Analyzing Railway Service Network for Containers Transportation without Tracing System

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***Abstract*—The containers transportation becomes more and more important in the freight traffic, so, the best organization of their transportation can influent goods price.The current study focuses on railway service network optimization under considering the moving of containers from one point to other. The main contribution of this paper is to construct optimal railway service network for containers transportation system taking account railway traffic organization. The main objective function minimizes total logistic cost of transported containers, while the constraints of containers redistribution, constraints of trains' capacity and constraints of railway station capacity will be also analyzed. Finally train stopping plan which defines and limit auxiliaries operation during the main transportation i.e. between forming station and sorting station will be constructed using the 0-1 variables.**

***Index Terms*—containerization, tracing system, logistic costs, non tracing system**

I. Introduction

In recent years, the containerization plays an important role in the freight transportation and occupies more and more place in the transportation research. Due to the several advantages of containers, containerization allows the transportation of goods at the door of one customer to door of others. We say that, it allows the door – to – door transportation. However, the containerization of goods has an economic impact on price of goods. Many imported and exported goods are containerized.

The *containerization* is defined as the using of the box called containers in the domestic or the international transportation. This containerization facilitates the transfer of goods from one mode to other mode due to the standardization of the box. In recent years, we observe the development of containerization due to its advantages. The *tracing system* is a method which gives the position and the Origin and Destination (O-D) of each entered container in the network i.e. the position of any container that is in the network may be know due to the system that shows all information on it. Analogically,*the non tracing system* represents the method that doesn't define the O-D of containers but that shows only the departure node and the arrival node of containers during the operating period.

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The *logistics costs* are the costs that intervene during the process of transportation of containers. These costs must be minimized due to the economic and social factors. The high logistic costs have an impact on final price of goods.

Several literatures have focused on railway network design, containers and freight transportation. Reference [1] focused their study on the intermodal model which minimizes total cost established by [2]. They have applied the Dijstra algorithm to solve intermodal transportation problem. Reference [3] developed an integer programming model to optimize operational costs of the rail segment of containers intermodal transportation with objective to minimize total operational cost using the delivery time constraints, inventory constraints for each origin and the hub, train capacity and railway line capacity constraints. These model cannot be used to solve more complicated problem, while [4] studied the effect of planning horizon length on empty containers management for intermodal transportation network based on an integer program that seeks to minimize total costs related to moving empty containers and they have concluded that the long planning horizon can encourage the use of inexpensive, slow transportation modes, such as barge. Reference [5] have presented transshipment of containers at a containers terminal and have proposed the using of simultaneous scheduling of jobs at automated stacking cranes (ASC) and the Automated Guided Vehicles (AGV) while [6] have studied alternative bundling strategies for containers barge transport in the port of Antwerp and have shown that all scenarios give efficiency improvements in the handling of barge at sea terminals and their study didn't use other railway operations. Reference [7] Studied a comparative evaluation of existing and innovative rail-road freight transport terminal. Ref. [8] studied Rail-Sea Intermodal Transportation Volume Forecast Method Based on Assignment of Hinterland Containers using the multinomial logit model as optimization process and the results have shown that the market is firstly sensitively on the cost and secondly on the time and service quality; [9]focused their research on logistics scheduling to minimize inventory and transport cost with objective to minimize the sum of work-in-process (WIP) inventory cost and transport cost which includes supply and delivery costs. They have used a polynomial – time algorithms to solve several special

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cases. Their study didn't integrate production while a logistic scheduling model must integrate supply, production and delivery; [10] Studied Modeling of transport costs and logistics for on-farm milk segregation in New Zealand dairying using genetic algorithm to search an optimal solution for the farm milk collection pick-ups. Their study recommends the use of same goods for the truck but this method may also require more need of trucks. Reference [11] have focused their study on an reverse logistics model into in-plant recycling process using linear optimization model for calculating minimum annual transport costs and optimal way for efficient transport; [12] have focused their research on a multiple-method analysis of logistics costs. The main goal is to examine the differences and the interdependencies in the logistics cost components and in the total logistics costs. Ref. [13] Studied a strategic network choice model for global container flows in order to analyze possible shifts in future container transport demand and the impacts of transport policies. Their results have shown that it is able to predict quite well the yearly container flows to and from all countries using major and minor container ports around the world and the results provide us with interesting insights into port choice and the using of long distance railway connection between Europe and China.

In the area railway network design, [14] investigated freight train connection service of large-scale railway system using simulated annealing (SA) method. Their study showed that the SA method allows to minimize the cost of accumulation delay and reclassification delay, while, Optimization model for resorting capacity of marshalling station with proportion of direct trains has been studied by [15]. An algorithm using an emerging technique known as very large-scale neighborhood (VLSN) search is developed by [16], [17] studied the several real-life transportation scheduling problems such as locomotive, railroad blocking problems. A model of railway master scheduling problem with objective to calculate network value as a linear combination of variable train paths was studied by [18].

The remainder of this paper is organized as follow: Section 2 describes model and specifies the used parameters and decision variables, while Section 3 shows its formulation and required constraints. The new simplified model is specified in Section 4. The research conclusion and future research orientation are developed in Section 5.

II. Model Description

The current model minimizes total logistic costs and ensures railway network organization. Arrival containers must be sent to their destination directly or through train forming station and/or sorting station (see Fig. 1). After forming operation the containers may be sent to their destination or to sorting station S. This model takes account the start and the following destination of containers. We assume that each arrived containers at origin i has to choice between direct trip i-j, i-F-j, i-F-S-j and i-S-j.

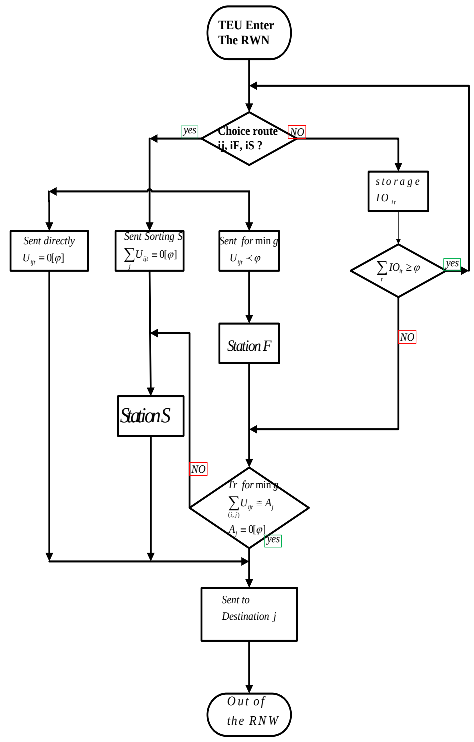

Figure. 1. Process of containers operations in the simple railway network

According to Fig. 2, the following parameters and decisions variables will be used:

- UAO_{ijt} is the total number of arrived containers that must be sent from origin i to destination j during the period t and UA_{it} is the total number of containers that must be moved from origin i to several destinations j.
- U_{ijt} is the total number of containers sent directly from origin i to destination j during the operating period t;
- U_{iFt} is the total number of containers sent from origin i to train forming station F during the operating period t;
- U_{FSt} is the total number of containers moved between railway station F and S during the time period t, while U_{iSt} stands the total number of containers sent from origin i to train sorting station S during the time period t;
- U_{Sjt} is the total number of containers moved from station S to destination j during the time period t, while, U_{Fjt} stands the total number of containers moved from station F to destination j during the time period t.

All arrived containers must be transported from their origin ito their destination j and we denote C_{ij} the transportation cost of containers from origin i to destination j. Let C_i *and* C_j be respectively the cost of loading and unloading of containers at origin i and at destination j. C_F *and* C_S are respectively the train forming cost at station F and the train sorting cost at station S. A_p is the auxiliary cost intermediary station p. SC_F *and* SC_S are respectively the storage cost of containers at station F and at station S. IO_{it} , IF_t *and* IS_t are respectively the inventory amount of containers of origin i, station F and S during the time period t.

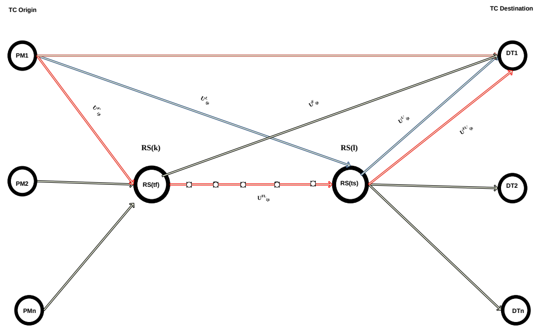

Figure 2. Sample railway network with containers flow

III. MODEL FORMULATION

The main objective of this study is to construct a new model which minimizes total logistic cost and defines railway traffic organization. For each traffic flow, we are mainly interested on the start and the following stop point of this flow i.e. containers that must be move from origin i to destination j through F will be analyzed first from i to F after, from F to j. Therefore, we assume that all arrival containers UAO_{ijt} must be transported from their origin to their destination.

The model can be expressed by the above formula:

$$\begin{aligned}\min Z = &\sum_{i=1}^{n}\sum_{j=k+1}^{m}\sum_{t=1}^{T} UAO_{ijt}\left(C_{ij}+C_i+C_j\right)\\ &+\sum_{t=1}^{T}\left[\frac{C_F}{\varphi}\left(U_{FSt}+\sum_{j=k+1}^{m}U_{Fjt}\right)+\frac{C_S}{\varphi}\left(U_{FSt}+\sum_{i=1}^{n}U_{iSt}\right)\right]\\ &+\sum_{t=1}^{T}\sum_{p=n+1}^{k}\frac{A_p}{\varphi}\left[U_{FSt}y^p_{FSt}+\sum_{j=k+1}^{m}\left(U_{ijt}y^p_{ijt}+U_{Fjt}y^p_{Fjt}\right)+\sum_{i=1}^{n}U^p_{iSt}\right]\\ &+\sum_{i=1}^{n}\sum_{t=1}^{T}ST_i IO_{it}+\sum_{t=1}^{T}ST_F IF_t+\sum_{t=1}^{T}ST_S IS_t\end{aligned} \tag{1}$$

Subject to:

$$UA_{it}+IO_{it-1}-\left(U_{iFt}+U_{iSt}+\sum_{j=k+1}^{m}U_{ijt}\right)=IO_{it}\ ,\forall\, i,t \tag{2}$$

$$\sum_{i=1}^{n}U_{iFt}+IF_{t-1}-\left(U_{FSt}+\sum_{j=k+1}^{m}U_{Fjt}\right)=IF_t\ ,\forall t,F\ \ fixed \tag{3}$$

$$U_{FSt}+\sum_{i=1}^{n}U_{iSt}+IS_{t-1}-\sum_{j=k+1}^{m}U_{Sjt}=IS_t\ ,\forall t,S\ \ fixed \tag{4}$$

$$IO_{it}\le CS_i\ ,\forall i,t;\ IO_0=0 \tag{5}$$

$$IF_t\le CS_F\ ,\forall t;\ IF_0=0 \tag{6}$$

$$IS_t\le CS_S\ ,\forall t;\ IS_0=0 \tag{7}$$

$$\sum_{t=1}^{T}U_{ijt}\le\varphi N_{ij}\ ,\forall i,j \tag{8}$$

$$\sum_{t=1}^{T}U_{iSt}\le\varphi N_{iS}\ ,\forall i \tag{9}$$

$$\sum_{t=1}^{T}U_{iFt}\le\varphi_{iF}N_{iF}\ ,\forall i \tag{10}$$

$$\sum_{t=1}^{T}U_{Fjt}\le\varphi N_{Fj}\ ,\forall j \tag{11}$$

$$\sum_{t=1}^{T}U_{Sjt}\le\varphi_{Sj}N_{Sj}\ ,\forall j \tag{12}$$

$$\sum_{t=1}^{T}U_{FSt}\le\varphi N_{FS}\ ,\forall\ F,S\ \ fixed \tag{13}$$

$$\alpha\le\sum_{p=1}^{k}y^p_{ijt}\le\beta\ ,\forall\ i,j,t \tag{14}$$

$$\alpha\le\sum_{p=1}^{k}y^p_{Fjt}\le\beta\ ,\forall\ j,t \tag{15}$$

$$\alpha\le\sum_{p=1}^{k}y^p_{iSt}\le\beta\ ,\forall\ i,t \tag{16}$$

$$\alpha\le\sum_{p=1}^{k}y^p_{FSt}\le\beta\ ,\forall\ t \tag{17}$$

$$\sum_{t=1}^{T}\left[y^p_{FSt}+\sum_{i=1}^{n}\left(y^p_{iSt}+\sum_{j=k+1}^{m}y^p_{ijt}\right)+\sum_{j=k+1}^{m}y^p_{Fjt}\right]\le M_p\ ,\forall p \tag{18}$$

$$U_{ijt},U_{iFt},U_{iSt},U_{Fjt},U_{Sjt},U_{FSt}\ \ \text{integer} \tag{19}$$

$$y^p_{ijt},y^p_{iSt},y^p_{Fjt},y^p_{FSt}\in\{0,1\}\ ,\forall i,j,t,p \tag{20}$$

The objective function (1) minimizes total logistic costs and represents in the first part, the sum of total transportation, loading and unloading cost; the second part is the sum of train formation and train sorting cost, while the firth part of this function shows the total auxiliaries costs in the route i.e. between station F and S and finally, the fourth part give total storage cost of containers at origin, station F and S.

The current model has used five types of constraints such as:

- Constraints of containers redistribution:According to these constraints all arrival containers must be redistributed the depending of railway network. So, the arrival containers at origin i must be allocated between direct transport from i to j, for train formation i.e. from i to F and for sorting i.e. from i to S. Therefore, part of containers can be not sent and this part stands the inventory part of origin i. analogically, the arrival containers at station F allows to form train that must be sent to destination j or to sorting station S. According to constraints (2) – (4),for each origin, station F and S, the sum of arrived containers and inventory part of precedence time must be equal to the sum of sent containers and current time inventory part.

- Constraints of storage capacity: For each origin, F, S, when there is an inventory part, this part cannot exceed the inventory capacity of origin F and S during the period t. The assumption is shown by constraints (5) – (7).
- Constraints of train capacity: For each link, the number of transported containers must be meet with the number of planned train. Therefore, train may be formed with containers and others freight, in this case, total transported containers cannot exceed the proportion of containers per train. Constraints (8) – (13) give the train capacity constraints and other constraints may be shown that limit network capacity.
- Constraints of train stopping plan: Containers can have an auxiliaries' operations between station F and S i.e. at the intermediaries' stations. Therefore, in order to respect delay and to reduce logistic costs, we introduce the decision variables that define train stopping plan. Each decision variable used in constraints (14) – (17) takes the value 1 if and only if train must stops at station p, otherwise it become zero. So, constraints (14) – (17) show that each group of train has a minimum number of stop $\alpha = 2$ in this study due to the halt of train at frontier stations of the two countries and the maximum number of stops β.
- Constraints of station capacity:Each railway station has a limited number of stopping trains per day.According to constraints (18), the total number of stopping trains at station p cannot exceed its capacity M_p. This constraints force train to stop when the number of provided halts of station is not reached, otherwise it must continue.

Constraints (19) specify that all containers flow in the railway network must be integer parameters, while constraints (20) show that the decision variables take only two values. The value 1 when the group of containers must stop at station p and the value zero for otherwise.

Summary:This model uses a very large number of parameters, decision variables and constraints and its programming with mathematical software Lingo 11.0 is not easy. The number of containers flow parameters is T(mn+2n+2m+1), while the number of decision variables is Tk(mn+m+n+1) where, N is the number of intermediaries stations. i.e. the index p=1,..,k. According to constraints (2) – (17), there are more than (2mnT+mn+4nT+2mT+2n+2m+6T+k+1) number of constraints. Due to the large number of constraints, we recommend to use other simplified model which aims to minimize total logistic cost using a small number of variables, parameters and constraints. In the below section, we will analyze a simplified model which considerably reduces the number of used constraints.

IV. New Model Formulation

This model analyzes the transportation of imported containers without storage cost and time planning horizon i.e. the model is built for one operating day. For this, the total number of arrived containers must be sent to other destinations. Due to model analyzes one operating day planning, there is not storage and inventory part i.e. the inventory constraints are outline.

The new model can be expressed by formula (21) – (37):

$$\min Z = \sum_{i=1}^{n}\sum_{j=k+1}^{m} UAO_{ij}\left(C_{ij}+C_i+C_j\right) + \frac{C_F}{\varphi}\left(U_{FS}+\sum_{j=k+1}^{m}U_{Fj}\right)+\frac{C_S}{\varphi}\left(U_{FS}+\sum_{i=1}^{n}U_{iS}\right) + \sum_{p=n+1}^{k}\frac{A_p}{\varphi}\left[U_{FS}y_{FS}^{p}+\sum_{j=k+1}^{m}\left(U_{ij}y_{ij}^{p}+U_{Fj}y_{Fj}^{p}\right)+\sum_{i=1}^{n}U_{iS}^{p}\right]$$

(21)**Subject to:**

$$UA_i = \left(U_{iF}+U_{iS}+\sum_{j=k+1}^{m}U_{ij}\right), \forall\, i \quad (22)$$

$$\sum_{i=1}^{n}U_{iF} = \left(U_{FS}+\sum_{j=k+1}^{m}U_{Fj}\right), F\ \ fixed \quad (23)$$

$$U_{FS}+\sum_{i=1}^{n}U_{iSt} = \sum_{j=k+1}^{m}U_{Sj}\ , \forall\ S\ \ fixed \quad (24)$$

$$U_{ij} \le \varphi N_{ij}\ , \forall i, j \quad (25)$$

$$U_{iS} \le \varphi N_{iS}\ , \forall i \quad (26)$$

$$U_{iF} \le \varphi_{iF} N_{iF}\ , \forall i \quad (27)$$

$$U_{Fj} \le \varphi N_{Fj}\ , \forall j \quad (28)$$

$$U_{Sj} \le \varphi_{Sj} N_{Sj}\ , \forall j \quad (29)$$

$$U_{FS} \le \varphi N_{FS}\ , \forall\ F, S\ \ fixed \quad (30)$$

$$\alpha \le \sum_{p=1}^{k} y_{ij}^{p} \le \beta\ , \forall\ i, j \quad (31)$$

$$\alpha \le \sum_{p=1}^{k} y_{Fj}^{p} \le \beta\ , \forall\ j \quad (32)$$

$$\alpha \le \sum_{p=1}^{k} y_{iS}^{p} \le \beta\ , \forall\ i \quad (33)$$

$$\alpha \le \sum_{p=1}^{k} y_{FS}^{p} \le \beta\ , F, S\ \ fixed \quad (34)$$

$$y_{FS}^{p}+\sum_{i=1}^{n}\left(y_{iS}^{p}+\sum_{j=k+1}^{m}y_{ij}^{p}\right)+\sum_{j=k+1}^{m}y_{Fj}^{p} \le M_p\ , \forall p \quad (35)$$

$$U_{ij}, U_{iF}, U_{iS}, U_{Fj}, U_{Sj}, U_{FS}\ \ \text{int}\,eger \quad (36)$$

$$y_{ij}^{p}, y_{iS}^{p}, y_{Fj}^{p}, y_{FS}^{p} \in \{0,1\}\ , \forall i, j, p \quad (37)$$

The objective function (21) minimizes total logistic costs that are the sum of transportation, loading and unloading cost (first part of formula); the train formation and train sorting costs (second part of formula) and the auxiliaries' costs (the last part of formula). Constraints (22) – (24) represent the containers redistribution in the network and show that the total arrived containers at each origin, station F and S must be equal to the departure containers. Constraints (25) – (30) stand the train capacity constraints and they also define the number of required train for containers transport. So, for each link, the number of containers cannot exceed the provided train capacity of this link. We construct train stopping plan with constraints (31) – (34). According to these constraints each group of containers have a bounded number of halts between station F and S. The minimum number of halts is 2 that corresponds to the frontier of two countries, while the maximum number of halts cannot exceed the value $\beta, (\beta \le k)$ here k is the total number of intermediaries' station between F and S.

Summary:This model has several advantages and is easy to program using software Lingo 11.0. Therefore, it may be not efficient as the first due to the random arrival of containers. Other factor is that, the railway capacity may be not sufficient to transport all arrival containers. The number of containers flow parameters is mn+2n+2m+1 hence, this number is T times less than the first model. The number of decision variables is k(nm+n+m+1) i.e. also T times less than the first model. The most advantage of this model is the reduction of number of constraints that stands: 2nm+4n+3m+k+4.

V. Conclusion

In this study, we have analyzed a specific case where the containers must be transported by railway network from sea port to containers destination. The main contribution stands the construction of the railway network that minimizes total logistics costs and ensures the best organization of containers transportation. The study shows that two models may be used. The first model used more parameters and decision variables. A large number of parameters and decision variables can influence the results. Due to the large number of parameters and decision variables, the using of Mathematical software Lingo is not recommended however, other programming software can be used. Other research may be done which analyzes this problem as multimodal transportation problem where there are three transportation areas. Supply area cover running distance from each origin to interchange terminal F, the second area stands main transport from terminal F to terminal S and the last area becomes the zone from terminal S to freight destination. In this case, on some part of transportation may be operated railway service and/or highway service network.

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