

# TRUCK ARRIVAL MANAGEMENT AT MARITIME CONTAINER TERMINALS

Daniela Ambrosino  
Lorenzo Peirano  
Dept. of Economics and Business Studies (DIEC)  
University of Genova  
Via Vivaldi 2, 16126 Genova, Italy  
E-mail: [daniela.ambrosino@economia.unige.it](mailto:daniela.ambrosino@economia.unige.it)  
[lorenzo.peiran@gmail.com](mailto:lorenzo.peiran@gmail.com)

## KEYWORDS

Truck appointment system, container terminal, mixed integer linear programming model.

## ABSTRACT

In this work the management of truck arrivals in a maritime terminal is investigated as possible strategy to be used for obtaining a reduction in congestion and gate queues. In particular, a non-mandatory Truck Appointment System (TAS) is considered.

Inspired by the work of Zehedner and Feillet 2013, we propose a multi-commodity network flow model for representing a maritime terminal. We solve a mixed integer linear programming model based on the network flow for determining the number of appointments to offer for each time window in such a way to serve trucks in the shortest time as possible, thus granting trucks a “good” service level. Some preliminary results are presented. Solutions show the effectiveness of the proposed model in flattening the arrivals distribution of vehicles.

## INTRODUCTION

Container maritime terminals play an important role in the logistic networks and have to be efficient intermodal nodes. In the last years mega vessel containerships have been used in order to reach economies of scale by transporting even larger numbers of containers. Thus new problems arise in the container terminals: the need of unloading and loading more containers in even smaller amounts of time requires new management strategies for avoiding congestion.

The efficient management of import and export flows is fundamental for both the terminals and the collectivity. Infact, congestion inside and outside the terminal may cause serious environmental traffic problems, besides a limitation of the efficiency of the terminals themselves. Two strategies can be used for obtaining a reduction in congestion and gate queues: the first strategy is the extension of the gate capacity, generally associated to an extension of the area of the terminal; the second strategy concerns the Truck Arrival Management (TAM).

Strategies that are not related to TAM are, for example, in Dekker et al. 2013, in which a chassis exchange system

is described, in Cullinane and Wilmsmeier 2011, in which dry ports strategies are suggested as strategic choice for maritime terminals aimed at reducing the traffic on the roads and moving it onto the rail networks. Dry ports strategies are particularly useful when terminals are close to urban and suburban areas, characterized by heavy traffic (Roso et al. 2009). In Ambrosino and Sciomachen 2014 the problem of locating dry ports for freight mobility in intermodal networks is faced.

TAM strategies aim at obtaining an efficient usage of resources inside the terminal, good service time to clients, no congestion inside and outside the terminal. Alessandri et al. 2008 propose a model for determining the best allocation of the terminal resources in such a way to optimize some key performance indexes.

TAM strategies are generally based on truck appointment systems. In fact, usually, for what concerns the number of trucks approaching the terminal, there are some peaks in particular hours of a day (Guan and Liu 2009), and it is obvious that a better distribution in the arrival of trucks at the terminal, will cause smaller queues and will increase the efficiency of the terminal.

A Truck Appointment System (TAS) defines a maximum number of trucks that can approach the terminal and pass the gate during the time windows in which the working day is split.

Truck appointment systems have been introduced by some terminals in order to balance truck arrivals, such as Vancouver, Los Angeles and Long Beach (Morais and Lord 2006). The performances of these TAS are not uniform, thus suggesting that it is necessary to implement different TAS in accordance with specific local conditions (Chen et al. 2013).

Huynh and Walton 2008 stress that only if there is a correct dimension of the system, adequate to the terminal size, such that an efficient usage of the resources of the terminal is permitted, it is possible to obtain advantages from TAS. The authors consider TAS an instrument for controlling the flows and optimizing the resources usage in the terminal; they propose a method for determining the maximum number of vehicles that, in each time window, can be accepted in each zone of the terminal.

Moreover, their study takes into account the delays and the non-arrivals, searching for robust solutions. To the authors' knowledge, only another very recent work takes into account the problem of possible truck arrival deviation from the schedule in the appointment system: in Li et al. 2016 a set of response strategies for neutralizing the impact of disruptions is presented.

Among the papers investigating the problem of how to define the appointment quota for each window, in Zhang et al. 2013 an optimization model for determining these quotas while minimizing the waiting time at the gate queues and the yard waiting time, is proposed.

Chen et al. 2013 propose a time window control program to alleviate gate congestion, that is based on three steps: *i)* estimate truck arrivals based on the time window assignment and the distribution pattern of truck arrivals *ii)* estimate truck queue length using a non-stationary queuing model *iii)* optimize time window in such a way to minimize the total system cost, i.e. the truck waiting time, the idling fuel consumption, the cargo storage time and the storage yard fee.

In Zehedner and Feillet 2013 the authors evaluate the impact of the TAS in the port of Marseille that uses straddle carriers (SC) to serve trucks, trains, barges, and vessels. They present a minimum cost multi-commodity network flow model in which each commodity represents a container flow from/to a transport mode. The model simultaneously determines the number of truck appointments to accept and the number of straddle carriers to allocate to different transport modes with the objective of reducing overall delays at the terminal.

In Chen et al. 2013b the problem of sizing each window has been solved by minimizing the total number of shifted arrivals and the total truck waiting time. The authors show that good results in terms of truck idling emission can be obtained by shifting also a small number of trucks from peak to off-peak periods.

In Chen et al. 2011 another strategy used to obtain a different distribution of truck arrivals, based on time dependent tool pricing, is described. The authors propose a method that firstly determines the arrival distribution  $d^*$  that minimizes the total queues time and the disadvantages for trucks. Secondly, they try to define the pricing tools able to modify the trucks' behavior and to obtain a truck arrival process equal to  $d^*$ , while minimizing the average price paid by trucks.

In Phan and Kin 2015 the focus is on the importance of defining terminals strategies to reduce congestion by including also decisions and requirements of trucking companies. A mathematical model to make the appointment system adjustments for truck arrival times and to propose a negotiation process among trucking companies and the terminal, has been proposed. In Phan and Kin (2016) the authors suggest a new appointment process by which trucking companies and terminals

collaboratively determine truck operation schedules and truck arrival appointments.

Some papers concerning different congestion issue are, among others, Sharif et al. 2011 which analyzes the potential benefits of providing real-time gate congestion information; Ambrosino and Caballini 2015 that addresses the problem of minimizing the trucks' service times at container terminals while respecting certain levels of congestion. The terminal road cycle is described in detail and a spreadsheet is used for deciding, for each truck having executed the check-in, if it should be allowed to enter the terminal and, if yes, which service level it will be given.

In this paper we investigate the management of truck arrivals by proposing a non-mandatory TAS.

Inspired by the work of Zehedner and Feillet 2013, we propose a multi-commodity network flow model for representing a general terminal where the resources are dedicated to each modal transport, and trucks approaching the terminal can decide to book or not their arrivals. A mixed integer linear programming model is proposed for determining the number of appointments to offer for each time window in such a way to serve trucks in the shortest time as possible, thus granting trucks a "good" service level.

The paper is organized as follows: in the next section we present the network flow model and the mixed integer linear programming model. Then, experimental tests on random generated data derived by a real case study of an Italian terminal are reported. Finally, conclusions and further research are given.

## THE NETWORK FLOW MODEL

Starting from the model in Zehedner e Feillet 2013, we propose the following network flow for representing a general terminal. The time horizon under investigation is  $T$  and is split into  $s$  periods of time, i.e.  $T = \{t_1, t_2, \dots, t_s\}$ . Each truck approaching the terminal in the considered time horizon is a unit of flow that enters the network and has to exit within a given due date.

For example  $T$  can be a working day (from 6 a.m. to 10 p.m) split into 16 periods of one hour; these time periods represent the 16 time windows in which a truck can book the access to the terminal, of course, in accordance with its preferred arrival time.

Let be  $C = \{1, 2, \dots, n\}$  the set of  $n$  trucks that have to approach the terminal to deliver and /or to pick up containers during the time horizon  $T$ .

Let us introduce the following notation used to characterize each truck  $k \in C$ :

- $p_k \forall k \in C$  represents the number of operations that truck  $k$  has to execute inside the terminal (i.e.  $p_k=2$  if truck  $k$  has to deliver an export container and to pick up one import container). The maximum value of  $p_k$

is 4 (i.e. 2 export 20' containers to deliver and 2 import 20' containers to pick up).

- $r_k$  such that  $t_1 \leq r_k \leq t_s, \forall k \in C$ , represents the slot of time in which truck  $k$  approaches the terminal;
- $d_k$  such that  $r_k \leq d_k \leq t_s, \forall k \in C$ , is the due time for vehicle  $k$ ; this means that truck  $k$  has to leave the terminal, having executed all  $p_k$  operations, within slot  $d_k$ .

Let us define the graph  $G = (V, A)$  used for representing the terminal road cycle as described in Ambrosino and Caballini 2015 i.e. truck arrivals, the gate queue, the truck service inside the terminal and, finally, the truck exits.

$V$  is the set of vertices given by the union of the following subsets  $V = O \cup G \cup Y \cup S$  where:

$O = \{O_k \mid k \in C\}$ , where  $O_k$  represents the origin node for truck  $k$ ;

$G = \{G_t \mid t \in T\}$ , where  $G_t$  represents the time period  $t$  in which the trucks are at the gate queue;

$Y = \{Y_t \mid t \in T\}$  where  $Y_t$  represents the time period  $t$  in which the trucks are inside the terminal for executing the unloading/loading operations;

$S = \{S_k \mid k \in C\}$  where  $S_k$  represents the sink node for truck  $k$ .

$A$  is the set of arcs given by the union of the following subsets  $A = A_1 \cup A_2 \cup A_3 \cup A_4 \cup A_5$  where:

$A_1 = \{(O_k, G_t) \mid k \in C, t = r_k\}$ : for each truck  $k$  there is a link between its origin node ( $O_k$ ) and the gate queue node, related to the period of time  $t$  equal to the truck arrival time ( $r_k$ ).

$A_2 = \{(G_t, G_{t+1}) \mid 1 \leq t \leq t_{s-1}\}$  is the set of arcs connecting each gate queue node  $G_t$  with node  $G_{t+1}$ ; these arcs are used for representing the trucks remaining in the gate queue from time period  $t$  to  $t+1$ ;

$A_3 = \{(G_t, Y_t) \mid t \in T\}$  for each time period  $t$  there is an arc connecting each node  $G_t$  with the corresponding node  $Y_t$ ; these arcs are used for representing trucks that in time period  $t$  enter into the terminal through the gate;

$A_4 = \{(Y_t, Y_{t+1}) \mid 1 \leq t \leq t_{s-1}\}$  is the set of arcs connecting each node  $Y_t$  with node  $Y_{t+1}$ ; these arcs are used for representing the trucks remaining inside the terminal for completing the unloading/loading operations from time period  $t$  to  $t+1$ ;

$A_5 = \{(Y_t, S_k) \mid k \in C, r_k \leq t \leq d_k\}$  each truck  $k$  can be inside the terminal in time period  $t$  such that  $r_k \leq t \leq d_k$ , thus there are some links connecting nodes  $Y_t$ , of these time periods to the sink node  $S_k$ ; these arcs are used for representing the truck exit.

Each truck  $k$  is here considered as a unit of flow, that has to go from the origin node  $O_k$  to the node  $G_t$  with  $t = r_k$ . After that there are two possibilities: 1) the truck  $k$  is served by the gate and enters the terminal, that is the flow enters into the corresponding node  $Y_t$ ; 2) the truck  $k$  remains in the gate queue, that is the flow enters into node  $G_{t+1}$ . When the truck is inside the terminal, it has to pass from a node  $Y_t$  to the next  $Y_{t+1}$  until it has finished all

terminal operations ( $p_k$ ); after that, it will leave the terminal reaching node  $S_k$ .

In Figure 1 is depicted a network flow for representing three trucks arriving at the terminal respectively in  $r_1=1, r_2=2$ , and  $r_3=2$ , having as due time  $d_1=3, d_2=4$  and  $d_3=3$ .

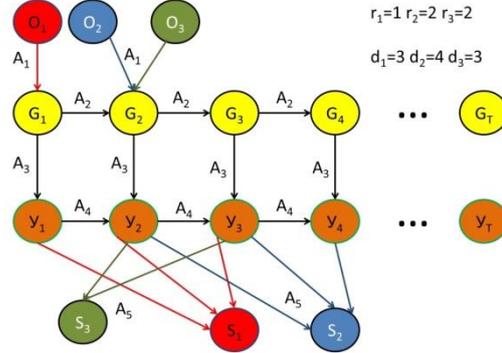


Figure 1: the network flow for 3 trucks

### The Mixed Integer Linear Programming Model

The main aim of this work is to use the network flow in order to determine the best way for serving trucks that enter the terminal, i.e. to minimize the truck service time given by the total time spent by each truck inside the terminal and the total time spent in the gate queue.

Let us introduce the notation useful for presenting the mixed integer linear programming (MILP) model here proposed.

Let be:

- $a_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_1$  such that  $\{i=O_k, j=G_t \mid t=r_k\}$ :  $a_{ij}^k=1$  if truck  $k$  reaches the terminal and goes to the queue gate.
- $q_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_2$  such that  $\{i=G_t \mid r_k \leq t \leq d_{k-1}, j=G_{t+1} \mid r_k \leq t \leq d_{k-1}\}$ :  $q_{ij}^k=1$  if the unit of flow (the truck  $k$ ) passes through the arc  $(i,j) \in A_2$ , that is the truck  $k$  remains in the queue from time period  $t$  until time period  $(t+1)$ .
- $e_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_3$  such that  $\{i=G_t \mid r_k \leq t \leq d_k, j=Y_t \mid r_k \leq t \leq d_k\}$ :  $e_{ij}^k=1$  if the unit of flow (the truck  $k$ ) passes through the arc  $(i,j) \in A_3$  that is the truck  $k$  at time period  $t$  enters the terminal.
- $y_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_4$  such that  $\{i=Y_t \mid r_k \leq t \leq d_{k-1}, j=Y_{t+1} \mid r_k \leq t \leq d_{k-1}\}$ :  $y_{ij}^k=1$  if the unit of flow (the truck  $k$ ) passes through the arc  $(i,j) \in A_4$ , that is the truck  $k$  remains inside the terminal from time period  $t$  until time period  $(t+1)$  for concluding unloading/loading operations.
- $x_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_5$  such that  $\{i=Y_t \mid r_k \leq t \leq d_k, j=S_k\}$ :  $x_{ij}^k=1$  if the unit of flow (the truck  $k$ ) passes through the arc  $(i,j) \in A_5$ , that is the truck  $k$  in time period  $t$  has completed its  $p_k$  operations and leaves the terminal. The unit of flow  $k$  reaches its sink node.
- $b_k \in \{0,1\}, \forall k \in C$ , is equal to 1 if vehicle  $k$  has a booking.

- $g_t \geq 0, g_t \in \mathbb{N}, \forall t \in T$ , is the set of integer variables representing the number of gate lanes that are devoted to trucks having a booked appointment for time period  $t$ . Note that this set of variables is useful for defining the size of the booking system.
- $z_k \in \{0,1\}, \forall k \in C$  is the set of auxiliary variables used for linearizing a set of constraints in the MILP model:  $z_k = a_{ij}^k * b_k$ .

Let us now introduce the parameter used in the model:

- $c1_{ij}^k, \forall k \in C, (i,j) \in A_2$  such that  $\{i = G_t | r_k \leq t \leq d_k, j = G_{t+1} | r_k \leq t \leq d_k\}$ : is the cost for having truck  $k$  in the gate queue from time period  $t$  to  $t+1$ ;
- $c2_{ij}^k, \forall k \in C, (i,j) \in A_5$  such that  $\{i = Y_t | r_k \leq t \leq d_k, j = S_k\}$ : is the cost associated to truck  $k$  that leaves the terminal. The main aim is to serve each vehicle in the lower time as possible. The lower is the difference between the time period  $t$  in which the truck leaves the terminal and its due time  $d_k$ , the higher is this cost;
- $\alpha_k$  represents the benefit for having truck  $k$  booked;
- $l_b^U$  is the maximum number of gate lanes that can be reserved to booked vehicles;
- $\pi$  is the maximum number of vehicles that can be inside the terminal;
- $\pi^U_t$  is the maximum number of unloading and loading operations that can be executed during time period  $t$ ;
- $\mu_b$  is the target service time for booked trucks fixed by the terminal management, i.e. average time that booked trucks may spend in the terminal. This average time is computed as time in the gate queue and service time for entering the terminal.
- $\lambda$  represents the number of vehicles that can be processed by each gate lane in each time period.

The resulting model is the following:

M1)

$$\begin{aligned} \text{MIN} \quad & \sum_{k \in C} \sum_{(G_t, G_{t+1}) \in A_2} c1_{G_t, G_{t+1}}^k * q_{G_t, G_{t+1}}^k + \\ & + \sum_{k \in C} \sum_{(Y_t, S_k) \in A_5} c2_{Y_t, S_k}^k * x_{Y_t, S_k}^k - \sum_{k \in C} \alpha_k * b_k \end{aligned} \quad (1)$$

$$\text{s.t.} \quad a_{O_k, G_t}^k = 1 \quad \forall k \in C, t = r_k \quad (2)$$

$$\sum_{(Y_t, S_k) \in A_5} x_{Y_t, S_k}^k = 1 \quad \forall k \in C \quad (3)$$

$$(a_{O_k, G_t}^k + q_{G_{t-1}, G_t}^k) = (q_{G_t, G_{t+1}}^k + e_{G_t, Y_t}^k) \quad \forall k \in C, t | r_k \leq t \leq d_k \quad (4)$$

$$(e_{G_t, Y_t}^k + y_{Y_{t-1}, Y_t}^k) = (y_{Y_t, Y_{t+1}}^k + x_{Y_t, S_k}^k) \quad \forall k \in C, t | r_k \leq t \leq d_k \quad (5)$$

$$z_k \leq a_{O_k, G_t}^k \quad \forall k \in C, t = r_k \quad (6)$$

$$z_k \leq b_k \quad \forall k \in C \quad (7)$$

$$z_k \geq a_{O_k, G_t}^k + b_k - 1 \quad \forall k \in C, t = r_k \quad (8)$$

$$z_k \leq e_{G_t, Y_t}^k \quad \forall k \in C, t = r_k \quad (9)$$

$$\mu_b \geq \frac{1}{g_t * \lambda - \sum_{k \in C} z_k} \quad \forall t \quad (10)$$

$$g_t \leq l_b^U \quad \forall t \quad (11)$$

$$\sum_{k \in C} y_{Y_t, Y_{t+1}}^k \leq \pi \quad \forall t | t \leq |T|-1 \quad (12)$$

$$\sum_{k \in C} p_k * x_{Y_t, S_k}^k \leq \pi_t^p \quad \forall t \quad (13)$$

Objective function (1) minimizes the costs associated to the trucks in the queue at the gate and the costs for serving the truck near their due time, while trying to maximize the total number of booked vehicles.

Constraints (2) force each vehicle  $k$  to arrive at its preferred time  $r_k$ , i.e. each truck  $k$  leaves its source node in  $r_k$ , while constraints (3) ensure to each vehicle  $k$  to reach its sink node.

(4) and (5) are the flow conservation constraints for nodes of set  $G$  and  $Y$ , respectively.

Constraints (6), (7), (8) define variable  $z_k$  as the product of variables  $a_{ij}^k$  and  $b_k$  in order to preserve linearity in the model. These constraints, together with constraints (9), replace the following ones that are necessary to guarantee that a booked truck  $k$  enters the terminal as soon as it arrives at the gate:

$$a_{O_k, G_t}^k * b_k \leq e_{G_t, Y_t}^k \quad \forall k \in C, t = r_k$$

Constraints (10) limit the time spent in the queue outside the terminal by booked vehicles, this maximum queue time is decided by the terminal operator and it is set by parameter  $\mu_b$ .

Set of constraints (11) bounds the number of gate lanes reserved to booked vehicles, while constraints (12) limit the number of vehicles inside the terminal from time period  $t$  to the following  $t+1$ .

Lastly, constraints (13) represent the terminal capacity for handling operations: the total number of operations executed in each time period  $t$  must be no greater than the terminal handling capacity.

## An Extension of the Previous Network Flow Model

A drawback of model M1 is the following: a truck can not book the access to the terminal in a time period different from its preferred arrival time  $r_k$ . Anyway, for increasing the capability of the booking system of modifying the arrival process to the terminal it is necessary to give the possibility to the appointment system to book for period of times different from preferred truck arrivals.

The disadvantage for the truck operator that is obliged to modify his behavior, will be compensated by the advantages derived by having fixed and known the service time at the terminal. Moreover, the allowable deviation between preferred and booked time period is limited.

Thus, we have modified both the network flow and the model in such a way to permit to a truck  $k$  to book an appointment for a time period different from  $r_k$ .

In Figure 2 the new network flow is depicted.

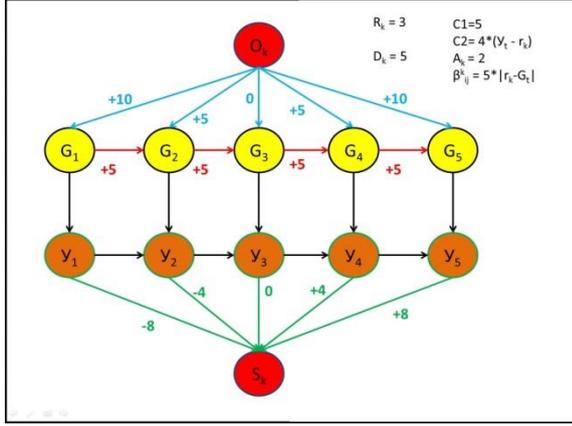


Figure 2: example of network flow for one truck with a maximum absolute deviation of 2 periods

Let be  $\Delta$  the maximum deviation from the preferred arrival time ( $r_k$ ) of vehicle  $k$ , thus follows:

- $A_1 = \{(O_k, G_t) \mid k \in C, r_k - \Delta \leq t \leq r_k + \Delta\}$ ;
- $A_5 = \{(Y_t, S_k) \mid k \in C, r_k - \Delta \leq t \leq d_k\}$ ;
- $a_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_1$  such that  $\{i = O_k, j = G_t \mid r_k - \Delta \leq t \leq r_k + \Delta\}$ ;
- $x_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_5$  such that  $\{i = Y_t \mid r_k - \Delta \leq t \leq d_k, j = S_k\}$ ;
- $q_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_2$  such that  $\{i = G_t \mid r_k - \Delta \leq t \leq d_{k-1}, j = G_{t+1} \mid r_k - \Delta \leq t \leq d_{k-1}\}$ ;
- $e_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_3$  such that  $\{i = G_t \mid r_k - \Delta \leq t \leq d_k, j = Y_{t+1} \mid r_k - \Delta \leq t \leq d_k\}$ ;
- $y_{ij}^k \in \{0,1\}, \forall k \in C, (i,j) \in A_4$  such that  $\{i = Y_t \mid r_k - \Delta \leq t \leq d_{k-1}, j = Y_{t+1} \mid r_k - \Delta \leq t \leq d_{k-1}\}$ ;
- $z_k$  is changed as  $z^k_i$  such that  $k \in C$  and  $i = G_t \mid r_k - \Delta \leq t \leq d_k$ , to better explain the product  $a_{ij}^k * b^k$  including the time of arrival at the gate.

Constraints of model M1) defined for  $t$  such that  $r_k \leq t \leq d_k$ , must now be defined for  $r_k - \Delta \leq t \leq d_k$ , and those defined for  $t = r_k$  must now be defined for  $r_k - \Delta \leq t \leq r_k + \Delta$ . Moreover, constraints 2) must be modified as follows:

$$\sum_{(O_k, G_t) \in A_1} a_{O_k, G_t}^k = 1 \quad \forall k \in C$$

Finally, in the new model (from now we will refer to it as M2) we try to minimize also the deviation between the trucks appointments and their preferred arrival time ( $r_k$ ). For this reason we define:

- $\beta$  the cost paid for having modified the arrival time at the terminal.

The new component of the objective function is:

$$\beta * \sum_{k \in C} \sum_{i = G_t} (|t * z_i^k - r_k|)$$

## COMPUTATIONAL RESULTS

In this section we report the results obtained by solving model M2 for some random generated data derived by a real case study of an Italian terminal.

Figure 3 shows the arrival distribution in a working day of the terminal used for generating data. As usual this distribution presents a peak of the truck arrivals.

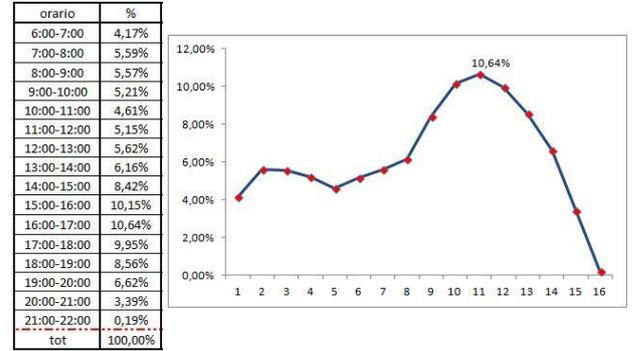


Figure 3: arrival distribution

In this experimental campaign, we have considered a wide range of different scenarios.

First of all, we have analyzed the differences between implement a 1-hour time window and a 2-hours time window, where the latter one offers an easier organization for haulers, at the cost of less efficiency for the terminal.

Secondly, we have simulated three different possibilities for the daily total arrival of trucks: in the first case the total number of vehicles results less than the average of the work situation (1.800 trucks per day), in the second one the total number of vehicles results in average with the work situation (2.000 trucks per day) and in the last scenarios the total number of vehicles results higher than the average work situation (2.200 trucks per day).

To deeply analyze the behavior of the model, and mostly to validate it, we have also generated scenarios by changing the number of operations to be executed at the terminal by trucks.

Moreover, to study how the policy of assured maximum time elapsed in the queue impacts on the model solutions, various values of  $\mu_b$  have been applied.

Lastly, we have used three different average times for gates operations ( $\lambda$ ) to identify the operational target terminal handlers should aim for.

Each scenario has been named following the nomenclature shown in the Table below.

A	Value	Value			
		1	2	3	4
A	Time windows width	1 hour	2 hours		
B	Total daily arrivals	1800	2000	2200	
C	Number of operations (partition)	50/50/0/0	40/40/20/0	40/40/15/5	
D	Maximum time in queue	10 minutes	20 minutes	30 minutes	40 minutes
E	Handling capacity (number of vehicles served)	60	90	120	

Table 1: Scenarios nomenclature

All generated scenarios have been solved up to optimality by model M2.

By varying  $\mu_b$ , we can observe in Figure 4 little changes in the optimal arrival distributions.

Solutions obtained by imposing a maximum time to spend in the gate queue for booked trucks of 40 minutes do not differ much from those obtained by having this limit equal to 10 minutes. Thus terminal operator can persuade hauler to book their entry by promising a smaller amount of time spent in the queue while limiting the risks of operational problems.

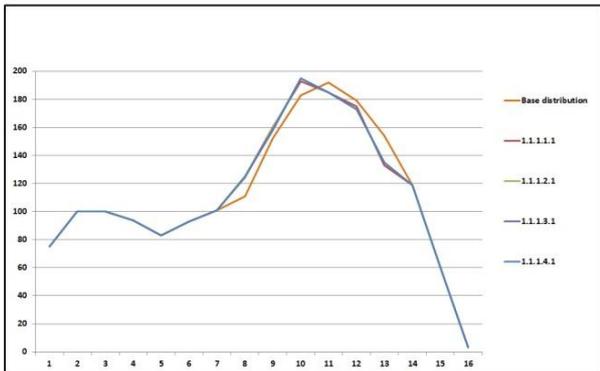


Figure 4: arrival distribution varying  $\mu_b$

More interesting is the study of the solutions obtained by varying parameters  $\lambda$ . As shown in Figure 5 when the time required for serving one truck at the gate passes from 60 to 45 seconds, a significant redistribution of trucks arrivals can be observed, while passing from 45 to 30 seconds significant changes are no more evident.

This is due to the fact that in these scenarios, the number of entrances is limited by terminal handling capacity, where in the case with 45 seconds both constraints, time spent in queue and handling capacity, affect the solution.

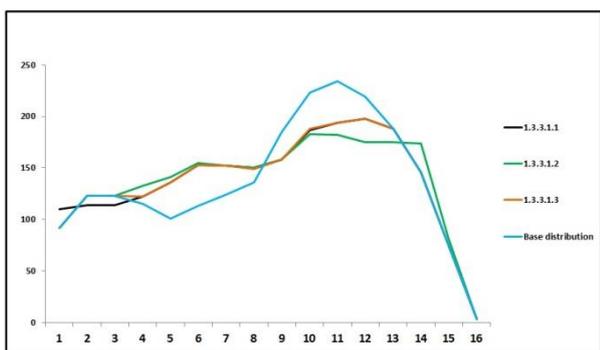


Figure 5: arrival distribution varying  $\lambda$

Increasing the number of operations to be executed at the terminal by trucks, pushes the model to increasingly modify arrivals distribution.

A lower number of operations associated to each truck allows the terminal to easily handle the whole traffic, especially with a low number of daily arrivals, while the terminal reaches its full handling capacity when an higher

number of operations is considered. The graph of Figure 6 shows how the model modifies the arrival distributions.

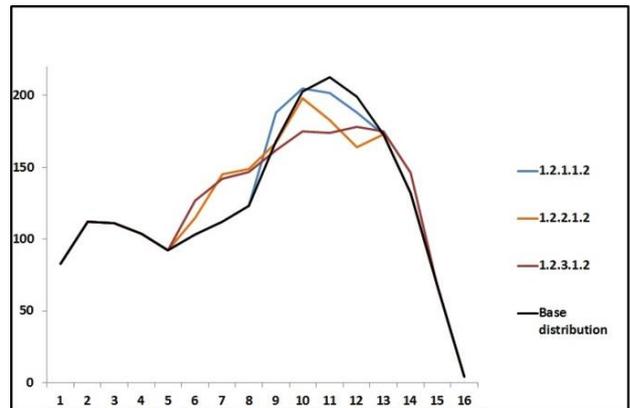


Figure 6: arrival distribution varying the number of operation to execute

Similarly, the model increases its action in redistributing trucks arrivals at terminal when the daily total number of trucks ( $|C|$ ) increases, as shown in Figure 7.

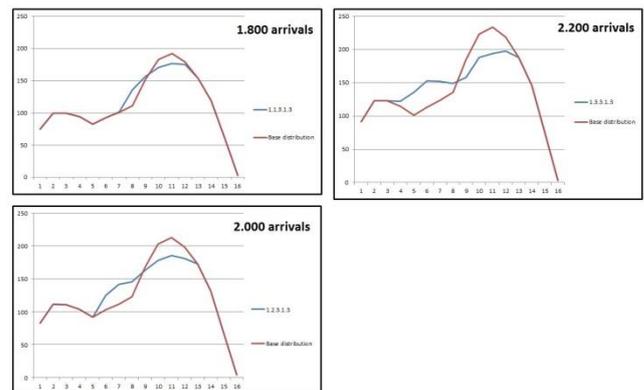


Figure 7: arrival distributions for different and increasing  $|C|$

## CONCLUSIONS AND FUTURE WORKS

In order to tackle the problem of increasing queues outside container terminals, the implementation of a non-mandatory truck appointment system is studied.

Optimal size of the system, capable of decreasing congestion while trying to impact as little as possible hauler operational plans, is obtained by a mixed integer linear optimization model, used for defining optimal flows in the network flow model which simulates the operability of a container terminal during a workday.

Solutions found demonstrate the effectiveness of the model to re-shape arrivals distribution and to adapt to shifting conditions, both external (number of arrivals, number of operations to be executed inside the terminal) and internal (mostly operational target, such as maximum

time spent in the queue by booked vehicles and average service time at gates).

Future developments focus on the modification of the network flow, in such a way to better simulate the behavior of trucks once inside the perimeter of a container terminal. For this reason the width of the time windows will be decreased. Moreover, a limitation on the time spent in queue for not booked vehicles will be included in the model.

The optimization model will be developed using C# programming language, this addition allows the simulation of a wider number of scenarios for both a better understanding of the problem and validating the model.

## REFERENCES

- Alessandri, C.; M. Cervellera; M. Cuneo; and M. Gaggero. 2008. "Nonlinear Predictive Control for the Management of Container Flows in Maritime Intermodal Terminals." *Proceedings of the 47th IEEE Conference on Decision and Control Cancun, Mexico, Dec. 9-11.* .
- Ambrosino, D. and C. Caballini. 2015. "Congestion and truck service time minimization in a container terminal." *Maritime-Port Technology and Development. Proceedings of the International Conference on Maritime and Port Technology and Development, MTEC 2014, 1-10.*
- Ambrosino, D. and A. Sciomachen. 2014. "Location of Mid-Range Dry Ports in Multimodal Logistic Networks." In: Raffaele Cerulli, Giovanni Felici, Anna Sciomachen. *Procedia - Social and Behavioral Sciences.* Elsevier, No 108, 118-128.
- Chen, G.; K. Govindan; and Z. Yang. 2013. "Managing truck arrivals with time windows to alleviate gate congestion at container terminals." *International Journal of Production Economics*, No 141, 179–188.
- Chen, G.; K. Govindan; and M.M. Golias. 2013b. "Reducing truck emissions at container terminals in a low carbon economy: proposal of a queueing-based bi-objective model for optimizing truck arrival pattern." *Transportation Research Part E*, No 55, 3–22.
- Chen, X.; X. Zhou; and G.F. List. 2011. "Using time-varying tolls to optimize truck arrivals at ports." *Transportation Research Part E*, No 47, 965–982.
- Cullinane, K. and G. Wilmsmeier. 2011. "The contribution of the dry port concept to the extension of port life cycles." In: Bose, J.W. (Ed.), *Handbook of Terminal Planning.* Springer, New York, 359–379.
- Dekker, R.; S. van der Heide; E. van Asperen; and P. Ypsilantis. 2013. "A chassis exchange terminal to reduce truck congestion at container terminals." *Flexible Service Manufacturing Journal*, No 25, 528–542.
- Guan, C.Q. and R.F. Liu. 2009. "Container terminal appointment system optimization." *Maritime Economics and Logistics*, No 11(4), 378–398.
- Huynh, N. and C. M. Walton. 2008. "Robust Scheduling of Truck Arrivals at Marine Container Terminals." *Journal of Transportation Engineering.* August, 347-353.

- Morais, P. and E. Lord. 2006. "Terminal appointment system study." *Transport Canada, Ottawa.* <<http://trid.trb.org/view.aspx?id=792769>>.
- Phan, T.M.H. and K.H. Kim. 2015. "Negotiating truck arrival times among trucking companies and a container terminal." *Transportation Research Part E*, No 75, 132–144.
- Phan, T.M.H. and K.H. Kim. 2016. "Collaborative truck scheduling and appointments for trucking companies and container terminals." *Transportation Research Part B*, No 86, 37–50.
- Roso, V.; J. Woxenius; and K. Lumsden. 2009. "The dry port concept: Connecting container seaports with the hinterland." *Journal of Transport Geography*, No 17-5, 381-398.
- Sharif, O.; N. Huynh; and J.M. Vidal. 2011. "Application of El Farol model for managing marine terminal gate congestion." *Research Transport Economics*, No 32, 81–89.
- Zehendner, E. and D. Feillet. 2014. "Benefits of a truck appointment system on the service quality of inland transport modes at a multimodal container terminal." *European Journal of Operational Research*, No 235, 461–469.
- Zhang, X.; Q. Zeng; and W. Chen. 2013. "Optimization model for truck appointment in container terminals." *Procedia-Social and Behavioral Sciences* No 96, 1938–1947.

## AUTHOR BIOGRAPHIES



**DANIELA AMBROSINO** is assistant professor of Operation Research at the University of Genoa, Italy. She is teaching Operation Research for management and Optimization and Simulation for maritime transport.

Her main research activities are in the field of distribution network design and maritime logistic. Her e-mail address is: [daniela.ambrosino@economia.unige.it](mailto:daniela.ambrosino@economia.unige.it)



**LORENZO PEIRANO** is postgraduate in Maritime Economics and Ports Management at the University of Genoa, Italy. He occasionally collaborates with the University of Genoa for research activities in maritime logistics. He is working at Aldieri Autotrasporti S.p.A.

(Italy) as airfreight forwarder.

This paper is mainly inspired by his postgraduate degree dissertation awarded by the Italian society of Operational Research in September 2015.

His email address is [lorenzo.peirano@gmail.com](mailto:lorenzo.peirano@gmail.com)