A SIMULATION BASED STUDY OF THE EFFECT OF TRUCK ARRIVAL PATTERNS ON TRUCK TURN TIME IN CONTAINER TERMINALS

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KEYWORDS

Container Terminal, Truck Arrival Pattern, Truck Turn Time, Discrete Event Simulation, Truck Appointment System.

ABSTRACT

In container terminal operations, the delay of containers delivery is a common problem that confronts both the terminal operator and the customers represented by the trucking companies. One source of this delay is due to the long waiting time of the transporting trucks at container terminals (CTs). In this paper, the problem of long turn time for external trucks is studied. An extensive review of the previous work available in the literature that focused on landside problems in CTs is presented. After identifying some gaps, we conclude that the arrival pattern of external trucks and its impact on the truck turn time needs to be more understandable. A discrete event simulation model is developed to study the effect of various truck arrival patterns on the truck turn time in CTs. The simulation results showed how the arrival patterns influence the turn time of external trucks. Moreover, we suggest how CT operators can reduce the turn times without reducing the terminal gates' productivity and recommend how to consider the arrival pattern in designing an appointment system for external trucks in CTs.

INTRODUCTION

Container terminals (CTs) received considerable interests from researchers in recent years. This is due to the importance of container terminals as essential nodes in global supply chains. The global trade growth put more pressures on CTs to manage its activities and schedule its resources properly. These growing activities increased the complexity of CT related planning and operational control problems. By solving CT's problems efficiently, the terminal puts its position on the map of global competitiveness among other container terminals. The increasing number of containers causes higher demands on the seaport container terminals, container logistics, and management, as well as on technical equipment (Steenken et al. 2004). As a result, CTs are forced to enlarge handling capacities and strive to achieve gains in productivity (Stahlbock and Voß 2008).

Container terminals can be divided into five areas, namely the berth, quay, transport, storage yard, and gate, as illustrated in Fig. 1 (Carlo et al. 2013). These five areas can be described in three main areas as follows: the berth and the quay are called the "Seaside", the yard storage is "yard side" while the gate is called the "Landside". Each side has some operations which interact with others (Fig. 2). Sometimes, these interactions are studied as integrated problems. Solving the integrated problems has many benefits. Karam et al. (2014) showed that the integration achieves the required performance of each individual problem and gives better solutions.

The yard is considered the center area of any CT. As a result, yard operations interact with both seaside operations and landside operations. Fig. 2 describes the main areas of the terminal and the operations interactions. The main seaside operations are: berth allocation for vessels, quay crane allocation, handling containers from/to the vessel using quay cranes, and

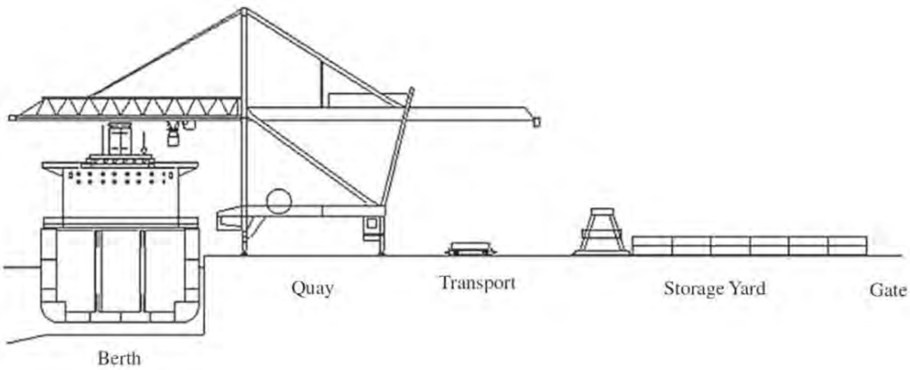

Fig. 1 Container Terminal Main Areas (Carlo et al. 2013).

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loading/unloading containers to/from the internal transport means. Internal trucks are delivering containers between seaside and yard. The yard area main operations are: loading/unloading of containers to/from internal and external trucks, and stacking containers in the appropriate locations in the yard, as well as premarshalling of containers. To transport containers between the terminal and the hinterland, external trucks can access the terminal via the terminal gates. The main landside operations are described in the next section.

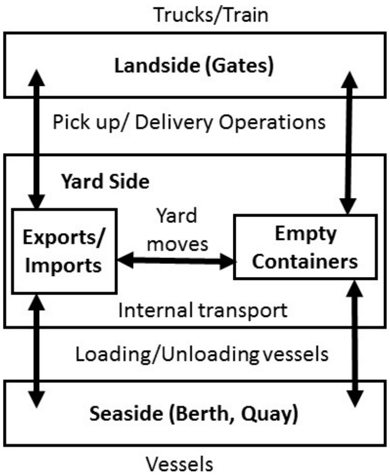


Fig. 2 Operation areas of a seaport container terminal and transport flows

Seaside operations and yard operations received abundant interest from researchers while landside operations still need more efforts to tackle problems in this important area of the CTs. In this paper, focus will be more on the land side operations. Various problems will be addressed, solution strategies and approaches for the landside operations from the literature will be shown with more attention to the use of simulation as a powerful solution methodology for this class of problems.

The remainder of this paper is organized as follows. The next section will discuss operations and problems in the landside. After that an extensive literature review for landside operations will be introduced. The problem description follows, with an explanation of the used simulation model and the experimental results. Conclusions and future work will be addressed last.

LANDSIDE OPERATIONS AND PROBLEMS

The landside is considered the connecting point between the terminal and the hinterland. When a terminal receives an announcement for vessel(s) arrival, the terminal announces to the customers. Once the customers know the expected arrival schedule of the vessel(s), they make orders to trucking companies or their own trucks to deliver or pickup their containers. In some seaports, trucking companies have to make an appointment based on the expected arrival of the vessel and the terminal schedules. Some trucks may go to the terminal without an appointment. At the terminal gates, the trucker’s identity, the truck's documents and the container's documents are checked. Export/Import containers are scanned before entering/leaving the terminal. When these operations are finished, the truck is directed to the yard. The gate operator gives the trucker the precise location and the route that he/she should take to reach the container location at the storage block.

At the yard, a yard crane will load the import container to the truck or unload the export container from the truck. The handling operation of the yard crane is also scheduled. CTs often separate the storage locations of export blocks and import blocks. All previous operations need to be well managed and planned in the long term and scheduled in the short term to guarantee high productivity and service quality level for the terminal.

Problems in the landside can be studied from two perspectives. The first is the customer perspective, and the second is the terminal perspective. In CTs, the operations in the landside are interacting with the yard operation (see Fig.2), and the main objective of landside operations is to serve the external trucks at the gates and the yard. The terminal main goals are: increasing the utilization of the terminal equipment and facilities and achieving high customers’ satisfaction. Customer’s satisfaction occurs when they are served at minimal time and cost. The more time the trucks wait at the gates and the yard, the more queuing problems will occur. As a result, the long queues of trucks at the terminals lead to delays and cause emissions, congestion, and high cost for both the terminal and the customer (Gharehgozli et al. 2014). More focus on the delay problem for external trucks will be addressed in this paper.

Due to the complex interactions of processes in CTs, simulation has been used to solve many CT problems. Moreover, Control techniques which relate to the dynamic behavior of the equipment are even more difficult to analyze and benchmark, therefore necessitating the presence of a tool that can replicate the behavior of a real terminal (Angeloudis et al. 2011). It is difficult to predict the actual events such as arrival times of trucks and the actual number of arrivals. Simulation is very effective in doing such predictions. On the other hand, it is very important to study the “what if” scenarios to take the right decisions in the short-term and long-term.

LITERATURE REVIEW

In this section, the published papers after 2008 that focused on landside operations are reviewed with more attention for the trucking problems at gates and yard.

Simulation based work to solve landside problems is also covered.

Truck operations in the landside are evaluated using some performance metrics like “Truck turn times”. Both terminal and truckers wish to minimize the truck turn time. The turn time is defined as the time from the truck arrival at the terminal gates to the time of departure. Huynh (2009) provided a mathematical model to examine the effect of limiting truck arrivals on truck turn time and crane utilization. To obtain the average truck turn time, the authors used a discrete event simulation (DES) model and heuristics to solve their model. As an extension for their work, Huynh and Walton (2011) produced DES model to simulate various appointment rules. They examined the individual appointments vs the block appointment and studied its effect on truck turn time and crane utilization. In a previous work, Huynh and Hutson (2008) examined the sources of delay for dray trucks at container terminals. They used decision trees as a powerful data mining tool.

To reduce the transportation cost, Namboothiri and Erera (2008) proposed an integer programming model and solved it using heuristics. The solution provided the best set of appointment reservations and routes for a fleet of trucks. Guan and Liu (2009) formulated a non-linear optimization problem and applied a multi-server queuing model to analyze marine terminal gate congestion and quantify truck waiting cost. They found that the truck appointment system seems to be the most viable way to reduce gate congestion and increase system efficiency. An optimization model for truck appointments is formulated by Zhang et al. (2013) to reduce heavy truck congestion in the terminal. The queuing process described by a Baskett Chandy Muntz Palacios (BCMP) queuing network. To solve the model, a method based on Genetic Algorithm (GA) and Point wise Stationary Fluid Flow Approximation (PSFFA) was designed. Zehendner and Feillet (2013) quantified the benefits of using the truck appointment system for improving the service quality in CTs. A combined solution approach is adopted to solve the proposed mixed integer linear programming model. A DES validates the results obtained by the optimization model in a stochastic environment. The management of export container arrivals is studied by Chen and Yang (2010). They proposed an integer programing model and solved it using genetic algorithm (GA). In their paper, the transportation cost is reduced by adopting a time window management program.

Studying queuing behavior in container terminal received some interest. Kim (2009) proposed a non-linear integer programming model integrated with a stationary queuing model. Both waiting and operation cost are reduced. Another stationary time-dependent queuing model was introduced by Chen et al. (2011). The authors analyzed time-dependent truck queuing processes with service time distributions at gates and yards of a port terminal. However, it is improper to use stationary queueing models to stochastically analyze a queueing system that is non-stationary in nature (Chen et al., 2011). An appointment system designed by a non-stationary queueing model was introduced by Chen et al. (2013a). The authors proposed two appointment systems: static and dynamic. GA was used to solve the optimization problem and simulation to compare results. Chen et al. (2013) proposed a method called ‘vessel dependent time windows (VDTWs)’ to alleviation of gate congestion. A hybrid algorithm using GA and simulated annealing was used to solve the optimization problem.

Researchers targeted the environmental objective for lowering the carbon dioxide emissions. In this context, Chen et al. (2013b) developed a bi-objective model to minimize both the truck waiting times and truck arrival pattern change. A GA based heuristics was used to solve the model and resulted in reduction of truck emissions using a small shift in truck arrivals.

Simulation was used in solving landside problems such as congestion, waiting, resources idling and emissions. Sharif et al. (2011) used agent-based-simulation to minimize congestion at seaport terminal gates by using the provided real-time gate congestion information and simple logic for estimating the expected truck wait time. Also, Veloqui et al. (2014) provided a DES model for truck arrival at the gate and yard. Various scenarios were simulated to reduce queues by using a commercial simulation software (FlexSim CT). A recent DES model to reduce empty truck trips by implementing a coordinated truck appointments was proposed by Schulte et al. (2015). Their model reduced the emissions but not the congestion.

Previous research also addressed yard operations like yard crane scheduling and container stacking. Online stacking rules are studied by Borgman et al. (2010). A DES tool is used to improve the yard efficiency. The impact of truck announcement on online stacking rules was studied by Asperen et al. (2011) as an extension work for Borgman et al. (2010). A DES model showed the benefits of using the truck announcement for increasing stacking yard efficiency. A new concept of chassis exchange terminal (CET) is presented by Dekker et al. (2013) to reduce terminals congestion by using simulation. Geith et al. (2014) provided an integer programming formulation for container pre-marshalling problem to minimize the containers mis-overlays with the minimum number of container movements. In a later work, Geith et al. (2016) used a variable chromosome length GA to solve the container pre-marshalling large size problems.

More studies were performed to improve the efficiency of yard operations using the information from gates.

Zhao and Goodchild (2010a) used simulation to evaluate the use of truck arrival information to reduce container repositioning during the import container retrieval processes. Zhao and Goodchild (2010b) also investigated the effectiveness of truck arrival information in reducing truck transaction times within container terminals by using the revised difference heuristic. A computer-based simulation is developed. Zhao and Goodchild (2013) extended their work and provided a hybrid approach of simulation and queuing theory to model the container retrieval operation and estimate the crane productivity and truck turn-time. The authors quantified the impact of using a truck appointment system on the yard efficiency of container terminals.

Smoothing truck arrivals in peak hours became a necessity for both container terminals and trucking companies. To achieve this goal, Phan and Kim (2015) addressed a negotiation process among multiple trucking companies and a terminal for smoothing truck arrivals in peak hours. A nonlinear mathematical model is formulated to develop an appointment system using the proposed negotiation process. They recommended to use simulation to validate their procedure of solution. The most recent paper by Li et al. (2016) discussed the deviation of trucks arrival from their appointments. DES is used to evaluate the performance of their proposed solution strategies.

PROBLEM DESCRIPTION AND SOLUTION FRAMEWORK

In container terminals, export container are brought to the seaport by external trucks and import containers are picked by external trucks to be delivered to the hinterland. One of the most imperative issues for the external trucks is the long truck turn time (TTT). The following equation describes the TTT:

$$TTT=Twg+Tsg+Twy+Tsy+Txg \quad (1)$$

Twg: waiting time at gate.
Tsg: service time at gate.
Twy: waiting time at yard.
Tsy: service time at yard.
Txg: time spent at gate exit.

Terminal operators need to reduce the TTT as much as possible. The truck turn time has direct and indirect impacts on the terminal efficiency. As direct impacts, shorter waiting times and service times reduce the congestion outside the gates and within the yard area. In addition, decreasing the turn time increases the terminal throughput and reduces the processes cost. Indirectly, emissions are reduced by less waiting and idling of the trucks and terminal equipment.

The gate operators usually force the trucks to wait outside the terminal or at specific waiting areas within the terminal to avoid the congestion at yard. This creates new congestions at the gates. Moreover, not all terminals have enough waiting space within the terminals. The appointment systems for the external trucks are considered a managerial solution for the long TTT and congestions. There are many factors that affect the TTT like the gate capacity, gate working hours, resources within the terminal and truck arrival patterns. In this paper a discrete event simulation model to study the effect of the arrival patterns on the TTT and how the arrival patterns can be considered in improving the truck appointment system is presented. Also, an approach to develop an optimum appointment schedule is proposed based on the simulation results.

In the literature, many studies evaluated the impact of using an appointment system and arrival information to reduce the waiting, congestion, cost and emissions. Some of them tried to reduce the truck arrival to achieve these goals. Huynh and Walton (2008, 2011) studied the effect of limiting the truck arrivals to reduce (TTT). However, the reduction of truck arrivals disrupts the containers delivery times. To our best knowledge, studying the effect of arrival patterns of the external trucks was not considered enough in the previous literature.

THE PROPOSED SIMULATION MODEL AND EXPERIMENTS

Fig. 3 shows the 3D model for the main areas of the container terminal: quayside, yard area, and gate side. This simple model considers one gate, one yard block, one yard crane, one quay crane, and one vessel. FlexSim CT software is used as a special simulation software for container terminal operations. FlexSim CT provides the advantage of the built-in CT library. This library enables the modeler to save the time of building the container terminal objects and planners.

Both export and import container arrivals are simulated. Various truck arrival patterns are tested under stochastic situation. Investigating the truck turn time changes with various patterns is provided in the paper. The main target is to illustrate how to keep the TTT at minimum and maintain the gate throughput as high as possible. One vessel is proposed to reach the terminal at the beginning of the week. The vessel is assumed to deliver 200 import containers and to be charged with 200 export containers which come via the gate by the external trucks. Similarly, the imports will be picked up during the week by the external trucks. The model parameters are shown in Table 1. These parameters are the default parameters in FlexSim CT with little modification according to some practical experience. In Fig. 4 the process flow is described.

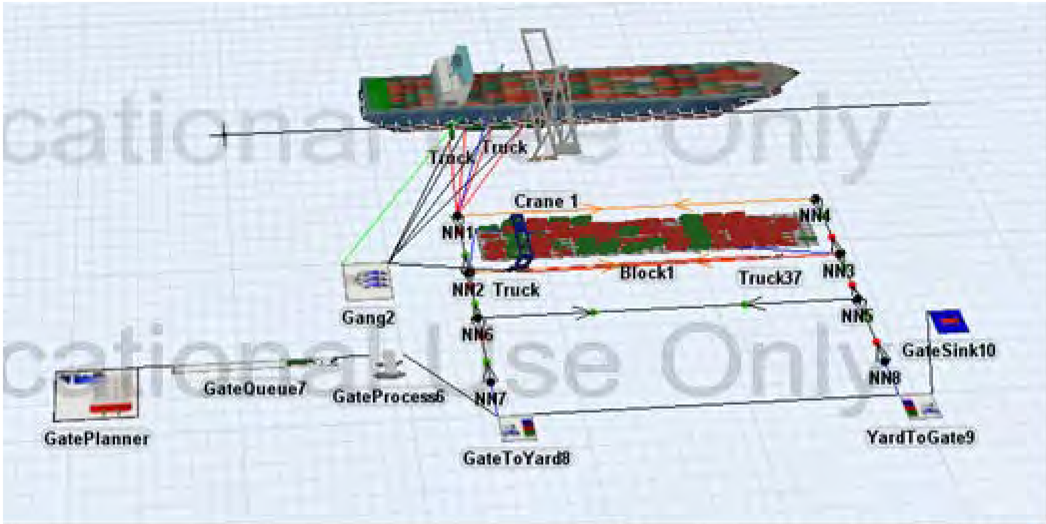


Fig. 3 Discrete Event Simulation Model

Table 1: Simulation Model parameters

Gate parameters	
Working hours/day	6:00 am – 8:00 pm
Trucking speed (max)	300 m/min
Process time	Triangular (5, 15, 10)
Pick up travel time	triangular(2,5,3)
Drop off travel time	triangular(2,5,3)
Dwell time variability	12 hrs.
Yard parameters	
Container dwell time	3 Days
Pick up time	triangular(0.2,2.0,0.5)
Drop off time	triangular(0.2,2.0,0.5)
Yard crane speed (max)	180 m/min
Quayside parameters	
Quay care speed (max)	120 m/min

Five arrival patterns are tested; the default arrival pattern (Def.), increasing arrival pattern (Inc.), decreasing arrival pattern (Dec.), uniform arrival pattern (Uni.), and distributed-peak arrival pattern (Dist.) (Fig. 5). The vertical axis represents the number of external trucks and the horizontal axis represents the day's working hours. These five patterns are developed using the "Gate Planner". The gray bars represent the arrival pattern that is needed to be matched by the gate planner. At the beginning of each week, red (dark) bars are drawn over the pattern to show the actual number of containers scheduled for each hour (both pickup and drop-off).

The default pattern shows that the arrivals reach a peak at the middle of the day. In some cases, the peaks the arrivals are at the end or beginning of the day. This situation is simulated using the increasing and decreasing patterns. The uniform arrival pattern proposes a stable level of arrival over the day. For the distributed-peak arrival pattern, the arrival peaks are distributed to the beginning and the end of the working day. Fig. 5 shows a screen shot for the arrival patterns and the actual arrivals in a specific day after running the model.

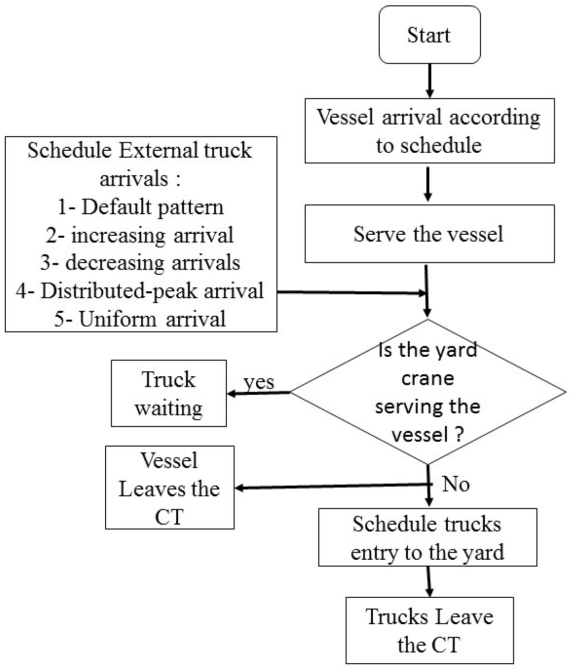
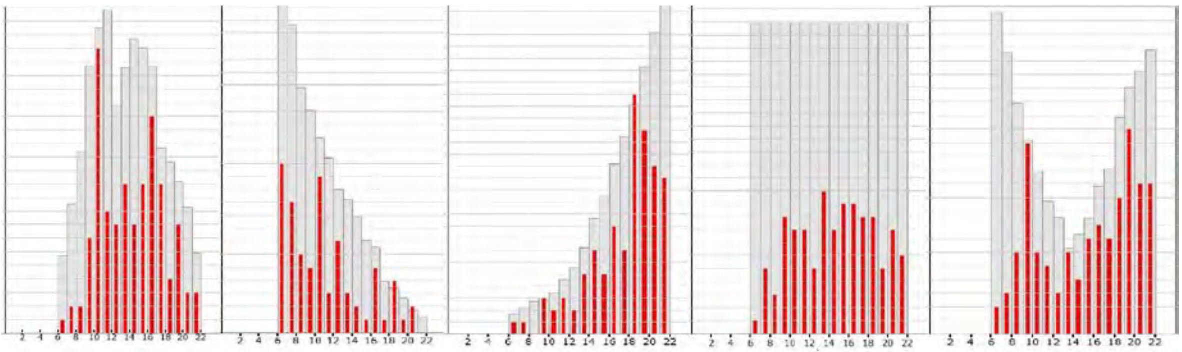


Fig. 4 Process Flow

RESULTS

The model is run for 50 replications in the steady state with a one week length for each replication, and the performance statistics are collected for each pattern as illustrated in (Table 2.).



(a) (b) (c) (d) (e)

Fig. 5 Arrival Patterns: (a) Default Arrival, (b) Decreasing Arrival, (c) Increasing Arrival, (d) Uniform Arrival , and (e) Distributed-Peak Arrival

The performance metrics studied are the average TTT, minimum and maximum TTT, and maximum queue length at the gate. The average truck turn time exhibited different values for each pattern. Uniform arrivals exhibited the minimum value of TTT among all patterns. The decreasing arrival pattern had the maximum TTT of about 6 hrs. As noticed from the results, the average gate throughput is kept at the same level. This means that the arrival pattern can be used to reduce the TTT without limiting truck arrivals or reducing terminal productivity.

Table 2: Simulation Results

Performance metrics	Def.	Inc.	Dec.	Uni.	Dist.
Average TTT (min)	29.3	48.8	55.1	**20.5**	25.1
Min TTT (min)	11.4	11.4	11.3	11.4	11.3
Max TTT (min)	266.5	417.2	361.6	198.9	200.4
Max Queue length (trucks)	26	41	35	19	19
Average Gate throughput/week	398	398	398	398	398
Variance of gate throughput/week	80.4	71.3	69.2	71.6	67.7

From the results, the uniform arrival pattern exhibited the lowest average of TTT. A t-test with 0.05 significance level is conducted to compare the TTT averages for the uniform pattern and distributed- peak pattern. The t-test results showed that the average TTT of the uniform arrival is significantly less than the distributed-peak arrival's average. Based on this result, the simulation work is extended to obtain the best arrival schedule per each hour. To do that, 10 replications for the uniform arrivals are performed and the scheduled arrivals for each hour of the working day is recorded. Fig. 6 shows the average numbers of trucks which are expected to achieve the minimum truck turn time and max gate throughput. Using truck schedules, the terminal operators can design an appointment system which avoids the congestions and long queues at the gates.

CONCLUSIONS AND FUTURE WORK

Truck delays are a common problem in container terminals. Long truck queues affect the efficiency of seaports and cause congestion problem at gates and yards. To reduce the turn time of external trucks, one needs to dig for factors that influence these delays. One of the most important factors is the arrival pattern of the trucks. In this paper a simple DES model is developed to show how the effect of the arrival patterns on the truck turn time and gate congestion can be studied. The results showed that shorter delays at CTs could be achieved without reducing number of truck arrivals or increasing the terminal resources. Moreover, simulation can help in designing the appointment systems in CTs.

For future work, we intend to study truck delays at Alexandria seaport in Egypt and introduce some strategies to obtain the optimum arrival patterns for truck arrivals. In addition, the appointment system shall consider the stochastic nature of inter-arrival times and other important factors.

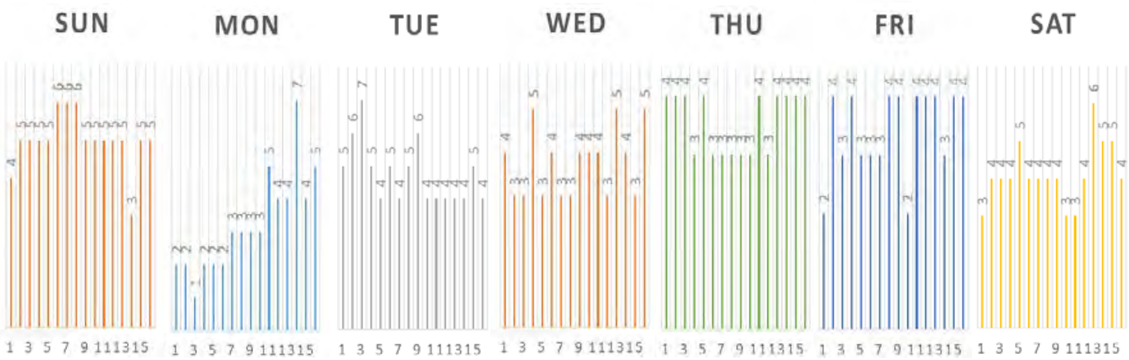


Fig. 6 Scheduled arrival during the week according to a uniform arrival pattern for 16 working hours/day

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