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Designing of Functional Areas of Intermodal Terminals

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This article is about the design of intermodal terminals. The classification of intermodal terminals and their role in the transport chain have been presented. Particular attention has been paid to the design of functional zones of the intermodal terminal serving both containers as well as swap bodies and semi-trailers. Technical and technological requirements for these zones have been determined. Theoretical example of calculation of selected functional zones of intermodal terminal is presented.

Keywords: intermodal terminal, container, TEU.

1. INTRODUCTION

As defined by the European Conference of Transport Ministers (ECMT), the United Nations Economic Commission for Europe (UNECE) and the Organization for Economic Co-operation and Development (OECD), the terminal is an area for storage of intermodal loading units, that is equipped with equipment for handling of intermodal loading units [4], [15].

Therefore, the intermodal transshipment terminal is an object that is accompanied by appropriate organization and infrastructure. It is designed to perform a smooth transshipment between the means of transport of various transportation modes and to carry out handling operations. Handling involves operations on intermodal loading units such as containers, swap bodies, semitrailers and full truck load road vehicles. Intermodal terminals can be classified according to various criteria, including, type of intermodal loading units, type of means of transport involved in the refit and delivery of intermodal loading units from and to the terminal, terminal operations expressed in annual amount of intermodal loading units (TEUs) and functions performed by the terminal in intermodal transport networks. A detailed classification of intermodal terminals taking into account the division criteria is shown in figure 1 [4], [8], [13].

Intermodal transshipment terminals play an important role in rail and road transport. Their effective use depends on their specific requirements, conditioning their functioning. The most important conditions that have to satisfied are [2], [4], [5], [10], [11], [13]:

- good connection to the road and rail network;
- possibility to service trains with a length of at least 600 m;
- transshipment capacity (recommended for gantry cranes or other high-performance handling equipment;
- sufficient terminal capacity and area (10 - 15 ha).

Intermodal transport terminals are not only transshipment hubs but also service centres for the carriage of cargo and many additional services. Transshipment terminals are the places, where freight forwarders, warehousing companies, transport operators, and administrative services - veterinary inspection, customs, etc. are operating.

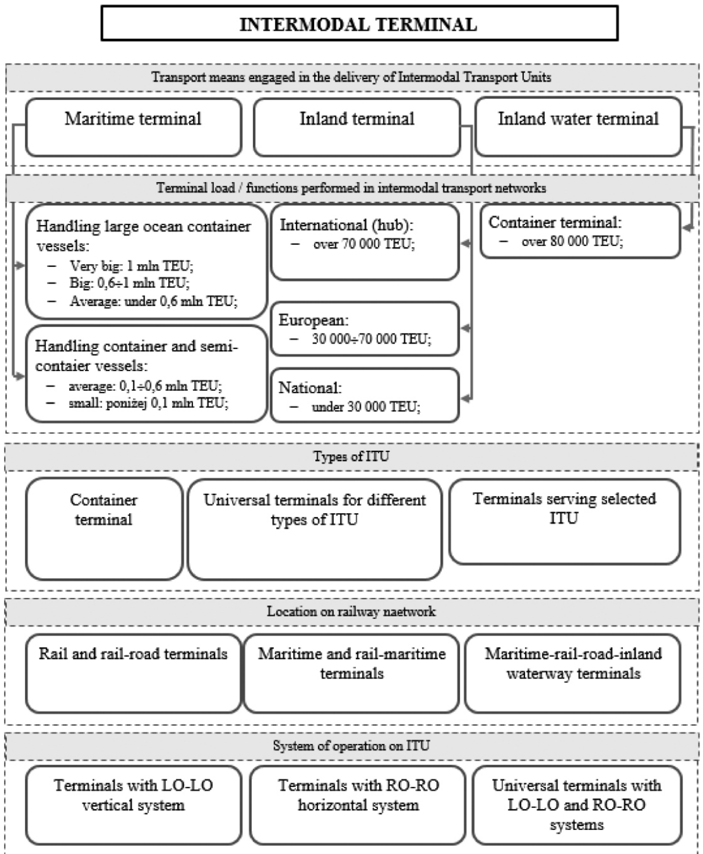

Fig. 1. Classification of intermodal terminals.
Source: [3].

2. TECHNOLOGICAL REQUIREMENTS FOR INTERMODAL TERMINALS

The vast majority of intermodal terminals in Poland are terminals located on the railway network. Hence, in the remainder of this article, the most attention will be paid to terminals.
According to the GE24 Working Group documents, the minimum requirements for intermodal (rail-road) terminals relate to [14]:

- the minimum interval time between the acceptance of the consignment for transport and the dispatch of the train, as well as the arrival of the train and the setting train for unloading - this time is set on 1 hour;
- shortening the waiting time of road vehicles for loading to minimum - no longer than 20 minutes;
- location of terminals in the places where the fast and free access to roads and business centres is possible;
- roadside location in relation to the railway network - it is desirable for the terminal to have their own arrivals and departures rail tracks, and also possibility for direct entry and exit for national rail tracks;
- an organization of work to provide 24-hour service, shorten the gap between the time of the last cargo acceptance and the departure of the train;
- automated data processing.

The choice of technical and technological solutions for the intermodal terminal located on the railway network should take into account the number and types of intermodal loading units being serviced per unit of time, e.g. per year or per day, the number and types of transport modes. Basically, technical-technological solutions include [6]:

- rail and road system of the terminal;
- storage locations for intermodal loading units;
- parking for intermodal transport units and parking places for vehicles;
- cargo loading fronts, buildings and maintenance facilities.

The road layout of the intermodal terminal should provide:

- road area which enable handling of road vehicles and traffic lanes for vehicles in the front of the load;

- internal communication and manoeuvring roads, providing road traffic and reloading machinery and equipment in the terminal area;
- terminal road system connecting the intermodal terminal to the public road network.

The total length of the road at the loading front should be equal to the length of the terminal rail tracks, which will ensure efficient use of the loading front. In case when the work technology of the loading front requires the turnaround of the road vehicle, the road loading front should be extended by the diameter of the loop for that turnaround. In this case, the horizontal arc radius should be at least 12 m, and if there is a loop for turnaround of the road vehicles, the minimum external radius should be 15 m. In the road system of the terminal, the distance of the road edge from the individual elements of the infrastructure should be [6], [8]:

- to the outer wall of the building not less than 1.50 m;
- from rail track axis, at least 3.50 m;
- from the rail track axis on the loading front, at least 2.70 m;
- from the loading unit standing on ground, at least 0.60 m;
- from the crane rail track, at least 1.50 m;
- from lighting poles and power lines (in street cross section) not less than 0.75 m.

It is also required that [6], [8]:

- the longitudinal inclination of the road on the loading front should be designed horizontally (an inclination of 0.15% and, in exceptional cases, 0.25% are allowed);
- longitudinal inclination for internal communication roads may be up to 0.5%;
- the inclination of the roads should be designed in the direction from the rail tracks. the inclination values depend on the type of paved road and range from 1.0% to 3.0%;
- the road lane width exactly 3.50 m, and in the case of a two-lane road, a road width of 6.0 m is allowed.

The width of the road on the loading front depends on the technology of road vehicles service (the possibility of longitudinal setting of road vehicles relative to the wagon, manoeuvring such as the reversing of a road vehicle) and should take into account the range of working manoeuvres of the handling equipment. The rail track system, to ensure the efficient operation of the terminal, should consist of:

- group of arrivals and departures rail tracks (P-O) to receive and set up intermodal trains;
- group of rail tracks on loading front;
- group of manoeuvring rail tracks connected with arrivals and departure rail tracks as well as with rail tracks on the loading front;
- group of auxiliary tracks used for: cars waiting for moving the on the loading front, connecting and disconnecting of trains, reserve cars;
- a group of transit and tracks.

When designing a track system for intermodal transport, it is necessary to [1], [12], [15]:

- maintain the track axis distance from the adjacent objects equal to half the width of the loading gauge uic-c1, plus one meter;
- in the case of an unpaved track, the distance from the track axis to the edge of the road should be 1.65 m and to the edge of the side ramp 1.73 m;
- the axle spacing for the unpaved track should be 4.50 m, and 4.75 m for the paved the minimum distance between the main track and loading track axis should be 6.0 m;
- loading tracks should be designed in straight and horizontal directions, especially for loading fronts equipped with cranes. the permissible longitudinal inclination should not exceed 0.5 ‰, in exceptional cases an inclination should not excide 1.5 ‰;
- tracks for cranes should be arranged horizontally and, if necessary, with the inclination not more than 0.5 ‰;
- according to the agreement, the recommended length of the track in the group of arrival and departure tracks should be 750 m.

Handling operations of loading units are performed on loading lanes and road lanes of the intermodal terminals, while the storage and sorting operations are performed on the storage lanes. In practice, the handling and road lanes on the terminal may partially overlap. This is due to the layout of the terminal and technological solutions (figure 2).

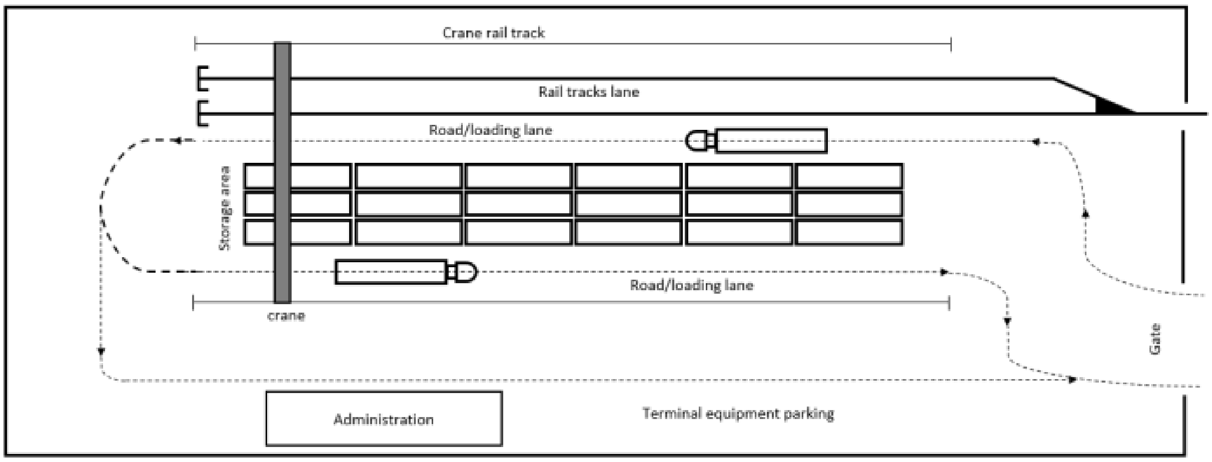

Fig. 2. Areas of the intermodal terminal.

The storage lane is used for short-term operational storage and for sorting of containers. On the other hand, the handling lane is designed for the operation of loading equipment.

In the storage areas of the transshipment terminals, operated by crane or lift trucks, containers are placed in the storage lanes. Their width should be 2,5 m (taking into account the width of the container 1C) plus 0,5 m for additional handling lane, providing a loose space for the free operation of the container [2].

The storage surface meets the technical and operational requirements of the stored units and should be capable of accommodating a load of 150 kN from the corner of the loading unit and 19÷240 kN from the wheels of the loading equipment. The storage capacity should be set individually for each terminal taking into account the terminal turnover, intermodal units loading technology, location of the storage areas relative to the communication lanes and the storage height.

Ensuring drainage of the storage and handling area requires the design of a transverse inclination equal to 0.5% and a longitudinal inclination of not more than 2%.

Additional facilities that can be found at intermodal terminals are parking spaces for loading units, car parks and loading ramps.

Parking spaces for loading units are designed to provide handling of container units and swap bodies. Places are used to store empty units. Due to the different technical characteristics of the stored units, separate areas for individual types of load units should be considered during design.

Parking and storage spaces with suitably prepared surface are designed for intermodal loading units which do not require special handling machinery and equipment for their operation, e.g. road vehicles and semitrailers.

The parking spaces located at the terminal are designed for the tractors and trailers and semitrailers for intermodal loading units and reloading equipment. Car parks should be designed in accordance with the requirements for roads and indoor yards. Parking spaces for road vehicles serving loading fronts should be designed in the immediate vicinity of them, while spaces for handling equipment are recommended to be designed in the immediate vicinity of repair and maintenance facilities.

3. INTERMODAL TERMINAL DESIGNING PRINCIPLES

Designing intermodal terminals requires a systematic approach based on a comprehensive analysis of the individual components of the terminal and the interrelations between them.

The design of intermodal terminals should be implemented in accordance with the following principles [3]:

- determination of annual and daily load on terminal expressed in number of load units and their structure;
- location of the terminal in the intermodal transport system;
- establishing a system for handling intermodal loading units within the transhipment range - vertical, horizontal or both. The choice of operating system is determined by the type of intermodal loading units serviced at the terminal and the handling equipment;
- shaping functional areas - taking into account operational/long-term storage areas and intermodal units handling systems;

– determination of the number and type of loading equipment;
– consideration of other terminal equipment, e.g. fire protection in accordance with current regulations and requirements.

In designing, the current standards and regulations should be used in the scope of functional and organizational solutions of the infrastructure. The design of the intermodal terminal should be carried out in four design stages [3]:

– Step 1: Formulating the logistics task for the terminal;
– Stage 2: Shaping the spatial areas of the proposed terminal;
– Step 3: Dimensioning the terminal functionalities;
– Step 4: Evaluation of terminal design solutions.

The individual stages of the design require detailed analysis of the rationalization of the processes and the equipment and configuration of the intermodal terminal.

The first step covers a range of analytical activities such as defining terminal's customers and determining the transshipment of the intermodal unit through the terminal, estimating the annual and average daily load of the proposed terminal and the intermodal units structure. In addition, the forecast of the load of the designed terminal and the structure of the intermodal loading units as well as the percentage of types of intermodal loading units in the terminal turnover should be estimated at this stage.

The second stage consists in shaping the process of flow of intermodal loading units by a terminal determining the way of performing particular operations. This requires determining the number of intermodal loading units in each terminal transition and establishing functional areas and communication systems.

In the third stage of the design of the intermodal terminal, the daily workload of the intermodal loading units should be determined. It will allow estimation of the number of loading equipment and human resources, taking into account their work category. In addition, in this step, the surfaces and cubic volumes of the storage spaces as well as loading fronts and communication lanes will be estimated. An important point in the design of the intermodal terminal is the calculation of the terminal's expenditures and operating.

The design of the intermodal terminal is implemented in a variant system, which requires evaluation of the individual solutions. Assessment of individual solutions with regard to evaluation indicators should be made using the comprehensive method in step 4. A detailed methodology for dimensioning of the intermodal terminal has been described in the work [3].

4. CASE STUDY

According to the above principles of intermodal terminals design, and using the methodology presented in [3], an example of dimensioning the functional zones of an intermodal terminal is shown below.

Design assumptions:

– terminal services intermodal transport (loading) units such as: ISO containers (1A, 1B, 1C), semi-trailers (NS) and swap bodies (NW);
– terminal services different rail directions: import, export, transit;
– the intermodal transport units (ITU) service technology requires intermediate handling (temporary storage) and direct handling of car-car and trailer-car;
– the average number of UTI serviced by the terminal per day is set out in table 1.

Table 1. Physical ITU.

	n_N	n_P	n_{P-N}	n_{S-S}	n_{T-BP}	n_{PN}	n_{PP}
1A	42	39	15	6	3	0	3
1B	30	24	6	6	3	0	6
1C	33	42	21	3	3	9	0
NW	6	6	0	0	0	0	0
NS	6	6	0	0	0	0	0

where:

- n_N – number of ITU in the rail transport import
- n_P – number of ITU in the rail transport export
- n_{P-N} – number of ITU in the rail transport transit
- n_{S-S} – number of ITU in the road transport transit
- n_{T-BP} – number of ITU in the rail transport transit without reloading
- n_{PN} – number of empty ITU in the rail transport export
- n_{PP} – number of empty ITU in the rail transport import

– in the intermodal terminal, ITU s may undergo several (max. three) transhipment operations;
– average storage time of ITU in the storage area is 36h;

The percentages of the number of operations for each type of ITU passing through the terminal are shown in Table 2.

$$LW = \left\lceil \frac{LM_{1kier}}{P_{wag} \cdot \alpha_{pp}} \right\rceil + L_{NS} = \left\lceil \frac{158}{3 \cdot 0,7} \right\rceil + 6 = 82$$

LM_{1kier} – train capacity for one direction,
P_{wag} – car capacity [TEU],
a_{pp} – train capacity utilization factor,
L_{NS} – number of semi-trailers.

Table 2. Percentage number of operations.

Operations number	***u*(*ko*^{N})**	***u*(*ko*^{P})**	***u*(*ko*$^{P\text{-}N}$)**	***u*(*ko*$^{S\text{-}S}$)**	***u*(*ko*^{PN})**	***u*(*ko*^{PP})**
1	10	10	20	0	10	10
2	80	80	80	100	90	90
3	10	10	0	0	0	0

where:
- ***u*(*ko*^{N})** – percentage of the number of operations performed on ITU in rail exports

Other symbols are compatible with those in table 1.

Terminal dimensioning:
The next stage is the designation of the number of equivalent units (Table 3) to determine the capacity of trains and storage areas (not including semi-trailers which are carried out on cars individually and storage space for them is reserved separately).

Table 3. Equivalent units (TEU).

Type	n_N	n_P	$n_{P\text{-}N}$	$n_{S\text{-}S}$	$n_{T\text{-}BP}$	n_{PN}	n_{PP}
1A	84	78	30	12	6	0	6
1B	45	36	9	9	5	0	9
1C	33	42	21	3	3	9	0
NW	6	6	0	0	0	0	0

Assuming that for a long period of time UTI's balance sheet should be balanced, the capacity of trains for containers and swap bodies is:

$$LM_{Z\_N} = LM_{Z\_P} = 243 \cdot 1,3 = 316 \text{ TEU}$$

Taking into consideration the possibility of operating two railway lines, the capacity of LM_{1kier} trains will be 158 TEUs in each direction. With the use of Sdgmnss (434S) cars of a capacity of 3-TEU, the demand for cars in one direction (including cars for semitrailers and a train capacity utilization factor of 0,7) will be:

The length of all cars for one rail direction will therefore be:

$$DW_{1kier} = \lceil LW \cdot D_W \rceil = \lceil 82 \cdot 18,34\ m \rceil = 1504\ m$$

where:
LW – number of cars,
D_W – car's length.

The above means 3 trains of 502 meters in length in each direction. Taking into account the locomotive (25 m) and the clearance of inaccurate set of cars (13 m), the length of the cargo lane at the terminal should be 540 m.

For ITU's subjected to intermediate handling, storage area has to be provided.

UTI's are subjected to 2 and more transhipment operations. Therefore, the capacity of the storage yard should be

$$LM = [(0,8+0,1) \cdot 155] + [(0,8+0,1) \cdot 156] + [(0,8) \cdot 59] + [(1) \cdot 23] + [(0,9) \cdot 9] + [(0,9) \cdot 14] = 371 \text{ TEU.}$$

Taking into account the cargo rotation coefficient of 1,3, the storage capacity of the storage area should be 483 TEUs.

Storage area should be also provided for semi-trailers LM_{NS} and swap bodies LM_{NW}, so:

- LM_{NW}=[(0,8+0,1)·(6 export swap bodies)]+ [(0,8+0,1)·(6 import swap bodies)] = 11. Taking into account the cargo rotation coefficient LM_{NW}= 15
- LM_{NS}=[(0,8+0,1)·(6 export semi-trailers)]+ [(0,8+0,1)·(6 import semi-trailers)]= 11. Taking into account the cargo rotation coefficient LM_{NS}= 15

Taking into account the 36 hour storage time of ITU, the total time required for ITU to be stored (containers only) is summarized in Tables 4 and 5.: containers considering the number of storage days expressed in containers and assuming that the containers in the storage area will be stacked up to level 3, the demand for storage fields will be 315 per day. Taking into account the cargo rotation coefficient, this value will increase to 414 spots per day.

The dimensions of the equivalent container (container 1C = length / width / height / 6,058/2,438/2,438 mm) and the clearance between the long and shorter sides of the container at l_{mani} = 50 cm are to be taken into account in calculating the length and number of container storage lanes. Hence, for the calculation of the size of the storage area, the length of the container was assumed to be 6.5 m. Also additional clearance (0.6m) was taken into account between the container storage and other objects such as crane or loading equipment. Therefore, considering the predetermined length of the rail tracks, the container terminal should provide 5 container storage lanes. The diagram of the intermodal terminal (operated by cranes) together with the individual functional areas are shown in Figure 3.

Table 4. Containers storage time.

	n_N	n_P	n_{P-N}	n_{S-S}	n_{PN}	n_{PP}
Storage time [h]	36	36	36	36	36	36
Number of TEU	155	156	59	23	9	14
Number of storage hours [container-hour]	5,580	5,616	2,124	828	324	504
Number of storage days [container-days]	349	351	133	52	21	32

Table 5. Semi-trailers and swap bodies storage time.

	n_N	n_P
Storage time [h]	36	36
Number of semi-trailers and swap bodies	6	6
Number of storage hours	36·6=216	36·6=216
Number of storage fields	216/16=14	216/16=14

Taking into account the analyses carried out in Table 5, 14 storage fields should be provided for semi-trailers and swap bodies. Taking into account the cargo rotation coefficient, this value will increase to 18 fields. On the other hand, for

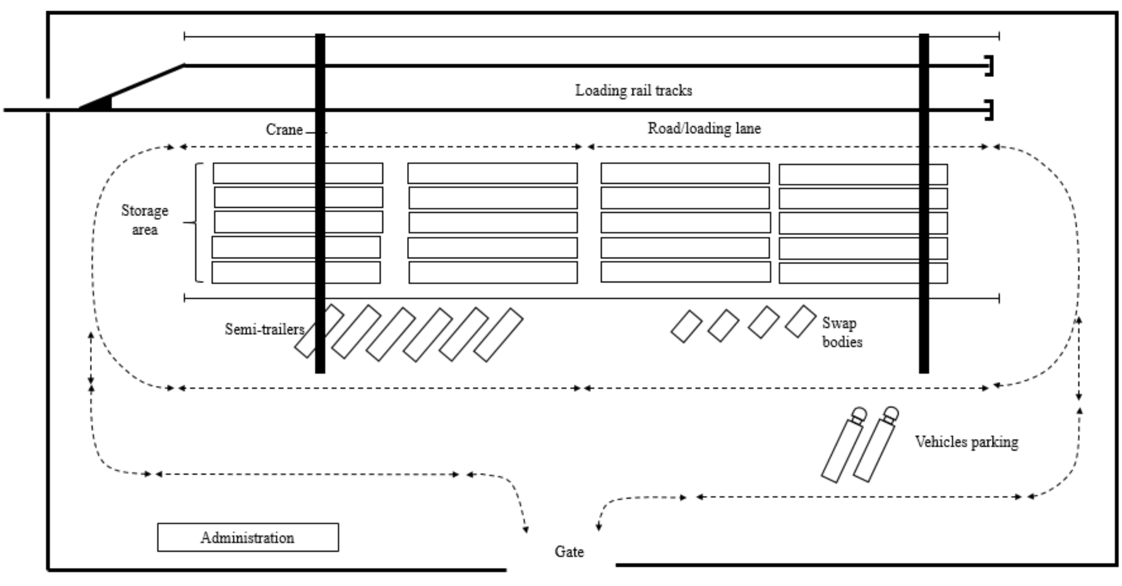

Fig. 3. Diagram of the intermodal terminal.

5. SUMMARY

Designing intermodal terminals is a complex process. A number of technical and technological requirements must be taken into account. Determining the size and capacity of terminal functional areas requires a number of calculations. The shape of the individual areas and as a result of the terminal is determined by the area for the investment, as well as by the anticipated technology and organization of the terminal work. The technology and organization of the terminal's operation depends mainly on the handling equipment (cranes, container lifting vehicles) and on the size and nature of terminal turnover.

Due to the increasing share of intermodal transport in the total number of freight movements, it is expected that in the near future the capacity of existing intermodal terminals in Poland will be exhausted. Therefore, the principles of intermodal terminals discussed in this article may be the basis for the design of terminal areas and their capacities.

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