

# MATHEMATICAL MODEL FOR SYSTEM RELIABILITY OF CARGO PACKING WAITING TIME FOR TRANSPORTATION

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## ABSTRACT

*This study deals with the development of a mathematical model for predicting the system reliability of the cargo packing waiting time of for a station for an automated machining system with various spares subject to failures. Transportation system is characterized by its comparatively long headway and fixed schedules that most of the cargo packing have been well aware of it. A numerical method using Simpson's Rule was selected as a method to address the problem of multiple integration resulting from the Weibull distribution in the spares model. A recursive algorithm was developed for predicting the system reliability of the cutting tools. This study demonstrates the application of the developed system reliability with the interrupted cutting process.*

**Keyword:** system reliability, waiting time, transportation model and queuing model.

## INTRODUCTION

The idea of integrating cargo packing has appeared as a result of considering seriously reducing the costs of cargo packing. A multimodal transport chain required the time for cargo loading and unloading. From the commercial point of view, a container is the most successful unit for integrating cargo packing. Consequently, the container fleet and container ships are the most important means of transportation in the international cargo traffic.

In the case of a container shipping line, carriers establish regular services and adjust their characteristics like route, intermediary stops, frequency, vehicle type, capacity etc. to satisfy the expectations of the largest number of customers possible. Externally, the carrier then proposes a series of services, often grouped in a schedule that indicates departure and arrival times at the stops of the route. Internally, the carrier builds a series of rules and policies that affect the whole system and are often collected in an operational plan.

In practice, cargoes are moved in containers that usually come in approximately twenty different equipment types and sizes (ETS). Containers are available in a variety of heights and can have other special characteristics that differentiate them, such as controlled atmosphere. Reference [3]

gives a complete list of ETS. Once containers are filled, they are then assembled for transportation purpose into container ships. A modern container vessel can carry up to almost 6000 TEUs at one time.

This study aims to develop a mathematical model to analyze the behaviors of cargoes for transportation in the international cargo traffic. For the liner operators, containers are a classic example of a commodity. Competition is thus vigorous because the service provided is usually very similar for all the liner companies. Prices are as a result low and margins very slim. Understanding the real cost of every operation and choosing the right policies can make the difference between failure and success for a containership liner. Due to the imbalance of the international trading, some areas are export dominant and some are import dominant.

## MATHEMATICAL MODEL

There are three planning levels: strategic, tactical and operational. Tactical planning aims to ensure, over a medium term horizon, an efficient and rational allocation of existing resources in order to improve the performance of the whole system. The main decisions made at the tactical level are service network design, traffic distribution, terminal policies, empty balancing and crew and motive power scheduling. Traffic distribution concerns the itineraries (routes) used to move the traffic of each demand and empty balancing determines how to reposition empty containers to meet the forecast needs of the next planning period. Container deployment problem is the combination of traffic distribution and empty balancing, which focus on how to maximize the total profit in a specific planning horizon, and at the same time, to make best use of the existing facilities. The aim is to ensure that the proposed services are performed as stated and demands are satisfied, while operating in a rational, efficient, and profitable way. A Schematic diagram of the service network is shown in figure 1.

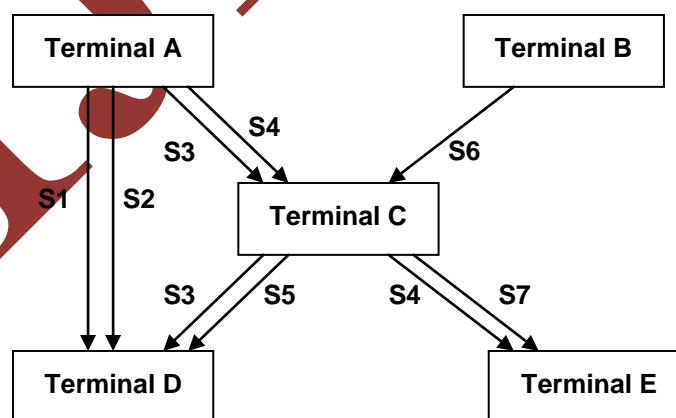


Fig. 1 schematic diagram of Service network

There are five terminals make up this network and seven services can be offered: five direct services (S1, S2, S5, S6 and S7) and two services with intermediary stops (S3 and S4). The figure does not indicate any physical route, services S1, S2, S3, S4 and S5 can make up six physical routes, i.e., {S1}, {S2}, {S3}, {S3, S5}, {S4, S3} and {S4, S5}, their differences being only at the level of their respective speeds and intermediary stops. Shipping company will choose route set according to their own policy.

Let  $G = (N, A)$  represent the physical service network. Vertices of  $N$  represent the terminals and the set  $A$  is the set of links representing the connections between terminals. The transportation demand is defined in terms of number of containers of a certain ETS  $e$  to be moved from an origin node  $o \in N$  to a destination  $d \in N$ . To simplify, we refer to the market or traffic-class  $f = (o, d, e)$  with a positive transportation demand  $d_f$ . It should be noticed here that  $d_f$  is a forecasting demand which means not all the demands are necessary to be satisfied. For the purpose of this report empty container reposition will be treated as another kind of commodity or demand. Thus empty balancing problem can be dealt in a uniform formulation.

### 1. Formulation: Deterministic Single Period Model

Given the deterministic set:

- N:** vertex set, or the set of terminals.
- A:** link set, which represents the connections between terminals.
- F:** traffic-class set indexed by  $f$ , or set of forecasting demands, including laden and empty containers.
- R:** a set of candidate routes considered by the shipping company, indexed by  $r$ .
- R<sub>f</sub>:** subset of  $R$ , which represents the valid routes for traffic-class  $f \in F$ .
- S:** a set of services provided by fleet, indexed by  $s$ .
- E:** a set of available equipment type and size, indexed by  $e$ .

The decision variable is defined as follows:

$x_{f,r}$ : The number of containers with traffic-class  $f$  shipped on route  $r$ , where  $f \in F$  and  $r \in R$ .

The liner programming model is then stated with the following objective function and constraints:

$$\max . \quad \sum_{f \in F} \sum_{r \in R_f} (\rho_f - K_{f,r}) x_{f,r} \quad \dots(1)$$

Where  $\rho_f$  is the expected revenue per container from transporting traffic-class  $f$  and  $K_{f,r}$  is the dynamic cost we discussed before. As you can see from equation 1, we aim to maximize the total service network revenue. The constraints listed below are not the ones imposed by carriers, but pertain to the demand requirement, ship's capacity and terminal's capacity and so on.

We know that the cargo demands can be selected to move or not, which is up to the profit contribution to the whole system. But anyway, for each traffic-class, the total number of cargo moved should not be larger than the forecasting number. This constraint can be expressed as:

$$\sum_{r \in R_f} x_{f,r} \leq d_f \quad \forall f \in F \quad \dots(2)$$

where  $d_f$  is a positive transportation demand.

From the view of commercial operation, maintaining empty routes or moving little containers on some routes are both uneconomical and must be avoided. The following constraint provides a method.

$$\sum_{f \in F} x_{f,r} \geq p_r \quad \forall r \in R \quad \dots(3)$$

where  $p_r$  is the minimum number of containers required on route  $r$ .

There are two kinds of capacities, i.e., leg capacity and terminal capacity. The leg capacity constraint states that the total flow on link  $(i, j)$  cannot exceed its capacities. Such capacities include volume capacity and weight capacity. Before we introduce the leg capacity, however, we need to define a parameter firstly.

*Define:*  $\alpha_{i,j}^{r,f} = 1$  if arc  $(i, j)$  belongs to the route  $r$  for traffic-class  $f$  where  $r \in R_f$ , otherwise  $\alpha_{i,j}^{r,f} = 0$ . Then we have  $\sum_{r \in R_f} x_{f,r} \alpha_{i,j}^{r,f}$  which means the total traffic flow of  $f$  on the arc  $(i, j)$ . Then

leg capacities can be expressed as:

$$\sum_{f \in F} \sum_{r \in R_f} \delta_f x_{f,r} \alpha_{i,j}^{r,f} \leq u_{i,j} \quad \forall (i, j) \in A \quad \dots(4)$$

$$\sum_{f \in F} \sum_{r \in R_f} \varepsilon_f x_{f,r} \alpha_{i,j}^{r,f} \leq v_{i,j} \quad \forall (i, j) \in A \quad \dots(5)$$

Constraint 4 states the volume capacity whereas Eq. 5 expresses the weight capacity. Here  $u_{i,j}$  and  $v_{i,j}$  represent the total space and weight capacity of service leg  $(i, j)$  respectively.  $\delta_f$  is volume required by a container with traffic-class  $f$  in TEUs.  $\varepsilon_f$  is weight required by a container with traffic-class  $f$  in Tons.

The terminal capacity constraint, however, is not so easy to express. As we know, for most of terminals, the total number of available lift is limited. In practice, different vessel service  $s$  will be given different customer service level, in terms of the maximum number of containers moved, at terminal  $i \in N$ . Consequently we can define terminal capacity using this customer service level, denoted as  $w_{i,s}$  for the combination of terminal  $i$  and service  $s$ . Note container movement includes loading and discharging. Thus the problem is when such loading and discharging operations are needed and then we can calculate the total number of containers moved. There are three cases under which loading or unloading operations occur: terminal  $i$  is the loading port for traffic-class  $f$ , i.e.,  $o = i$ ; terminal  $i$  is the unloading port for traffic-class  $f$ ,

i.e.,  $d = i$  and traffic-class  $f$  needs to transfer from service  $s$  to other service  $s$  (or from service  $s$  to  $s$ ).

Now let's define the following notations and parameters.

$F_i^o$  :  $\{f | f \in F \text{ and } o = i\}$ , set of traffic-classes whose origin is port  $i$ .

$F_i^d$  :  $\{f | f \in F \text{ and } d = i\}$ , set of traffic-classes whose destination is port  $i$ .

$F_i$  : set of traffic-classes, for which port  $i$  is neither an origin nor a destination.

$\beta_{i,s}^{r,f} = 1$  if service  $s$  comes in port  $i$  and  $(i, s)$  belongs to the route  $r$  for traffic-class  $f$ , where  $r \in R_f$ , otherwise  $\beta_{i,s}^{r,f} = 0$ . See Fig. 3 (b).

$\gamma_{i,s}^{r,f} = 1$  if service  $s$  leaves from port  $i$  and  $(i, s)$  belongs to the route  $r$  for traffic-class  $f$ , where  $r \in R_f$ , otherwise  $\gamma_{i,s}^{r,f} = 0$ . See Fig. 3 (a).

$\lambda_{i,s}^{r,f} = 1$  if there exists service transformation at port  $i$  and  $(i, s)$  belongs to the route  $r$  for traffic-class  $f$ , where  $r \in R_f$ , otherwise  $\lambda_{i,s}^{r,f} = 0$ . See Fig. 3 (c). Here  $\lambda_{i,s}^{r,f} = 1 - \beta_{i,s}^{r,f} \cdot \gamma_{i,s}^{r,f}$  because  $\beta_{i,s}^{r,f} \cdot \gamma_{i,s}^{r,f} = 1$  means service  $s$  passes the port  $i$ .

Based on these definitions, now we can write terminal capacity constraint as:

$$\sum_{f \in F_i^o} \sum_{r \in R_f} x_{f,r} \gamma_{i,s}^{r,f} + \sum_{f \in F_i^d} \sum_{r \in R_f} x_{f,r} \beta_{i,s}^{r,f} + \sum_{f \in F_i} \sum_{r \in R_f} x_{f,r} \lambda_{i,s}^{r,f} \leq \sigma \cdot w_{i,s} \quad \forall i \in N, \forall s \in S \quad \dots(6)$$

where  $\sigma$  is adjustment factor because of the extra container movements during loading and unloading operations.

The flow within the service network is different kinds of containers. Thus, for a certain equipment type and size, the number of containers flowing into a node should be equal to the number of containers flowing out. This is expressed as network balance constraint.

$$\sum_{j \in N} \sum_{f \in F_e} \sum_{r \in R_f} x_{f,r} \alpha_{i,j}^{r,f} + \sum_{\substack{f \in F_i^d \\ f \in F_e}} \sum_{r \in R_f} x_{f,r} = \sum_{j \in N} \sum_{f \in F_e} \sum_{r \in R_f} x_{f,r} \alpha_{j,i}^{r,f} + \sum_{\substack{f \in F_i^o \\ f \in F_e}} \sum_{r \in R_f} x_{f,r} \quad \forall i \in N, \forall e \in E \quad \dots (7)$$

where  $F_e$  is the set of traffic-classes which utilize containers with equipment type/size  $e$ . Here

$\sum_{f \in F_e} \sum_{r \in R_f} x_{f,r} \alpha_{i,j}^{r,f}$  states the total flows with ETS  $e$  on link  $(i, j)$ .

$$x_{f,r} \geq 0 \quad \forall f \in F, \forall r \in R \quad \dots(8)$$

## CONCLUSIONS

The numerical results identify that mean waiting time of intercity transit passengers is greater than half of the intercity transit headway, when the feeder service is provided with poor reliability per second and on the contrary, mean waiting time will be less than half of the intercity transit headway when a reliable feeder service is provided. Moreover, for any negative

factors in entire service, the scheduled passengers always damaged more. In order to avoid long waiting time for total passengers, headway deviation of feeder buses should be less than 3.5 minutes. In terms of intercity transit capacity, it is suggested that at least 80 % of total arrival passengers should be satisfied. The result of this study provides planners with analytic model for accurately quantifying the relations between passenger waiting time of intercity transit system (e.g., high speed rail, commuter rail, and bus) and reliability of feeder bus services.

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