apron to transit storage, either in a shed or in an open lot.
4. Storage: Storage activities include sorting and staging as well as dwell while waiting for pickup or vessel arrival. Truck or rail loading/unloading takes place at the storage site.

Neo-Bulk Terminals

Neo-bulk includes any conventional cargo which is carried as full shiploads of the same cargo and which is not containerized. It is most often encountered as automobiles on a pure car carrier (PCC) vessel (also sometimes classified as roll-on, roll-off or ro-ro cargo), as lumber or logs, as steel, and as newsprint or paper products. The distinguishing element of neo-bulk is that it consists of a single cargo commodity. Therefore, most neo-bulk terminals are dedicated solely to that commodity. The following diagram is of an auto import terminal, the most specialized of the neo-bulk cargoes (refer to Figure 4):

Figure 4: Neo-Bulk Terminal Operations (Auto)



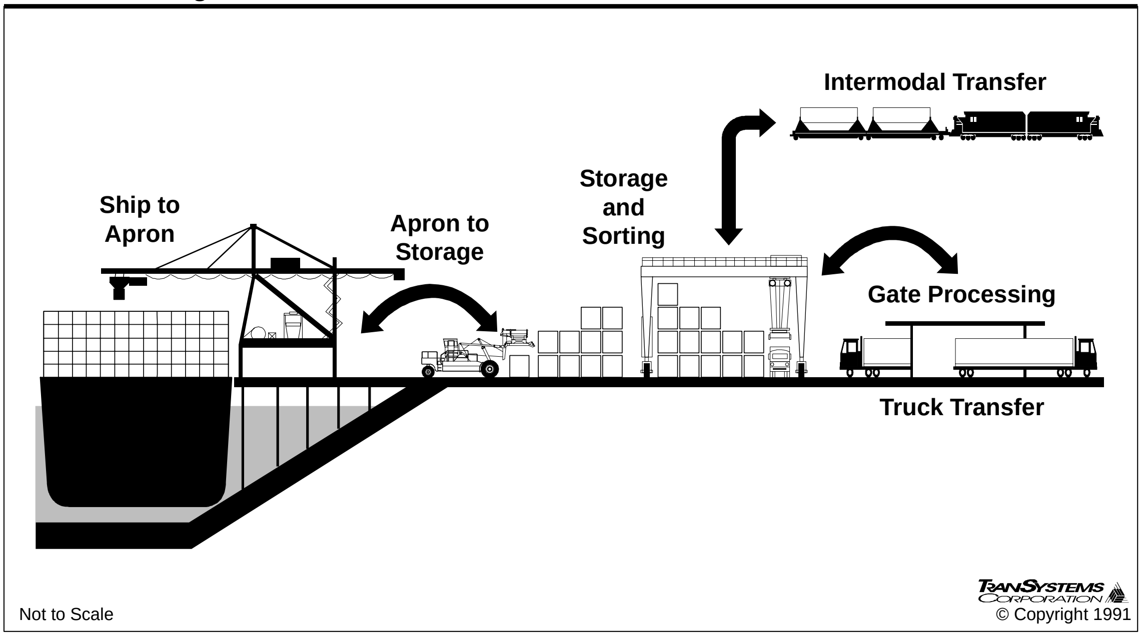
A typical neo-bulk/ro-ro auto terminal has five principal components which can be evaluated for productivity. These components are described as follows:

1. Vessel and Berth Activities: These activities comprise the berth availability and berth limitations on vessel capacity. Auto berths are often shared with other cargo types. Dedicated steel terminals more often have their own associated berthing.
2. Ship Loading or Discharge: Ro-ro auto are driven on or off the ship. For other neo-bulk cargoes loading or discharge can be carried out by ships gear or shore cranes.
3. Apron to Storage Transfer: Autos are driven from the wharf to storage or "first point of rest." Other neo-bulk cargoes are generally transported by fork-lift or flat bed truck.
4. Storage: Neo bulk cargo can be stored in a variety of enclosures (required for steel coil, newsprint or finished lumber) or open yard configurations (most often for auto, rough lumber or steel slab). The storage component of auto terminals may also include value-added activities carried out at the vehicle processing center.
5. Inland Transfer: Neo-bulk is transported by rail or truck. Autos are sometimes driven to local destinations or distributing centers.

Container Terminal

The figure below depicts the general operations flow diagram of a U.S. container terminal for imported and exported cargo (refer to Figure 5).

Figure 5: Container Cargo Terminal Operations



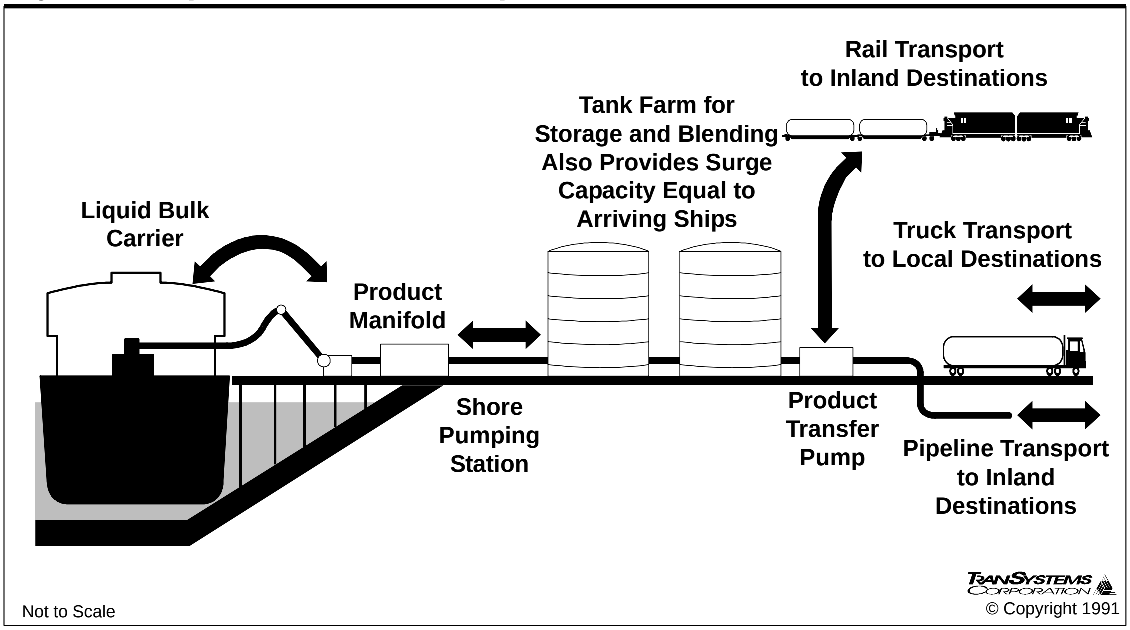
A container terminal generally has six components that can be evaluated for this type of maritime operation. These six components are described briefly as follows:

1. Vessel and Berth Activities: These activities comprise the berth availability and berth limitations on vessel capacity.
2. Ship-to-Apron Transfer: This activity is a function of the number and speed of container gantry cranes on the terminal wharf.
3. Apron-to-Storage Transfer: This includes the movement of unloaded cargo to the nearby storage site or the movement of "loaded" cargo from the storage site.
4. Storage: These are activities within the storage site including cargo sorting and staging, capacity for cargo storage and dwell time of containers on the terminal.
5. Intermodal Transfer: Where on-dock or near dock intermodal rail is available, this component is the transfer of cargo from the storage site to and from the intermodal ramp.
6. Gate Processing: On a container terminal, cargo documentation is processed at the terminal gate. Gate functions can also include security measures and truck dispatching.

Liquid Bulk Terminal

Like dry bulk terminals, liquid bulk terminals are often specialized for a particular cargo type. The majority of liquid bulk cargo in the United States is petroleum product which is imported and distributed from the port. Inland distribution modes can include rail, truck or pipeline. The following diagram illustrates the general operation of a liquid bulk terminal (refer to Figure 6):

Figure 6: Liquid Bulk Terminal Operations



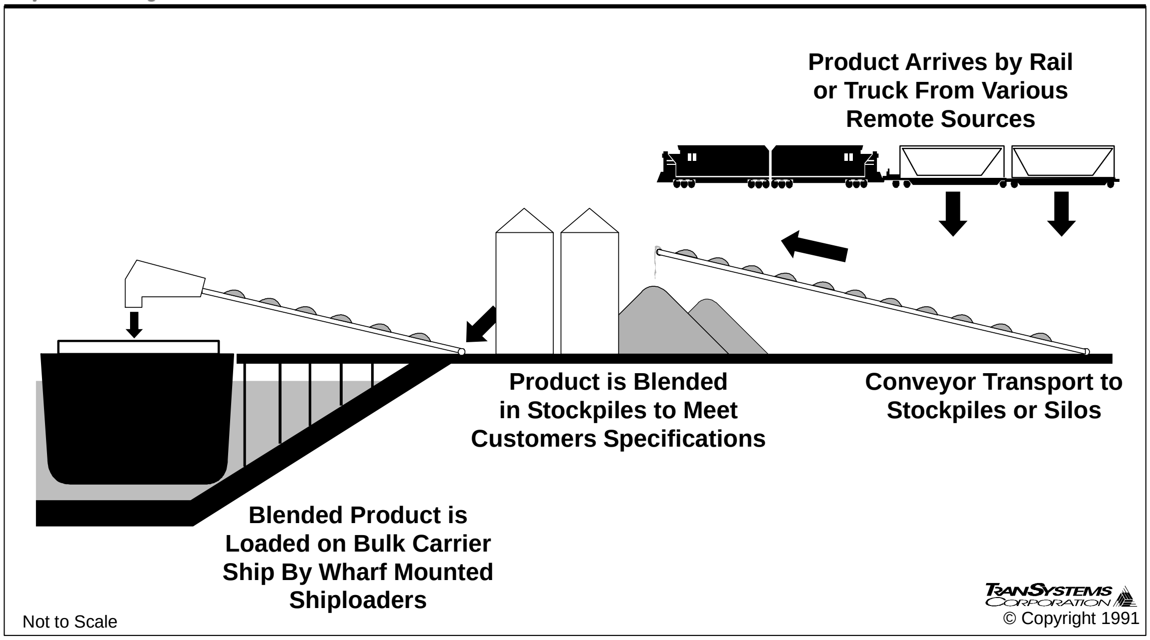
A typical liquid bulk cargo terminal has four principal components which can be evaluated for productivity. These components are described as follows:

1. Vessel and Berth Activities: These activities comprise the berth availability and berth limitations on vessel capacity. These limitations are particularly important where vessel draft is concerned.
2. Ship Loading or Discharge: Liquid bulk cargo is loaded by hoses and pumps located on the pier, discharge is accomplished through the use of ships pumps.
3. Storage: Liquid bulk cargo is stored at a tank farm on or near the terminal. The storage component of liquid bulk may also include value-added activities such a blending or processing.
4. Inland Transfer: Liquid bulk cargo is distributed by rail, truck or pipeline. The capacities of these modes determine the total storage required.

Dry Bulk Terminals

Major dry bulk terminals differ from container and break bulk operations in that the cargo most often arrives or departs by rail. Documentation of cargo transfer takes place as a function of scale activity at either the cargo conveyor or at the rail loading/unloading facility. In addition, dry bulk terminals are almost always constructed for a single cargo type and are usually unsuitable for other cargoes. With few exceptions, dry bulk terminals are also specialized for either export or import. The following diagram illustrates a typical dry bulk terminal configured for export (refer to Figure 7):

Figure 7: Dry Bulk Terminal Operations



A typical dry bulk cargo terminal has five principal components which can be evaluated for productivity. These components are described as follows:

1. Vessel and Berth Activities: These activities comprise the berth availability and berth limitations on vessel capacity. These limitations are particularly important where vessel draft is concerned.
2. Ship Loading or Discharge: Cargo loading or discharge is usually accomplished with specialized equipment on the wharf. This equipment could be clamshell grabs, bucket wheel unloaders, conveyors or loading spouts.
3. Apron to Storage Transfer: Cargo is transferred between the wharf and the terminal storage facility by conveyor belt, pneumatic tube or other high volume conveyance.
4. Storage: Dry bulk cargo can be stored in a variety of enclosures or open yard configurations. The storage component may also include value-added activities such a blending or processing.
5. Inland Transfer: Usually, dry bulk cargo is distributed inland by rail mode. If it is used or originates local to the port, then it can be transferred by truck.

MEASURES OF OUTPUT

To create an effective measure of terminal productivity, the evaluated unit of output should be normalized to a standard unit of measure. In general, this unit is *metric tons* of cargo per year or *annual tons of throughput*, often simply referred to as "throughput." However, there are several cargo specific units of measure to be considered for evaluating marine terminal productivity. Each cargo specific unit of measure can be converted to a tonnage.

Units of Measure:

Ton – Cargo is most often measured in long tons of 2,240 lbs. or metric tons of 2,205 lbs. Cargo on the U.S. inland transportation system is generally measured in short tons of 2,000 lbs. For evaluation of relative marine terminal performance, cargo units are normalized to a specific type of ton, generally, the metric ton.

TEU – refers to Twenty Foot Equivalent Units or equivalent capacity of one twenty foot container. A forty foot container is two TEU. The maximum weight of a standard 40 foot container is 32 metric tons. The average weight of *cargo* per TEU is about ten to twelve metric tons for loaded containers. If both loads and empty containers are considered, the average cargo weight is generally taken as 7.5 metric tons per TEU.

Barrels – petroleum liquid bulk cargo is usually measured in barrels of 42 U.S. gallons each. Usually there are 6.8 to 8.7 barrels per metric ton depending on cargo density. Non-petroleum cargoes are most often expressed in tons.

Units – the term *units* is used to refer to ro-ro cargo, containers (regardless of size) and unitized neo-bulk cargo such as bundles of lumber or steel. Automobiles are usually considered at 1.5 to 2.0 tons per unit. Unitized cargo such as lumber is generally about 12.5 to 15 tons per unit as limited by the capacity of the ships gear. Steel is often lifted in heavier units with specialized ships gear or shore cranes.

Dollars – cargo can also be measured in terms of its economic impact in dollars. Containerized cargo can range in value from a few hundred dollars per ton for raw materials such as hides or rough lumber to tens of thousands of dollars per ton for machine parts and consumer goods. When cargo starts to exceed a threshold of multiple tens of thousands of dollars per ton (as in the case of pharmaceuticals or high end electronics), it is more often shipped by air freight. For general purposes, containerized cargo averages $2,500 per ton, consistent with garment sub-assemblies and auto parts. Bulk cargoes can be evaluated on a world commodity market basis, Freight on Board (FOB) the destination port.

Measures of throughput are evaluated by cargo type in the specific units as recorded by the shipper, carrier or terminal operator. Depending on the cargo type and characteristics, they are then normalized to tons or dollars, whichever performance measure is being evaluated. The following table is a summary of the units in common use for evaluating cargo throughput (refer to Table 1):

Table 1: Units of Measure by Cargo Type

Cargo Type	TEU/FEU	Ton	Barrel	Unit	Dollar
Container	■	■		■	■
Break bulk		■			■
Dry bulk		■			■
Liquid bulk		■	■		■
Neo bulk		■		■	■

For the purpose of evaluating terminal performance, the annual terminal productivity will give the most representative set of monthly and seasonal throughput variations. Therefore, the *annual* throughput, in tons, TEUs or dollars per year, is used as the base measure of OUTPUT for evaluation of terminal productivity. This output or annual throughput will then be the measure for evaluating a variety of input variables.

INPUT VARIABLES

The input variables are also specific to the cargo type under consideration and to the particular performance measure which is being evaluated. Common input variables for evaluation of port performance include the following:

Terminal Area – this variable can be the gross area of a terminal where cargo is handled and stored in a yard or other outdoor areas. Terminal area is most often used with container terminals. Common values of annual throughput per terminal area range from about 1,500 TEU to 6,500 TEU per terminal acre in the US.

Storage Area – this variable more often refers to covered storage such as transit shed footprint or warehouse enclosures. A productive transit shed will pass approximately 2.5 tons to 3.3 tons per square foot per year.

Storage ton – tons are used to describe bulk storage areas as found in silos, domes or tanks. Tons of storage can also be used to describe break bulk cargo in covered storage structures. Because storage structures such as silos are often used for cargo processing or distribution, the productivity of these terminal features is directly proportional to the demand for cargo and is often much lower than that of strictly transit structures.

Berth – cargo such as break bulk and liquid bulk are often expressed as annual throughput per vessel berth or linear foot (meter) of berth length. Berth productivity is a function of the type of vessel calling and the type of cargo handling equipment available.

Man-hour – some measures of performance evaluate a terminal as annual tons or TEUs per man-hour unit of labor. This unit of labor can also be expressed as Full Time Equivalent (FTE) or the annual labor of one person, approximately 2000 man-hours. Maritime container terminals generally achieve an annual throughput of 800 to 1,500 TEU per FTE or 8,000 to 15,000 tons per FTE. As a comparison, break bulk cargo has an annual throughput of about 1,800 tons per FTE of terminal labor.

SUMMARY MEASURES OF TERMINAL PRODUCTIVITY (OUTPUT/INPUT)

Introduction

A summary of the general input and output values for different types of productive U.S. terminals is given in the following table. This summary is very generalized and has not been verified for all terminals or all parts of the country (refer to Table 2).

Table 2: General Standards for Productive U.S. Terminals

Cargo Type	Annual Throughput (output) by Input Variable				
	Terminal Area (acre)	Storage Area (sq. ft.)	Storage (Tons)	Berth (600 to 1000 linear feet)	FTE (2000 man-hours)
Container	6,500 TEU	♦	♦	250k TEU	1,500 TEU
Break bulk	42k tons	3.3 tons	26 tons	300k tons	1,800 tons
Dry bulk (grain)	♦	♦	27 tons	3,000k tons	♦
Dry bulk (coal)	120k tons	♦	23 tons	10,000k tons	♦
Liquid bulk (petroleum product)	♦	♦	10 tons	10,000k tons	♦
Neo bulk (steel)	125k tons	3 tons	♦	500k tons	♦
Neo bulk (autos)	4,000 units	♦	♦	120k units	♦

Source: San Pedro Bay Ports of Los Angeles and Long Beach 2020 Plan

♦ Note: these are measures which are not generally used to evaluate this type of cargo or which vary too widely to be effective general indicators of productivity.

U.S. marine container terminals are often compared to their European and Asian counterparts in an attempt to evaluate their relative productivity and potential for improvement. Although U.S. marine container terminals are employing current technology and engineering design, it has been acknowledged that U.S. terminals are operated under more restrictive parameters than most foreign container terminals and therefore, in general, have lower average throughputs per terminal area. The better U.S. container terminals generally yield between 2,500 and 6,500 TEUs per gross terminal acre. The mean for all U.S. container terminals is between 2,000 and 3,000 TEUs per gross terminal acre, depending on terminal locale, labor union jurisdiction and regional competitive climate.

A similar comparison can be made for non-U.S. marine container terminals. This evaluation produces terminal throughput productivity figures for the better foreign terminals, of between 6,000 and 9,000 TEUs per gross terminal acre, with a few Asian terminals reaching as high as 10,000 to 14,000 TEUs per gross terminal acre. It should be noted, however, that direct comparison between European, Asian and other foreign terminals with U.S. ports is difficult and must consider the inherent differences between the various national terminal systems. Each U.S. container terminal is in a unique setting which includes unique geometry and, many times, very different labor arrangements and competitive environs. Thus, in the final evaluation of terminal productivity, each marine terminal must optimize its own circumstances and operations with respect to its particular niche in the maritime marketplace.

Summary of Black Box Terminal Productivity Analysis

The black box approach to port productivity analysis is carried out using a five step methodology which results in a numerical ratio which can be expressed as OUTPUT/INPUT. In general, the *output* value will be a measure of annual throughput such as tons per year. The *input* value is selected by the analyst to include a terminal attribute which is measurable and which has an impact on the throughput of the terminal. The five steps used in this process are summarized as follows:

1. Disaggregate the port into discreet terminals.
2. Select an output value, normally tons per year of cargo imported and exported.
3. Select an input variable such as terminal area or berth length.
4. Compute the ratio OUTPUT/INPUT for each terminal.
5. Monitor the productivity level of the terminal or evaluate the computed ratios against regional or national productivity standards for comparison.

Use of Actual Throughput or Estimated Capacity as a Measure of Output

The throughput value to be used as a measure of output can be considered as one of two values. Either "*Actual Throughput*" or "*Estimated Throughput Capacity*":

> *Actual Throughput* is the measure of cargo the actually passed through a terminal in a given amount of time (typically one year).
>
> *Estimated Throughput Capacity* is the theoretical calculated cargo handling capability of a terminal over a given amount of time (typically one year).

It is important to understand that this method can only make assumptions as to the relative sensitivity of a given marine terminal's annual actual throughput or estimated capacity to the chosen input variable. In many cases market conditions or competition from other ports may result in lower measured productivity than that which would be observed if the terminal were operating at its maximum capacity.

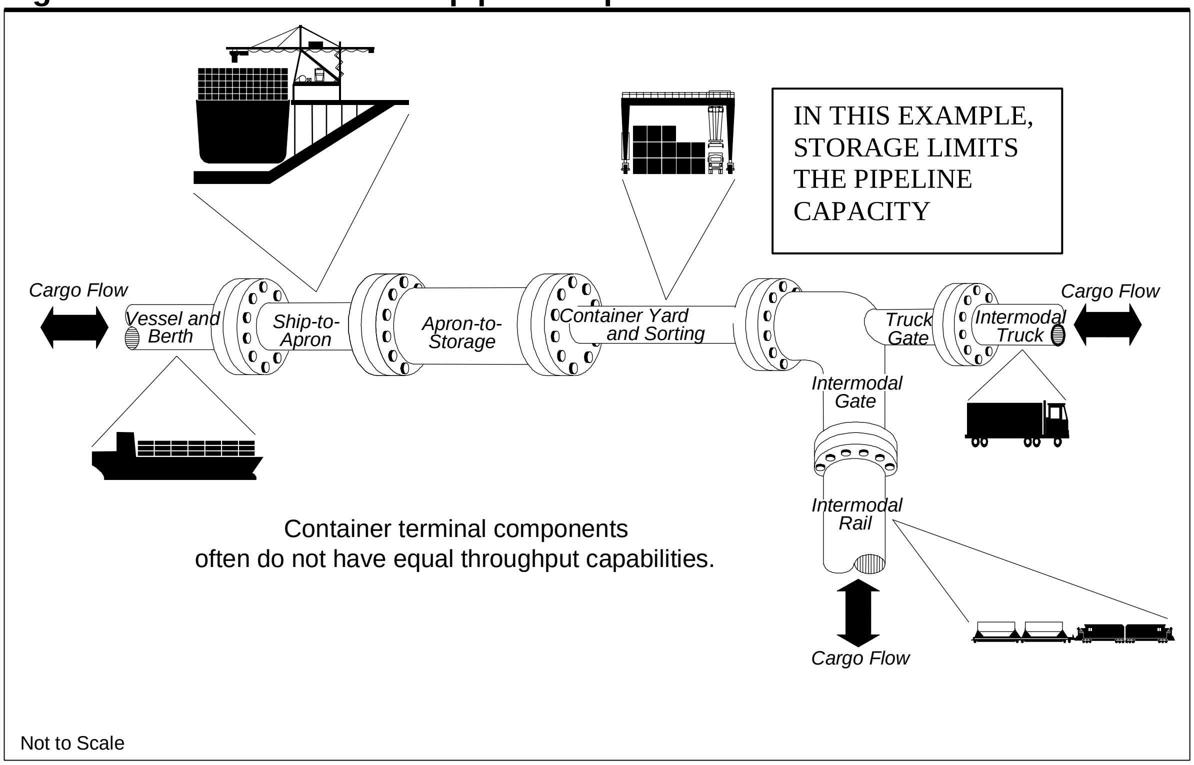
MEASURES OF TERMINAL THROUGHPUT CAPACITY (POTENTIAL OUTPUT)

Introduction

Terminal throughput is generally a measure of cargo export plus import movement over a fixed period of time (usually taken at one-year intervals). At some ports, certain cargoes such as coal or petroleum coke are only exported; and throughput is simply a measure of tons loaded per year. Containerized cargo, however, has more complex throughput characteristics. Therefore, in this paper, the methodology for evaluating measures of terminal throughput capacity will focus on containerized cargo. Other cargo types can be evaluated in a similar manner using a simplified analysis

In many ways, a marine terminal functions like a pipeline of various diameter pipes. Each segment of the pipeline represents each of the four to six terminal components discussed in the previous section. Among these components, there is usually only *one* which limits the capacity of the entire system. This analogy is illustrated in the following graphic (refer to Figure 8).

Figure 8: Container Terminal pipeline Operations

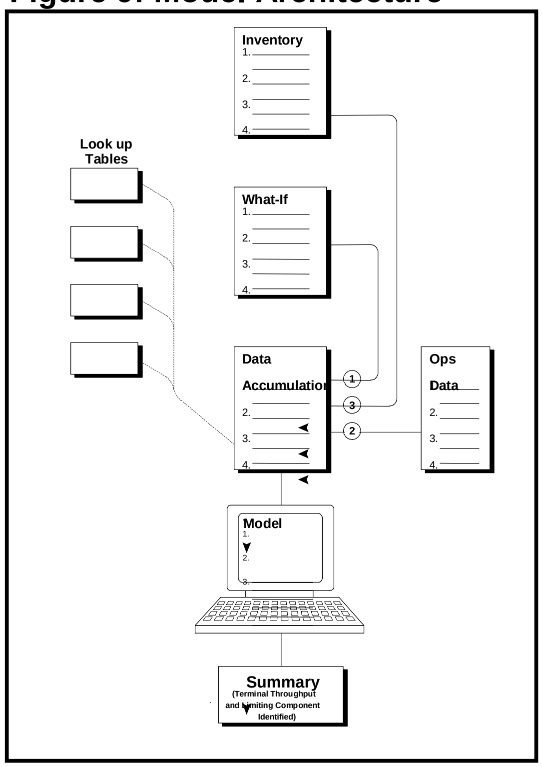


Therefore, it is often necessary to identify the limiting component of the terminal prior to selecting the *input variable* for evaluation of terminal productivity. That is, if storage capacity is the limiting component, as illustrated in the example above, then evaluation of berth capacity will not show a direct relationship to *output* or annual throughput capacity. The "black box" system would be considered *insensitive* to variations in berth capacity or berth availability. Therefore, it is sometimes necessary to disaggregate the "black box" into terminal components and evaluate the capacity of each component within the terminal. This process can be accomplished with a spreadsheet model which evaluates the terminal throughput capacity on a discreet component basis and provides an estimate of the Maximum Practical Capacity (MPC) of the terminal.

Marine Terminal Throughput Model Architecture

The computerized models used in evaluating marine terminal throughput capacity are spreadsheet-based programs designed to run on the standard microcomputer platform. The distinguishing features of the models are the look-up tables of actual terminal survey data and the "what-if" file, which allows the user to explore possible terminal modifications for their potential capacity improvements. A block diagram of a typical throughput model is illustrated in the following figure (refer to Figure 9):

Figure 9: Model Architecture



Terminal Components

The six measurable components of a marine terminal affecting cargo throughput capacity are represented in the static model, in the same order they were explained in the previous section for each type of marine terminal:

- *Vessel and Berth Activities*: This component estimates the cargo capacity of ships calling at the facility and the percentage of cargo transferred at each call. It also determines the berth occupancy ratio and the number of vessel calls which are possible in a year.

- *Ship-to-Apron Transfer*: The number and productivity of available cranes (or unloaders) are determined by this function and used to estimate the loading/unloading rate for each ship.

- *Apron-to-Storage Transfer:* Where this applies (primarily in container yards), this component evaluates equipment productivity within the terminal.

- *Storage Yard Capacity*: This component determines the storage yard's peak static capacity and estimates the yard's effect on throughput based on the cargo turnover rate and yard utilization factor.

- *Intermodal Transfer*: For those container terminals with intermodal capabilities, this component determines the intermodal rail throughput based on loaders, tracks, storage characteristics, throughput peaking characteristics and ICTF gate.

- *Gate Processing*: This component determines the container terminal peak gate processing capacity and analyzes its effect on average yard throughput.

Model Components

The terminal throughput models used to measure cargo capacity are made up of the following five sections:

1. Inventory File: Typical terminal features are transferred to this section from a separate computerized base.

2. What-If File: Data in this section will supersede date from the inventory file. If left blank, the model looks in the inventory file. If the inventory is blank, the model looks in the operations data file.

3. Operations Data File: This section contains default data based on typical terminal operations.

4. Data Accumulation File: This section accumulates data for use in the model. The data is retrieved from other files in the following priority:
- What If
- Inventory
- Operations Data

5. Computer Model: This section calculates the maximum practical throughput capacity (MPC) of the terminal for each of the six components. The results are summarized and the limiting component identified.

Modeling Results

This modeling process results in three primary products which can be used for terminal analysis. The foremost product is an estimate of overall terminal MPC under the conditions modeled. However, this capacity analysis is not a measure of productivity as it does not include input variables such as berth length or storage area. In addition, the MPC is not necessarily a reflection of the current terminal throughput.

The second product is an evaluation of the capacity of each terminal component, and the third product is the selection of the limiting component. These two products are useful in identifying the specific terminal *input* values, that is the values which most affect the terminal limiting component. These are the input measures which should be used in evaluating the OUTPUT/INPUT function of terminal productivity.

Therefore, using a terminal capacity modeling approach, the analyst can select the most meaningful input variables for assessing terminal productivity. In addition, this methodology allows the analyst to evaluate two productivity functions:

1) Current terminal productivity (under existing market conditions).
2) Maximum Practical terminal productivity (as determined by the throughput capacity model).

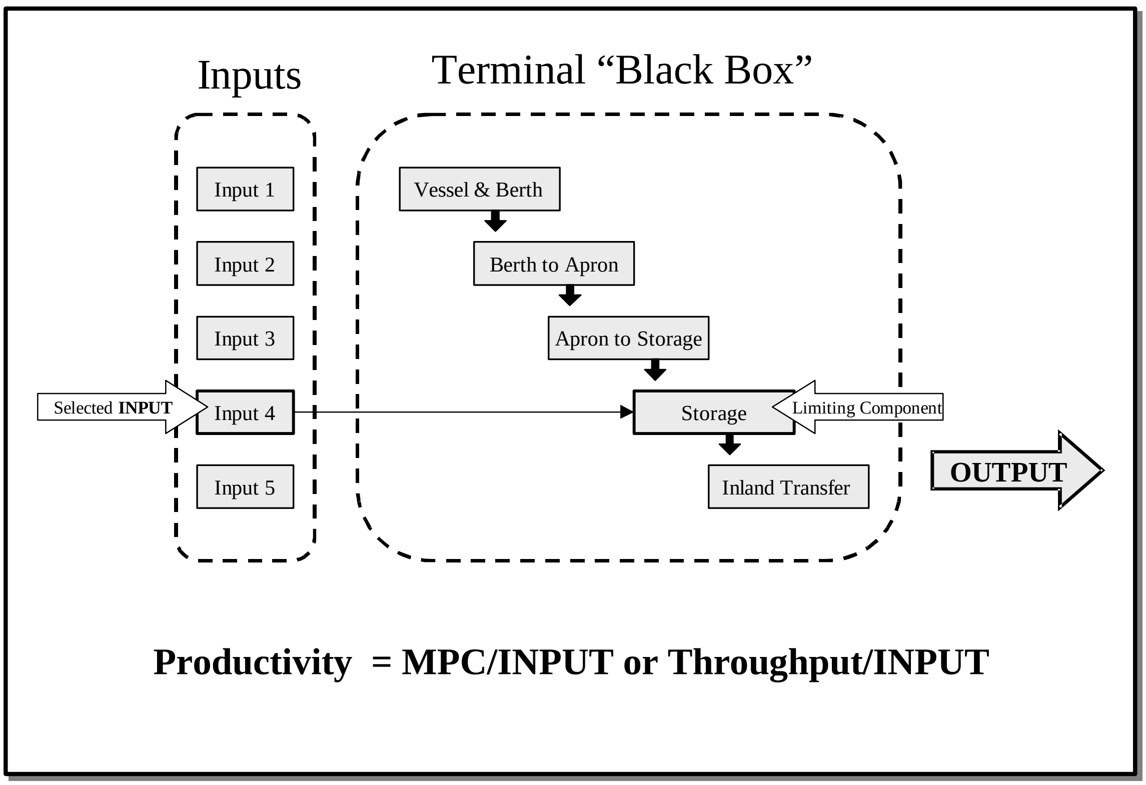
These two measures can then be compared to yield an evaluation of the impact of outside forces, such as market, labor conditions, or shipping patterns.

CONCLUSIONS

Port productivity in the United States is best evaluated in a process of successive disaggregation where the port itself is broken down into discreet marine terminals as classified by cargo type; and each terminal is evaluated by its individual components to determine the most sensitive component for evaluation. This process can result in a variety of measures of productivity and the analyst must select the proper units and methodology for evaluation as well as understand in advance the purpose of the study.

The methodology of evaluating the productivity of a disaggregated marine terminal for is illustrated by the following graphic (refer to Figure 10):

Figure 10: Marine Terminal Productivity Analysis Methodology



Note that the above methodology is applicable to calculating the productivity of the existing operations and throughput while also being applicable to calculating the potential productivity of a terminal's estimated throughput capacity.