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Krośnicka Karolina

Smolarek Leszek
Gdynia Maritime University, Poland

Determinants of cargo flow modeling in container terminals in conditions of "extended pre–gate”

Keywords

container terminals, extended pre-gate, cargo flow modelling

Abstract

The paper considers determinants of construction of the mathematical model describing in a macro scale a stream of cargo, flowing through a container terminal equipped with an extended pre-gate. Accordingly, the work analyzes the handling points and channels of container’s flows at a hypothetical terminal, as well as opportunities allowing to increase the flow’s efficiency by changing the random stream of arriving trucks and trains into the determined one.

1. Introduction

Reliable and timely delivery of containers to the port terminal is a key factor for its proper functioning. An optimal solution from the point of view of a work of the container terminal, although only a hypothetical one, is serving the total cargo turnover in a direct relation. In such an arrangement, containers should be provided by trucks directly to a waterfront in an order of ships’ ETA (expected time of arrival) and their load plans. In reality, however, it is necessary to buffer containers on storage yards before they are delivered to a ship. This is due to the large volume of cargo, which has to be stored simultaneously on the terminal, and due to the high level of randomness of containers appearing at a terminal gate. The solution allowing to convert a random stream of trucks onto a stream with a fixed order of service, is to build an external parking (so called pre-gate), directly adjacent to a terminal, and integrated with the terminal operational system (so called TOS). For several reasons, this solution is however currently insufficient:

- being a natural land reserve for the potential spatial expansion of the existing terminal, the area adjacent to the terminal had become too valuable;
- the growing volume of containers causes multiplication of a number of trucks coming to a terminal, and hence the number of parking lots on a "pre-gate " becomes insufficient, despite the still increasing share of rail transport in container terminals;
- growing size of container vessels causes large fluctuations in delivery of containers to a terminal (momentary concentration and de-concentration of cargo), what results with a necessity of increasing a capacity of storage yards in a terminal;
- terminal clients require more and more flexible time frames while serving their containers (for instance: cargo arrives at the last minute or even after a deadline, or much earlier than planned)
- due to congestion occurring in many of the world's container terminals more and more vessels notes several days delay with respect to the declared ETA.

Accordingly, most of the world container hubs, struggling with congestion, are considering or implementing an additional spatial element of a terminal - the remote outer gate, called extended pre-gate, sometimes also called “dry ports” [3], [4], [11], [12], [13], [14]. This solution, similarly like a pre-gate, allows for clearance of trucks with containers at the external gate, situated usually a dozen or even dozens of kilometers from a terminal [15], [16]. Extended pre-gate is associated with so-called strategic parking, located usually at the outskirts of the city or metropolitan region, and is directly connected with a highway or an expressway leading to the port. The remote gateway terminal (extended pre-gate), together with the strategic parking, play a role of an external buffer, which increases an efficiency of traffic flow to the container terminal – extended pre-gate allows trucks to appear at the declared time ("just in time") at the main gate of a terminal, and in the right order, determined by calls of ships. The use of extended pre-gate is possible, provided that there is no congestion on public roads leading to a terminal.

2. The problem statement and the aim of the paper

The aim of the work is to considers determinants of building a mathematical model describing in a macro scale a stream of cargo, flowing to a container terminal equipped with the extended pre-gate.

While creating this model, one should be aware that most of the actions undertaken on the terminal is uncertain in terms of a date of their commencement and duration time. These actions are related to such an operations on containers as: internal transport, storage, and most of all, import and export of containers to/from the terminal by external transport (trucks, trains, ships).

The theory of mass service, including queuing systems and networks, is an appropriate tool for modeling randomness arising from the mentioned above uncertainty, allowing for a complete description of processes taking place at container terminal in a macro scale.

The application of methods of mass service theory requires determination of: [2], [5], [9]

- dimensionality of notifications source – in case of the container terminal, we can assume an existence of an infinite source of notifications, as the demand for transport services is endless,
- a function (deterministic or random), describing time intervals between successive notification, where a notification could be understood as: an individual container in case of trucks, or "packages" of containers in case of trains (an average package would be about 50 TEU1s per train) or ship (from a few hundreds TEUs to 18,000 TEUs per ship),
- the number of points, where the flow of containers is served, as well as their location and directions of cargo handling,
- operating discipline, understood as a manner and order of handling containers,
- operating rules, so procedures applicable at a given handling point of the container terminal, both in normal and safe mode,
- order of service (priority class depending on ship's notification)
- deterministic or random function describing the service times at each of the handling points,
- the size of a buffer (storage yard, parking space, etc.).

The container terminal can be regarded as a system with no loss, since each upcoming container (notification) will be served.

3. Cargo handling points - the size, discipline of work, and order of service

Among the cargo handling points serving trucks on the container terminal equipped with extended pre-gate one could distinguished: strategic parking with the remote gate (extended pre-gate), the main gate of the terminal with waiting lanes in front, storage yards, and a waterfront area. For modelling the flow of cargo to the terminal in a macro scale, the latter two handling stations will be of secondary importance. It can be assumed that trucks deliver containers to the terminal in a continuous stream, as trucks appear at the gate every 1 minute on average (not taking under account the annual and diurnal variations of the terminal's work). Usually each truck carries a 40-feet container (FEU)[2] or two 20-feet containers (TEU), as these containers are rarely transported individually.

The rail service in a container terminal is usually independent on the car transportation system, and carried out parallel to it. In the standard configuration of the container terminal a train enters through the railway gate and is operated at the rail loading station (rail siding), with a help of gantry cranes (RMG[3], RTG[4]), or reach-stackers (RS) [1], [6]. The basic task of the railway gate is to register each of the train's entry/exit. Depending on the spatial organization of the container terminal most of the paperwork connected with serving the rail traffic is carried out either directly on the terminal rail siding or at the marshalling yard, situated in front of the container terminal.

The adopted model assumes that the strategic car parking for trucks will be accompanied by rail siding on which wagons with containers imported by rail are shunted according to an appropriate priority class, corresponding to the order of calling ships and their load plans. On the rail siding, working on a basis of a local marshalling yard (rail extended pre-gate),

[1] TEU – twenty feet equivalent unit; a unit corresponding to a container of length of 20 feet.

[2] FEU – forty feet equivalent unit; a unit corresponding to a container of length of 40 feet.

[3] RMG – rail mounted gantry

[4] RTG – rubber tyred gantry

containers are reported to TOS, and wagons with containers are dispatched to the container terminal in a proper order (see *Figure 1*).

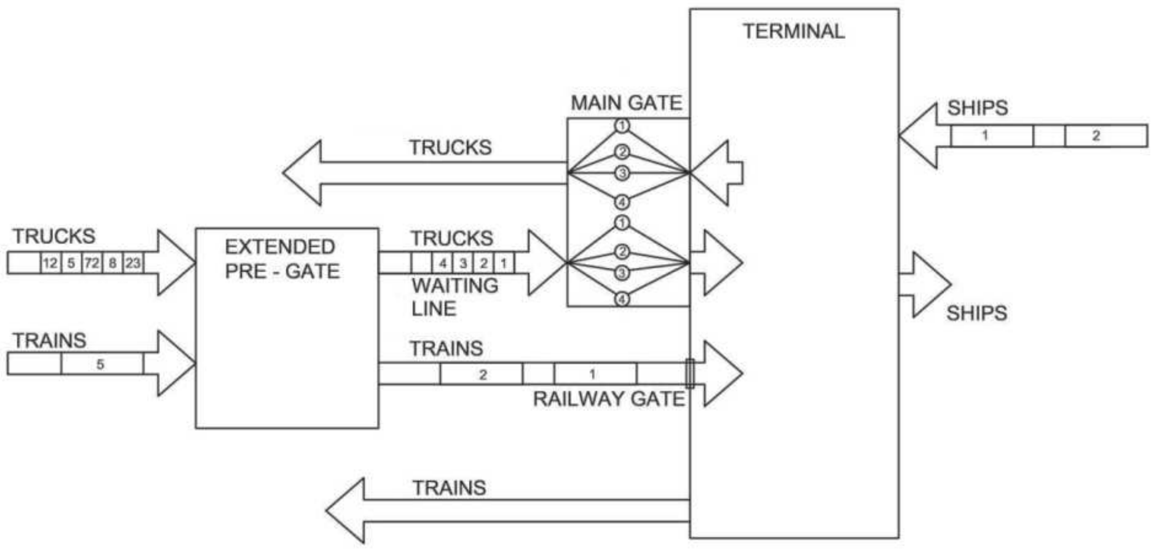

Figure 1. The scheme of the cargo flow at the container terminal, working under conditions of extended pre-gate accompanied by rail siding.

On the extended pre-gate (as on the pre-gate) all the checks related to containers (such as sanitary and epidemiological inspections, customs controls ect.), and connected with trucks and truck's drivers are carried out. Here the drivers receive the entry card to the terminal, which indicates desired time of appearance of a truck at the main gate. The high time accuracy of getting to the main gate of the terminal often means the need for implementing the intelligent traffic control system on public roads between strategic parking and the port terminal. Extended pre-gate must be available for drivers seven days a week, round the clock (with some short technical breaks) and should be equipped with an infrastructure serving trucks and their drivers, including among others: large monitored parking space, car service station, motel, catering facilities, administrative buildings of container terminal and competent authorities and agencies controlling the flow of goods (eg. customs).

A truck with a container arriving to extended pre-gate must be announced to the terminal operational system (TOS) in advance (indicating the container number and an estimated time of arrival of the driver. Currently, the accepted time tolerance for drivers arriving to the main gate of a terminal is typically +/- 2 hours in relation to the announced time. Therefore one could expected that the existence of the extended pre-gate might significantly shorten the "time window" for truck entering the main gate of the terminal. The task of the extended pre-gate is buffering and sorting randomly incoming stream of truck in such a way that they appear on the main gate in the order determined by ship's calls, and loading plans of particular vessels. It can therefore be assumed that after passing the extended pre-gate trucks with containers reach the waiting line in front of the main gate of the terminal in the proper time and in a desired order, sometimes only slightly disturbed by random accidents on the public roads between strategic parking and the main gate.

Containers transported by trucks might be operated at the terminal in three relations referring to the cargo flow in a national scale:

- import (indirect relation: ship – terminal storage yard – truck, or rarer direct relation: ship - truck),
- export (indirect relation: truck - terminal storage yard – ship, or rarer direct relation: truck - ship), and
- passage of a container through the terminal (container that enters a terminal, but is not intended for submission to the terminal). As the last of the relationship is very rare, it can be ignored while construction of the model.

In order to avoid "empty runs" while transporting containers to and from the terminal, each truck usually arrives to the terminal with a container and goes back with an imported container. Although it is some simplification of the process, this situation was taken into account while constructing the mathematical model.

The main gate of a terminal must provide a sufficiently high capacity. Therefore the gate consist usually on 4 entrance lanes and 4 exit lanes for truck. Each lane is a waiting line able to accommodate from 5 to 7 trucks (this value depends very much on the spatial arrangement of the terminal). In addition, depending on a temporarily traffic at the gate, some of the lanes could be the currently closed (in case of small traffic) or the number of exit and entrance lanes could be dynamically steered, dependent on the flow of traffic, by using the intelligent traffic lights' system. Implementing the extended pre-gate system demands separation of several (2-3) lanes at the main gate for fast service of already verified trucks (so called fast lanes). A crucial issue is to properly determine the necessary capacity of waiting lines before the main gate to provide a sufficient efficiency of service in the container terminal.

4. Operating rules of the extended pre–gate

Functions of the extended pre -gate are the same as those implemented in the pre-gate parking. Therefore, we can assume that working rules in both zones are analogous [17]. Below the operating rules of the extended pre-gate are described regarding to import relation.

Imported containers are usually available immediately upon completion of the ship's operation and vessel's departure, provided that they obtain customs release and all other appropriate permits. They must be also obtained by the operator by providing the PIN code to the customer or freight forwarder.

In import relation the driver is obliged to report to the office at the extended pre-gate and present the number of the container, which will be taken, as well as its PIN, driver's ID, and picking orders for verification. The extended pre-gate agent informs the driver of the traffic rules to and on the terminal and the ETA of the truck at the main gate. The truck leaves the extended pre-gate area and approaches the fast line in the front of the main gate complex. There is an entry inspection being performed, such as visual check and check of container seals. The received data verified by the gate's officer is entered to the terminal operational system (TOS) and the entry ticket is printed off, together with the location from which a container should be pick up. The driver parks at the indicated storage area and the container is loaded on a trailer by terminal devices (RTG, RS, SC[5]). Information about loading the container on the trailer is entered to the TOS. Before leaving the terminal, the driver is obliged to check the container for the accuracy of its labeling, and any failure should be reported at the gate, while leaving the terminal. Driver is also responsible for making sure that the container is safely loaded on the trailer vehicle. At the gate, after verification of the data, such as vehicle registration number, container number and the seal numbers on the container and entering them into the computer system, the driver leaves the terminal. Compatibility of these data with data stored in the system results in a confirmation of the transaction done properly.

The export relation of containers is similar to the import one

5. The container terminal as the queuing network model

Among the types of queuing networks which can be used to model the structure and organization of the container terminal the most interesting types of networks are: Jackson, Kelly or BCMP. Due to the transport process resulting from the method of implementation of the container handling we need to consider separately the transport in direction land-sea and sea-land. Each of these variants of the transport process requires modeling the use of other types of queuing networks.

The queuing networks, used for modeling the process of handling a container terminal are open queuing networks, with an unlimited number of applications.

Jackson's open queuing network consists of nodes (queues) with the following assumptions, [7]:

- each node is a FIFO queue,
- unlimited number of waiting places (infinite queue)
- service time in the queue obeys the exponential distribution
- in each queue, the service time of the customer is drawn independent of the service times in other queues
- upon departure from a one queue the customer chooses the next queue randomly
- the network is open to arrivals from outside of the network (source)
- from each source customers arrive as a Poisson stream.

Jackson network with only one customer class and unlimited overall number of jobs is the good model for the transport in direction sea-land because there are not any containers with priority.

The Kelly's network is open network with the following assumptions, [9]:

- different classes of customers,
- each type has a Poisson arrival process and a fixed route in the network,
- customers served at each system have exponential service time distribution. each system may serve several different customer classes,
- all systems have infinite capacity.

Service containers belonging to multiple classes in such a network will apply to the model of a container

[5] SC – straddle carrier

terminal, the relationship sea shore supports multiple classes of entries, and in this case, the terminal supports two classes' entries, car-to-ship and train to ship. For each of these classes' entries on the network path specified is fixed depending on the class of such notification. Use of this network type is possible for the container terminal, where there is no priority of service entries and customer cannot change the membership of a given class.

The BCMP queuing network is a multi-class network which, [7]:

- include different class of jobs, different queuing discipline and generally distributed service times,
- routes through the network may depend on the job type and the customer can change its class while passing through the network.

In this network there are four types of systems:

- Type 1: system with multiple servers, the service times are exponentially distributed and for different customer classes must be identical, the service discipline is FIFO;
- Type 2: system with one server, different customer classes have different general service time distribution with a rational
- Type 3: system with an ample number of servers (infinite server) and the mean service time for job classes can be different, the service times of the customers of different classes must have a rational Laplace transform;
- Type 4: system with one server, different customer classes has different general service time distribution with a rational Laplace transform, the service discipline is LIFO-PR (last in first out with preemptive).

Table 1. Examples of numerical characteristics for different types of queuing networks, [2], [5], [7], [8]

Network	ρ – indicator of network load	*N* – average number of customers	*T* – average service time	p_0 – non customers
Jackson	$\rho_i = \frac{\lambda_i}{k_i \mu_i}$	$\overline{K_i} = k_i \rho_i + \frac{\rho_i (k_i \rho_i)^{k_i}}{k_i! \, (1-\rho_i)^2} \cdot \frac{1}{\sum_{n_i=0}^{k_i-1} \frac{(k_i \rho_i)^{n_i}}{n_i!} + \frac{(k_i \rho_i)^{k_i}}{k_i! \, (1-\rho_i)}}$	$\overline{T_i} = \frac{\overline{K_i}}{\lambda_i}$	$p_0 = \frac{1}{\sum_{n=0}^{k-1} \frac{\rho^n}{n!} + \frac{\rho^k}{(k-\rho) \times (k-1)!}}$
BCMP FCFS	$\rho_i = \lambda_r \frac{e_{ir}}{k_i \mu_i}, (k_i \geq 1)$	$N_{ir} = \frac{\lambda_{ir}}{\mu_{ir}}$	$T_{ir} = \frac{N_{ir}}{\lambda_{ir}}$	$p_0 = pn_i \, dla \, k_i > 1$
BCMP LCFS - PR	$\rho_i = \lambda_r \frac{e_{ir}}{\mu_i}$	$N_{ir} = \frac{\lambda_{ir}}{\mu_{ir}}$	$T_{ir} = \frac{N_{ir}}{\lambda_{ir}}$	$p_0 = (1-\rho_i)\rho_i^{n_i}$
BCMP IS	$\rho_i = \lambda_r \frac{e_{ir}}{\mu_i}$	$N_{ir} = \frac{\lambda_{ir}}{\mu_{ir}}$	$T_{ir} = \frac{N_{ir}}{\lambda_{ir}}$	$p_0 = (1-\rho_i)\rho_i^{n_i}$

6. Conclusion

"Extended pre-gate" allows to convert a random stream of trucks driving to container terminal into a stream with a fixed order of service.

The theory of mass service, including queuing systems and networks, is an appropriate tool for modeling randomness arising from the mentioned above uncertainty, allowing for a complete description of processes taking place at container terminal in a macro scale.

The container terminal can be regarded as a system with no loss, since each upcoming container will be handled.

The accurate predictions of the cargo flow through a container terminal require a simulation, based on real data considering among others:

- the number of cars arriving/departing the main gate of the terminal within an hour,
- the number of pairs of trains operated on the terminal within an hour,
- the number of vessels calling to the terminal simultaneously, and on average per day
- size structure of calling vessels.

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