APPLICATION OF MULTISETS FOR INTERMODAL TERMINALS DESIGN

Mariusz KOSTRZEWSKI, Arkadiusz KOSTRZEWSKI

Warsaw University of Technology, Warsaw, Poland, EU, markos@wt.pw.edu.pl

Abstract

Arrangement of cargo tracks in the form of a railway siding system is one of key elements of intermodal terminals infrastructure, no matter whether it is connected to maritime or inland terminals. Several studies were presented in the literature review connected to the aspect of mentioned railway siding system. Authors of the paper present new approach to the problem with taking into account multisets which are modification of the concept of sets, well known from sets theory. The paper consists of literature review and references to literature that have made the realistic conditions of the analytical model. The paper also contains the analytical model and its description (this is the significant part of this paper), a brief reference to the implementation of analytical model into software and a computing example with use of mentioned software.

Keywords: Intermodal terminal, multiset, analytical model

1. INTRODUCTION

Intermodal terminals are believed to be one of last-mile infrastructure types. All of these types according to [1] are: private and public sidings, rail logistics centres and at least intermodal terminals which actually consists of *inter alia* track system with cargo lanes (railway sidings as such). Intermodal terminals, according to [1], are designed for transhipment of standardized loading units called as intermodal loading units which are operated between at least two modes of transport (intermodal - „involving two or more different modes of transport in conveying goods", terminal - „the end of a railway or other transport route, or a station at such a point", both quotes: [2,3]). Within standardised loading units e.g. containers, swap bodies and trailers are highlighted. From the railway infrastructure perspective intermodal terminals consist of:

- a transhipment area with loading tracks, loading/driving lanes for railroad means of transport (such as trucks) and areas for short term storage of intermodal loading units,
- tracks for rail operation (train arrival/departure, train splitting/composing, wagon parking etc.).

Intermodal terminals are sometimes treated as private sidings [1]. „Private sidings are privately owned and operated pieces of rail infrastructure, connecting loading facilities (which are not part of the rail infrastructure) to the public rail network", [1]. On the contrary, „public siding category contains public accessible loading tracks, mostly located directly in public railway stations and owned by the respective infrastructure manager", [1]. The infrastructure of public ones in most of cases represents historical status - it consists of short tracks rather the long ones, it is designed mostly for single wagon traffic, enriched by a loading lane and a side or a head ramp [1]. This kind of public tracks are very rare nowadays. In general, railway siding according to [4] is „a railway track designated by the infrastructure manager, connected directly or indirectly to the railway line, used to perform loading, maintenance or parking of railway vehicles or to move and incorporate railway vehicles into traffic on the railway network".

The existing rail infrastructure of that kind might be classified according to a proposal given in [1,5]: small sidings with total track length ≤ 300 m, medium sidings with total track length > 300 m and ≤ 1 500 m, large sidings with total track length > 1 500 m. In the case of intermodal terminals length of one track lane is c.a. 600 m or c.a. 800 m (depending on an information source), therefore it might be concluded that tracks in intermodal terminals are of medium length (and that is one of assumptions made in this paper).

Rail Transport Act [4] defines freight terminal as „a building structure or group of building structures including a railroad, equipped with loading equipment that enables loading or unloading of wagons or the integration of different modes of transport for carriage of goods". Intermodal terminals (defined and discussed in [6]) belongs to freight terminals. Intermodal terminal consists, *inter alia*, of a track system consisting of railway sidings. As it was mentioned, even in [1], this kind of terminal is considered sometimes as private siding. However, in order to avoid confusion, tracks of such kind would be called in this paper as (un)loading tracks.

In Federal Republic of Germany there are 154 intermodal terminals, whereas in Czech Republic: 21, in Slovak Republic: 11 (see: [7,8]) and in Republic of Poland there are 4 only, [1]. This is one of the reasons that design methods for intermodal terminals should be ready and approachable for hopefully, the changes taking place in order to increase the number of terminals in the Central-Eastern countries of Europe. Even such highly developed railway infrastructure for intermodal transport as in Switzerland need changes - these are described in [9]. According to trends analysts, the number of intermodal terminals may be increased by 5 % compared to 2015 which means 767 whereas in 2015 it was 730, [1]. This is one of the reasons why it is still worth undertaking the subject of intermodal terminals design.

In the literature different design procedures can be found. Lee et al. [10] present the most cumulated one, however authors describe also simulation studies connected to intermodal terminal design. It is important part of research since it allows to obtain *what-if* analyses. Other authors also use simulation models for intermodal terminals, e.g. [11] after [12]. Nevertheless, before making simulation model, the conceptual one is essential to be elaborated. For this purpose analytical model is worth considering, therefore presentation of analytical model is the main aspect of the paper. Numerical model is also briefly described, however it is presented mainly in order to signalise the work related to the construction of a full numerical model which is prepared in order to support a new method of intermodal terminals design. This contribution leads to description on chosen part of the conception. In the form of analytical model it shows the way of gaining the shortest train for predefined quantities of containers of different types, and a track length which enables convenient loading/unloading of containers on/from a train.

2. ANALYTICAL MODEL

As a first step of intermodal terminals design procedure, intermodal loading units should be identified. Almost all types of intermodal transport units are included in the analytical model, but this is not always necessary for real intermodal terminal design, so that certain types of intermodal loading units may be omitted for the application described in this contribution. That is why only containers are included later on in this paper.

Following parameters are predefined and described as equations (1-8): $\boldsymbol{J}$ - a set of numbers of all intermodal loading units operated in intermodal terminal, $\boldsymbol{K}$ - a set of numbers of all large universal containers operated in intermodal terminal, $\boldsymbol{NW}$ - a set of numbers of swap bodies served in intermodal terminal, $\boldsymbol{NS}$ - a set of numbers of semi-trailers operated in intermodal terminal, $\boldsymbol{ZD}$ - a set of numbers of road sets operated in intermodal terminal (the last three sets are omitted from further consideration), $\boldsymbol{T}$ - a set of large universal containers' types, $\boldsymbol{I}$ - a two-element set of information on a fact whether an intermodal loading unit is empty (*p*) or loaded (*ł*), $\boldsymbol{O}$ - a three-element set of information on a fact whether an intermodal loading unit is subject to a consignment/departure (*in*), arrival (*out*) or in transit (*tr*) operation.

$$\boldsymbol{K} \cup \boldsymbol{NW} \cup \boldsymbol{NS} \cup \boldsymbol{ZD} \subset \boldsymbol{J} \quad (1)$$

$$\boldsymbol{K} \subset \boldsymbol{J} \quad (2)$$

$$\boldsymbol{NW} \subset \boldsymbol{J} \quad (3)$$

$$\boldsymbol{NS} \subset \boldsymbol{J} \quad (4)$$

$$\boldsymbol{ZD} \subset \boldsymbol{J} \tag{5}$$

$$\boldsymbol{T} = \{t : t = A, t = B, t = C, t = E\} \tag{6}$$

$$\boldsymbol{I} = \{i : i = \ell, i = p\} \tag{7}$$

$$\boldsymbol{O} = \{o : o = in, o = out, o = tr\} \tag{8}$$

A list of quantities of large universal containers of type (*t*), empty (*p*) or loaded (*ℓ*), operated on departure (*out*), arrival (*in*) or transit (*tr*) is given in **Table 1**. These quantities are defined as equations (9)-(11).

$$k : \boldsymbol{T} \times \boldsymbol{I} \times \boldsymbol{O} \to \boldsymbol{K} \tag{9}$$

$$k(t, i, o) \in N^{+} + \{0\} \tag{10}$$

$$\boldsymbol{K} = \left\{ k(t,i,o) : k(t,i,o) = \begin{Bmatrix} k(A,\ell,out), k(A,p,out), k(A,\ell,in), k(A,p,in), k(A,\ell,tr), k(A,p,tr), \\ k(B,\ell,out), k(B,p,out), k(B,\ell,in), k(B,p,in), k(B,\ell,tr), k(B,p,tr), \\ k(C,\ell,out), k(C,p,out), k(C,\ell,in), k(C,p,in), k(C,\ell,tr), k(C,p,tr), \\ k(E,\ell,out), k(E,p,out), k(E,\ell,in), k(E,p,in), k(E,\ell,tr), k(E,p,tr) \end{Bmatrix} \right\} \tag{11}$$

The analytical model is presented in details for the operations on containers. Quantities in some calculations are described by additional parameters, as additional parameters will be necessary to calculate the length and number of tracks in a layout of cargo tracks. In the symbols of quantities of large universal containers of a given type (*t*), empty (*p*) or loaded (*ℓ*), operated on departure (*out*), arrival (*in*) or transit (*tr*), the parameter *d* has been additionally taken into account, as previously announced, in order to highlight the number of containers of a given length according to *t*-type in the arrangement of containers *d* and this parameter has been determined by the symbol $k(t,i,o,d)$. Additionally, an equation (12) has been introduced, where $\boldsymbol{A}$ is a set of wagons quantities used for transportation of containers, and where *m* is the type of container wagon.

$$\boldsymbol{A} = \{a_m : a_m, m = 1 \ldots M\},\ a_m \in N^{+} + \{0\} \tag{12}$$

In addition, one of types of wagons of the same length as an equivalent wagon length expressed in TEU is marked by symbol a_0. A number of containers of a given length and other parameters are included $k(t,i,o,1) \ldots k(t,i,o,d)$. They are operated on wagons belonging to set $\boldsymbol{A}$. Additional definitions are introduced for further calculations. These are the definition of container arrangement, multiset and other.

Def. *Multiset* - a generalisation of the concept of a set in which, unlike classical sets, one element may occur many times. However, no order of elements is given and this multiset differs from an ordered collection of fixed values, [13].

Def. *Cardinality of* $\boldsymbol{A}$ *set* is the number of elements of this set marked as $|\boldsymbol{A}|$.

Def. *The arrangement of containers along the train* with *n* number of different types of containers identical to the contents of the set $\boldsymbol{K}$ is any multiset created from the elements of the set of containers. For example, the sub-arrangement of containers is A-C-C on a given wagon means placing three containers on one wagon - one container of type A and two containers of types C. This arrangement is considered to be a multiset because of the double occurrence of the element „container of type C". Consideration of a single arrangement of containers (sub-arrangement) can therefore be treated as consideration of a single wagon. Certainly, within the same wagon different containers positioning (arrangement) can be considered.

Def. *Free space in a given sub-arrangement d* of containers consisting of *n* containers of a given length is marked as g_{Dd} and it is defined according to equation (13). The part of the equation (13) $(k(t,i,o,1)+\ldots+k(t,i,o,d)+\ldots+k(t,i,o,D))$ is equal to length of a given sub-arrangement *d*.

$$g_{Dd} = a_0 - (k(t,i,o,1)+\ldots+k(t,i,o,d)+\ldots+k(t,i,o,D)),\ g_{Dd} \geq 0,\ d = \{1\ldots D\} \tag{13}$$

Table 1 List of quantities of large containers of a given type (*t*), empty (*p*) or loaded (*ł*), operated on departure (*out*), arrival (*in*) or transit (*tr*); given with values used for computing example

Element	**Departure (containers)**		**Arrival (containers)**		**Transit (containers)**
t	$k(t,ł,out)$	$k(t,p,out)$	$k(t,ł,in)$	$k(t,p,in)$	$k(t,ł,tr)+k(t,p,tr)$
A	10	0	0	0	0
B	70	0	0	0	0
C	10	0	0	0	0
E	0	0	0	0	0

Def. *The distribution of containers along the train* is called a multiset, which consists of any subset of all container arrangements and all container sub-arrangements. Therefore, the distribution of containers along the train is e.g. (A-C-C)+(B-C)+(C-C-C) which means that these containers are transported in the arrangement of three wagons in the following sub-arrangements: on the first wagon three containers - one of type A and two of type C, on the second wagon two containers - one of type B and one of type C, and on the third wagon three containers of type C are placed.

Def. *An implementable distribution of containers along the train* is one where, for a given set of containers, all the arrangements of the considered distribution are feasible, and each container of the multiset under consideration is positioned at least once in any of the arrangement of the particular distribution of the containers along the train.

It is still necessary to determine the equation for calculation of required number of wagons with a fixed distribution of containers along the train. If there are *m* different types of wagons in quantities a_{dm} and the implementable distribution of containers *R*, in order to calculate how many wagons are needed to transport a given number of containers in a given distribution, the equation (14) is used, where there are *D* of different (sub-)arrangements included in the *R*-distribution, D_d is the *d*-th (sub-) arrangement, D_d^t is a sub-multiset of the *d*-th (sub-)arrangement containing only the *t*-type of containers and $\left|D_d^t\right|$ is cardinality of this multiset.

As it can be seen in equation (14), there is a division by zero - therefore additional restrictions are set as indicated below. Parameter a_{dt} denotes the number of *t*-type of containers when calculating the *d*-th arrangement. Subsequent ones are counted iteratively: $a_{(d+1)t} = a_{dt} - D_d^t \min\left(\left\lfloor \frac{a_{d1}}{\left|D_d^1\right|} \right\rfloor;\ldots;\left\lfloor \frac{a_{Dt}}{\left|D_D^t\right|} \right\rfloor\right)$.

Parameter a_R is the quantity of wagons needed for a given implementable *R*-distribution.

As it can be seen, the quantity of wagons depends on the order in which the container systems are selected for the calculation. For this reason, in order to unify the results, first the arrangements are set up from the one with the smallest amount of free space to the one with the largest one, and in this order they are substituted to the dependence.

$$a_R = \left. \left(k(t,i,o,1)\cdot\left|D_1^1\right| + \ldots + k(t,i,o,D)\cdot\left|D_1^t\right| + g_{D1}\right)\cdot \min\left(\left\lfloor\frac{a_{11}}{\left|D_1^1\right|}\right\rfloor;\ldots;\left\lfloor\frac{aDt}{\left|D_D^t\right|}\right\rfloor\right) \middle/ a_0 \right. +$$

$$+ \ldots + \left. \left(k(t,i,o,1)\cdot\left|D_D^1\right| + \ldots + k(t,i,o,D)\cdot\left|D_D^t\right| + g_{DD}\right)\cdot \min\left(\left\lfloor\frac{a_{d1}}{\left|D_1^1\right|}\right\rfloor;\ldots;\left\lfloor\frac{aDt}{\left|D_D^t\right|}\right\rfloor\right) \middle/ a_0 \right. \tag{14}$$

$$a_R \to \min$$

where $D_d^t > 0$, $g_{Dd} \geq 0$, $d = \{1\ldots D\}$, $d_0 > 0$, $t = \{1\ldots T\}$.

In an intermodal terminal, loading units transported by railways are operated and therefore it is required to design a system of cargo tracks (loading tracks) in the form of a railway sidings with certain lengths of parallel tracks. The required layout of the loading tracks should accommodate entire train composition. Based on previous considerations, it can be concluded that the track length l_t (length of cargo front) is described by the equation (15). If this length is greater than d_l = 800 [m] (standard adopted in currently designed logistics facilities of this type), then the equation (16) allows to determine a number of tracks on the railway siding l_b is applied. If the length of l_t is less than 800 [m] then the number of railway sidings is 1.

$$l_t = \left(k(t,i,o,1)\cdot\left|D_1^1\right| + \ldots + k(t,i,o,D)\cdot\left|D_1^t\right| + g_{D1}\right) + \ldots + \left(k(t,i,o,1)\cdot\left|D_D^1\right| + \ldots + k(t,i,o,D)\cdot\left|D_D^t\right| + g_{DD}\right) \tag{15}$$

$$l_b = \left\lceil \frac{l_t}{dl} \right\rceil \tag{16}$$

3. IMPLEMENTATION OF ANALYTICAL MODEL

The analytical model has been implemented in the MS Office software in the Windows environment (it is also possible to use it in the Apple Mac OS environment) - the functions and procedures using the Visual Basic for Application programming language known under the acronym VBA have been used for this purpose. The choice of this tool to implement the model was made because of the advantages of using this computer package, such as: universal availability and the fact that no additional software or compilers are required. The software is not discussed here because of the limitations of the length of the paper and because of the fact that it still is developed in other aspects than described in the paper.

4. NUMERICAL EXAMPLE

When data given in **Table 1** are entered into the software, several solutions are computed by the software. There are four groups of solutions' types in this software: suboptimal, acceptable, dominant and least favorable. In the case of suboptimal solution, the shortest length of train arriving at this intermodal terminal would consist of 45 Sgns(s) wagons and would measure 883.3 m, which would mean that two loading tracks would have to be used. The most favourable container sub-arrangements on wagons would be as follows: (A-C) + (B-B) + C, (A-C) + (B-B) + (C-C), (A-C) + (B-B) + (C-C-C). For the least favourable variant, 90 Sggns(s) wagons with a total length of 2334.6 m and sub-arrangement A + B+ C would be used.

5. CONCLUSION

The paper presents an analytical model with the use of multisets and its implementation. It is only a fragment of the full method of intermodal terminals design, although it is very important because it determines the size of cargo fronts and loading track systems/arrangements in a terminal. As results briefly exposed in section 4. show, the implementation of the analytical model gives satisfactory effects. Nevertheless, the research are going to be continued. What is more, in future also road transport will be analysed with consideration of parking space for trucks etc., as in [14], and several other aspects connected to intermodal transport design would be also taken into consideration.

REFERENCES

[1] GUGLIELMINETTI, Paolo, DISTEFANO, Alessandro, LAGRAULET, Marie F., ANGELINO, Antonio, PITULIS, Giorgio, DIETERDING, Lars, GAIDZIK, Marian, HILDEBRANDT, Johannes, HILDEBRANDT, Felix, KARCHER, Svenja, RIEBE, Eckhard and CROLLIUS, Adrian R. Design features for support programmes for investments in last-mile infrastructure. Final report [online]. Luxembourg: Publications Office of the European Union, 2016, 442 p. [viewed 2018-10-04]. Available from: https://ec.europa.eu/transport/sites/transport/files/2016-06-rail-final-report-design-features-for-lm-investments.pdf

[2] OXFORD, Oxford Dictionaries Online, 2015 [online]. [viewed 2018-10-04]. www.oxforddictionaries.com

[3] VILLIERS, Gerard de. Inland Intermodal Terminals and Freight Logistics Hubs. Southampton, UK: WIT Transactions on State of the Art in Science and Engineering, 2015. Vol. 86, Chapters 6, pp. 123-151.

[4] RAIL TRANSPORT ACT. Legal status at: 4 November 2018, Logbook 2017.0.2117 i.e. - Law of 28 March 2003 on rail transport.

[5] SBB CARGO. Anschlussgleise als Schlüsselfaktor im Wagenladungsverkehr. Final report [online]. Basel, Switzerland: Schweizerische Bundesbahnen SBB Cargo AG, 2009. [viewed 2018-10-04]. Available from: https://bit.ly/2RbZptO

[6] NADER, Mirosław, KOSTRZEWSKI, Arkadiusz and KOSTRZEWSKI, Mariusz. Technological conditions of intermodal transhipment terminals in Poland. Archives of Transport. 2017. Vol. 41, Issue 1, pp. 73-88.

[7] GNAP, Jozef, ŠULGAN, Marián, MAJERČÁK, Jozef., IŽVOLT, Libor, GAŠPARIK, Jozef, JAGELČÁK, Juraj and LIŽBETIN, Ján. Development of railway transport of chemicals in Slovakia in relation to adjacent countries and prepared combined transport terminals. Zilina, Slovakia: Chemical Logistics Cooperation in Central and Eastern Europe, University of Zilina, Faculty of Operation and Economics of Transport and Communications, 2010.

[8] GNAP, Jozef, KUBANOVA, Jaroslava. Selected Options for Modelling of Transport Processes Particularly in Relation to Intermodal Transport. In 18th International Scientific Conference-Logi 2017. Ceske Budejovice, Czech Republic: MATEC Web of Conferences, 2017. Vol.134, Article No.: 00015.

[9] BRUCKMANN, Dirk, DOBER, Patrik, GALONSKE, Niklas, SAABEL, Irmhild and WEIDMANN, Ulrich. Improving the container distribution by rail into Swiss sidings. Transportation Research Procedia. 2016. Vol. 14, pp. 645-654.

[10] LEE, Byung K, JUNG, Bong J., KIM, Kap H., PARK, Soon O. and SEO, Jeong H. A simulation study for designing a rail terminal in a container port. In PERRONE, L. Felipe., WIELAND, Frederick P., LIU, Jason, LAWSON, Barry G., NICOL, David M. and FUJIMOTO Richard M. (eds.) Proceeding of the 2006 Winter Simulation Conference. pp. 1388-1397.

[11] DEGANO, Cristiana, FEBBRARO, Angela Di. Modelling automated material handling in intermodal terminals. In Proceedings 2001 IEEE/ASME International Conference Advanced Intelligent Mechatronics. 2001. Vol. 2, no. 1, pp. 1023-1028.

[12] KARKULA, Marek. Selected aspects of simulation modelling of internal transport processes performed at logistics facilities. *Archives of Transport*. 2014. Vol. 30, issue 2, pp. 43-56.

[13] BLIZARD, Wayne D. Multisite theory. Notre Dame Journal of Formal Logic. 1989. Vol. 30, issue 1, pp. 36-66.

[14] GNAP, Jozef, VARJAN, Pavol and SEMANOVÁ, Štefánia. Logistics of Entry and Parking of Vehicles at Large Production Companies. In *18th International Scientific Conference-Logi 2017*. Ceske Budejovice, Czech Republic: MATEC Web of Conferences, 2017. Vol.134, Article No.: 00016.