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FACULTY OF MECHANICAL ENGINEERING AND INFORMATICS

THE EFFICIENT HORIZONTAL CONTAINER TRANSHIPMENT AND ITS IMPACT ON INTERMODAL RAIL-ROAD FREIGHT TRANSPORT

SUMMARY OF PHD THESIS

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1. Introduction

There are a number of analyses in the literature that address the issues of rail-road intermodal freight transport. One of the preconditions for continental rail-road intermodal freight transport is the existence of a relatively dense network of container terminals with advanced container handling [1], [2]. Another condition is that the costs of container handling do not affect significantly affect the price competitiveness of intermodal freight transport. Scientific publications have concluded that rail freight transport has a significant competitive disadvantage compared to road freight transport. I emphasize that this is not just about rail freight transport, but about rail-road intermodal freight transport, which has got competitive disadvantage compared to road transport in terms of price and transport time. The competitive disadvantage of rail transport in transport time is caused by its inflexibility. The research results summarized in the present dissertation may be significant in the paradigm shift of rail-road freight transport. In the history of paradigm shifts, it is often the case that new ideas are not accepted by even the professional public for a long time.

The container handling technology proposed in the present dissertation is extremely important, as the European freight rail network is 100% electricized in the main directions. Container loading under the electric rail overhead line is another important precondition for competitive rail-road intermodal freight transport. A number of EU-supported developments have also achieved this goal, namely container loading under the catenary, which is a forward-looking innovation with important potential. However, no breakthrough has been achieved so far.

Intermodal rail-road freight transport is often mentioned as a sustainable direction for the European transport system, which is a priority in European Commission documents [3]. In the present dissertation, I propose a new technical and organizational solution that can contribute to the achievement of the goals set by the EU. The aim of the research was to draw attention to new development opportunities and to show a new perspective to professionals interested in intermodal transport. The topic is interdisciplinary, further research of the details by experts in several fields, development of IT systems is essential.

2. Research methods and objectives

Logistics is an interdisciplinary field of science that is classified as a management science. Researchers and development professionals seek solutions for problems in logistics (transport, distribution, warehousing, etc.) in a variety of ways. The apparatus enabling the solution of the problem includes mathematical, formal logic, machine engineering, control technology and information technology procedures. In the present dissertation I used the following methods to research the problem raised:

- I present the known technical solutions for intermodal freight transport, evaluate their technical functions in terms of the development of rail-road intermodal freight transport,
- presentation of the current practice of intermodal freight transport provided by the widely used container handling,
- presentation of a competitive container transshipment machine designed with competitive machine design and applicable in the rail-road relationship,
- examining the effects of the new container handling technology on existing rail-road intermodal freight transport,
- examining the legal conditions that may be obstacles to the development of modern container handling and intermodal freight transport.

Researchers have developed new models (mathematical, freight flow, etc.) for the development of rail-road intermodal freight transport using different research methods, which are compared to draw conclusions from current practice. There is no example of a complex application of the above research methodology. At the same time, the complex research made it possible to formulate the requirements to be met, then to design the container handling machine that satisfies it, and finally to examine their impact on current continental intermodal freight transport practices.

The task to be solved within the framework of the research was named in the topic call and in the research plan: *“Nowadays, intermodal freight transport is very important, the expansion of which also requires technical, organizational and information technology developments. The research should examine and provide a technical, organizational solution for the impact of technical solutions ensuring the transhipment of efficient horizontal unit transshipment (intercontinental container, swap body, etc.) on the competitiveness of rail-road freight transport. What other conditions (business, IT, legal) are needed to significantly increase significantly the performance of rail freight transport.”*

The research plan also formulated the most important goals and topic areas that the research should cover:

- whether there is indeed a competitive disadvantage in terms of time and price for intermodal road-rail transport,
- the effect of technical solutions known or less known in the literature on the reduction of competitive disadvantages,

- with new technical solutions (with a newly designed container handling solution), is it possible to overcome the competitive disadvantage,
- whether the new engineering solutions result in new logistics organizational technology solutions that can eliminate the competitive disadvantage in terms of price and transport time.

3. Review of the literature related to the topic

In the literature, I examined the topicality of the topic with statistical methods. I searched the following complex terms in the SCOPUS database under "title, abstract, keywords" for the period 2010-2021:

- „container” AND „handling”
- „container” AND „transshipment”
- „inland” AND „container” AND „terminal”
- „rail-road” AND „container” AND „transshipment”

I presented the distribution of the results in bar charts according to three aspects:

- disciplines,
- year of publication,
- keyword breakdown.

According to the statistical evaluation, it can be clearly stated that the number of publications in the relevant topics has been constantly increasing in the last 10 years, i.e. the interest of the professional public in the topic is outstanding.

In the presentation of literary publications, I examined 29 publications in more detail. In addition, numerous studies have been conducted in recent years on the topic of rail-road intermodal freight transport, which represent the same scientific position as the publications examined. From the study of the literature, I drew the following, more important conclusions:

1. An effective way to reduce the environmental impact of the transport sector is to develop rail-road intermodal freight transport.
2. The economical distance of rail-road intermodal freight transport can be reduced by using intermediate stops for “get on the train” and “get off the train” of containers.
3. A precondition for the development of rail-road intermodal freight transport is modern container transshipment technology, which means the creation of transhipment capacity under the catenary, as Europe's main railway lines are electrified.

4. Profitable intermodal freight transport distance can be significantly reduced significantly in the event of changes in system parameters (transhipment cost, utilization, access time and distance, etc.).
5. The role of the legislator is essential to follow technical progress in order to improve the competitive position of rail-road freight transport.

4. A description of the container handling procedure developed during the research

In the present dissertation I review and evaluate the applicable container handling and intermodal freight transport procedures and innovations currently used at continental container terminals, and on intermodal container transhipment points, as follows:

- vertical container handling (2 pcs),
- horizontal, by gantry crane container handling (3 pcs),
- innovative horizontal container handling procedures (7 pcs)
- rail-road intermodal freight transport, container handling procedures, adapters (5 pcs),
- railway rolling stock developments for intermodal freight transport (7 pieces),

Despite the wide range of container handling procedures presented and the numerous developments for rail freight transport, the share of rail-road intermodal freight transport is low. In many cases, transport companies expect the development of intermodal freight transport from state intervention (restrictions on road traffic, price subsidies, etc.).

4.1. Requirements to be met

Literature data also support that one of the preconditions for the development of rail-road intermodal freight transport is modern container handling [1]. Knowing the widely used container handling procedures at the rail-road intermodal container terminals, as well as the recent technical development results, I determined the main functional requirements that can be used to reduce the competitive disadvantage of rail transport compared to road freight transport. The functions to be satisfied were identified as follows:

- safe applicability under the catenary,
- transhipment of MSZ ISO 668 containers (20-40 feet),
- transhipment of class “C” swap bodies according to MSZ EN 284,

- transhipment of class “A” swap bodies according to MSZ EN 452 (as the use of these swap body types is not widespread, its handling is not a priority requirement),
- be electrically powered for environmental purposes,
- be able to operate partially or completely automatically (without operator),
- do not require the simultaneous presence of rail and road means of transport,
- do not require a new intermodal transport unit design.

4.2. The developed container handling procedure

I came across the development and need for efficient container transhipment under catenary in 2001, and since then I have been researching relevant technical solutions and developing various designs. One of them was implemented at prototype level in 2008, but could not be applied in real conditions due to the difficulties of acceptance identified in the literature search of this dissertation. The development of the design has not stopped and several smaller, more diverse rail container transporter designs have been developed. The aim is to ensure that container transhipment is as efficient as possible, i.e. at lower cost.

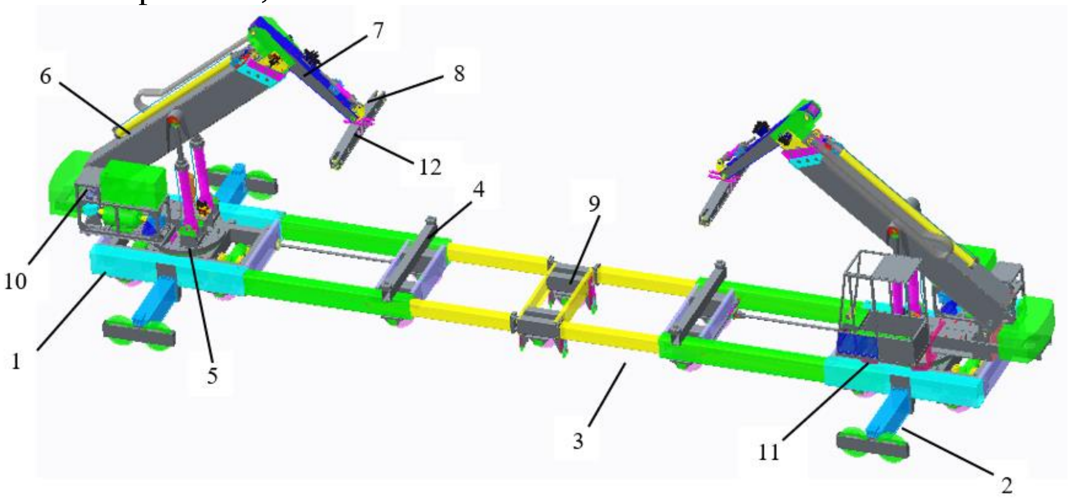

Figure 1. A model image of the HCT device[1]

The main structural elements of HCT (Horizontal Container Transshipment) according to the design state in 2018 (Figure 1):

- undercarriage (1), ensures movement in the direction of the track,
- a support structure (2) ensures the transverse stability of the equipment,
- the connecting beam (3) provides a mechanical connection between the right and left machine units,

[1] Own editing

- the container holder (4) performs a supporting function and ensures the temporary holding of the container,
- rotating platform (5) in the range of +/- 90 degrees allows the lifting device to be rotated,
- the lower boom structure (6) allows the load to be lifted and the telescopic structure to operate over a longer range,
- upper boom structure (7) provides penetration under the overhead contact line with low construction height,
- lifting beam (8) includes container gripping pins,
- an auxiliary carriage (9) fixes the middle part of the equipment to the rail, thus providing a fixed reference point for control the movements,
- hydraulic power supply (10) electrically driven, twin-pump design,
- the control cab (11) provides the location of the controls and operating personnel,
- beam joint (12) allows the lifting beam to rotate about the vertical axis as well as tilt to be parallel to the ground

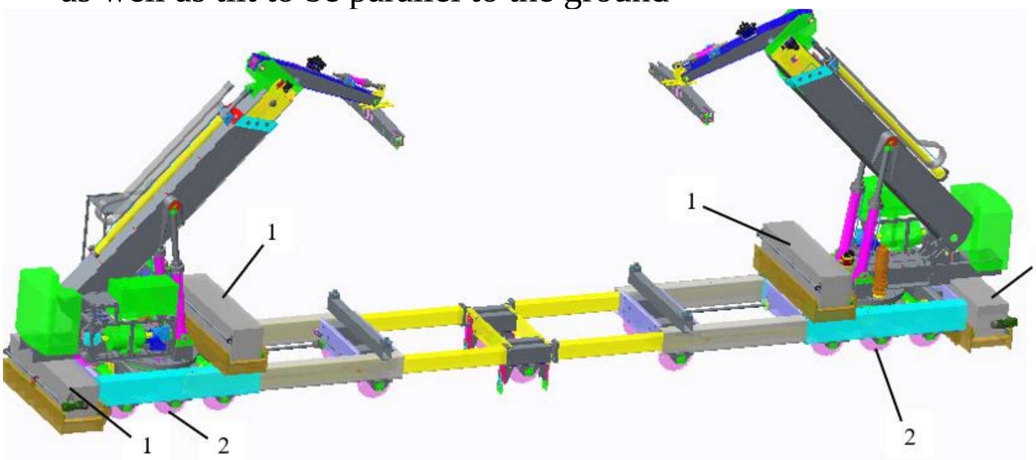

Figure 2. HCT with dynamic counterweight [2]

Figure 2 shows the 2019 design version of the HCT device, which is equipped with a dynamic counterweight (1) and therefore does not require the construction of a support rail. However, due to the higher counterweight mass, the weight of the machine increases and, with the intermodal unit to be lifted, approaches 120 tonnes. Consequently, in order to comply with the 20 tonne/axle load limit, the undercarriages of this design have three axles (2).

4.3. The developed rail-road intermodal freight transport model

The growth potential of intermodal freight transport is supported by numerous studies. In their presentation at the conference "Breakthrough innovations in intermodal freight transport" [52], Y. Bontekoning and H. Priemus emphasized „*Breakthrough innovations, be they technological,*

[2] Own editing

organizational or both, are necessary to increase the market share of intermodal freight transport. The main growth potential is in the market for perishable and high value goods for short distances, light bulk shipments and goods requiring speed, reliability and flexibility. ***Radical innovations will be needed to achieve a breakthrough in modal split and allow us to conquer these new markets.***" However, for the planning of new intermodal rail-road freight transport, it is essential to have a concrete knowledge of the main freight transport routes and traffic. Efficient container management has allowed the development of an intermodal container handling unit design that not only meets but also exceeds previous literature [1]. As a result, a new rail-road intermodal freight transport model was developed.

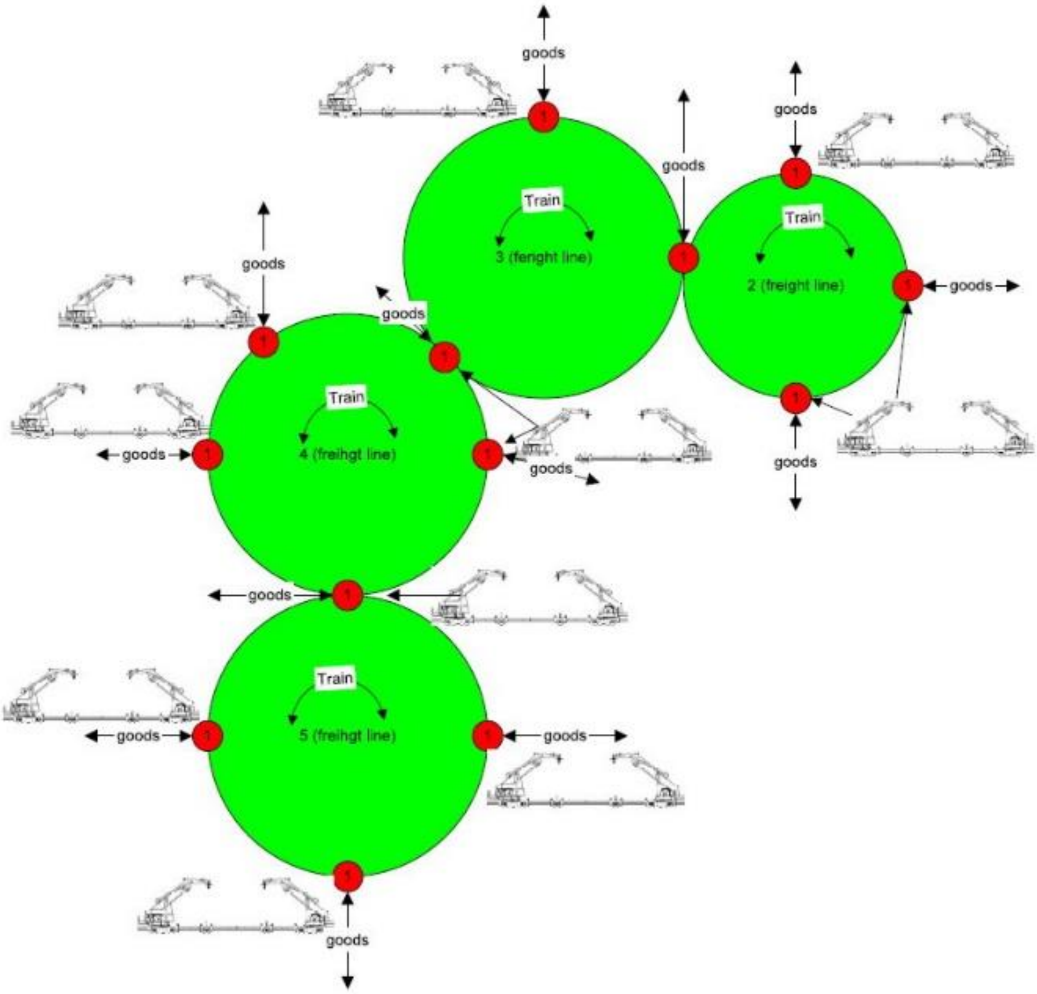

Figure 3. Intermodal freight transport model [3]

Figure 3 shows a freight model where the ITPs marked 1 are located at different distances from each other, while the circles marked 2-5 represent the round trip of freight trains. Goods can enter and exit the system at the ITPs marked 1 using HCT equipment. Along the main container transport

[3] Own editing

lines, ITPs are used to "get on the train" or to "get off the train" for loaded containers from a given area and to retrieve empty containers.

4.4. Construction of ITP

The advanced container handling technology presented in this dissertation can contribute to the development of a new terminal structure in the liberalized freight market that is more environmentally friendly and can improve the competitiveness of sectors with hight logistics costs. Some features of ITP equipped with HCT:

- There is no need to build a new freight terminal, as intermodal transfer points can be developed on existing underutilised freight terminal sites at relatively low cost.
- HCT can stack containers, which improves the utilization of the area.
- The simultaneous presence of a container train and a road transport vehicle is not required.
- It allows traffic to be de-concentration when, with the exception of the 20-30 km of road pre- and post-run, the goods move predominantly by rail.

HCT-supported container handling enables the development of an intermodal logistics system (physical internet) that can change terminal construction practices. Instead of high-capacity terminals, a network of small ITPs (or HUBs) can be created. The de-concentration of freight turnover is in line with the tendency for producer-suppliers and the emergence of more players, taking into account economic efficiency. Some of the organizational conditions requirement to be met for the creation and operation of ITPs are:

- Scheduled transportation of container freight trains in both international and domestic traffic. Train operation with the involvement of the railway operator in the region concerned. Trains run at such a tracking time that the container can be picked up by a train within 2-3 hours after delivery from the consignor.
- Establishment of a system of intermodal (rail-road) transhipment points under the management of a logistics company capable not only of handling containers but also of organizing customs duties for non-EU goods. In the case of Hungary, 22–23 pcs such ITPs may be required.
- Establishing the interest of companies interested in road transport in the operation of ITPs and in the performance of road pre- and post-runs.

In all cases, the new ITP is traversed by a railway line with catenary, which can be disconnected from the public railway catenary network. During service on the railway side, the catenary will be de-energized to meet current railway safety requirements. On the average ITP, along the railway track, approx. 0.5 hectare (5,600 m^2) (14 m wide, 400 m long), approx. 500 TEUs (approximately 250 pcs 40-foot containers) can be stored outside the area reserved for servicing the road vehicle.

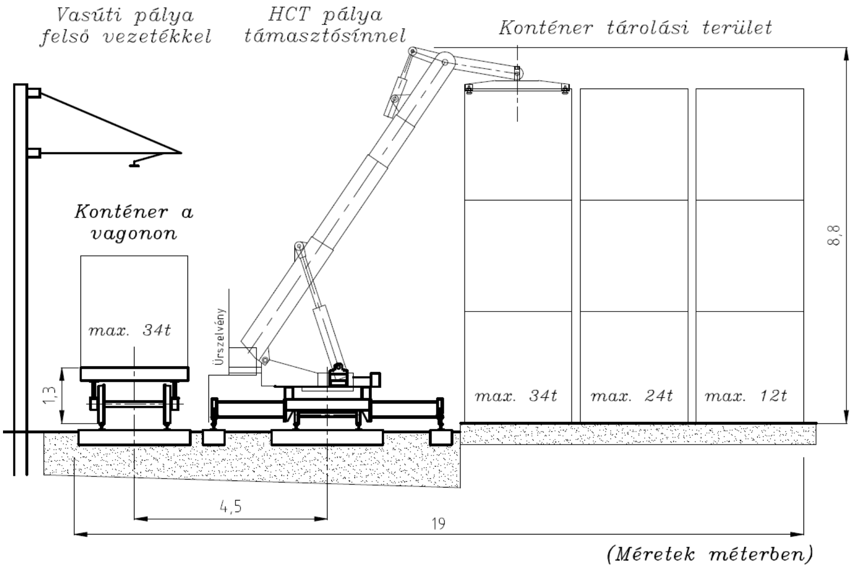

Figure 4. ITP section with HCT [4]

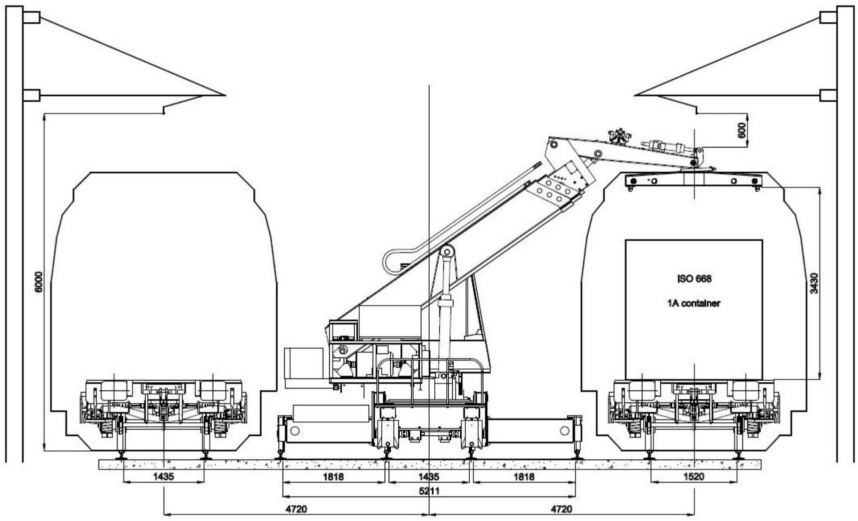

Figure 5. Rail-to-rail transhipment section with HCT [5]

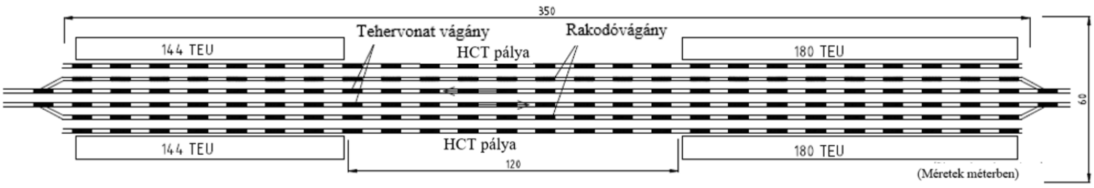

Figure 6. Layout of the two-track ITP [6]

[4] Own editing
[5] Own editing
[6] Own editing

The arrangement of the ITP on both sides of the double track main line is shown in Figure 6. The ITP on both sides of the main railway line can be connected to an overpass if necessary. This arrangement should be used in cases where the volume of rail traffic makes cross-traffic difficult.

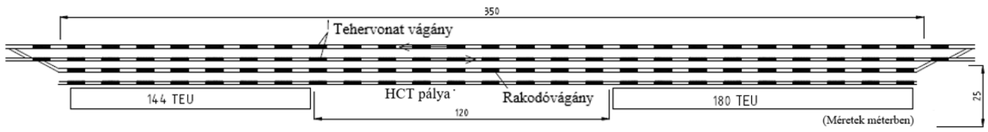

Figure 7. Single track ITP layout [7]

The ITP arrangement on one side of the double track main line is shown in Figure 7. In this case, the container train is stopped from both main railway lines on a loading track.

4.5. Examination of the legal environment

It is clear to the experts researching the development possibilities of intermodal freight transport that the solution of the issue requires development and intervention not only in the field of technology, but also in the field of legislation. In their article "*Developing intermodal transport for small flows over short distances (SFSD)*" [73], F. Barthel and J. Woxenius also examined the Swedish Light-combi project. „*The results show that market and financial uncertainties, insufficient network connections, and* ***policies that support existing technology*** *severely hamper the development and diffusion of SFSD systems.*" With this, the authors highlighted the importance of regulation, the conditions hindering development.

The legal environment has an impact on the applicability of the technical means of intermodal freight transport, on the relationship between the actors. In the present dissertation I have identified 9 specific legal locations, without the modification of which competitive intermodal freight transport is not possible. This means that the legislator has a key role to play in removing obstacles to the development of rail-road intermodal freight transport.

[7] Own editing

5. New scientific results

Thesis 1: After studying the international and national literature, I developed a new intermodal rail-road freight transport model and the container transhipment technology to serves it, which meets the competitive freight transport requirements. A freight transport system using the new container handling technology will ensure sustainable freight transport for context of rail-road intermodal freight transport. [S1] [S2] [S5] [S8]

The international and national literature describes several technical solutions for rail-road intermodal freight transport, which have only achieved their objective to a limited extent, given the low share of intermodal freight transport. Based on the analysis of the designs and engineering practice, I designed a complex rail container transhipment machine, which is a patented novelty in its mechanical solutions, meets the requirements of modern machines in terms of electronic and hydraulic control and meets the requirements of Industry 4.0. The new container transhipment machine, a track-laying machine that can be safely used under the railway overhead line above the freight train, allows efficient transhipment of containers between rail and road vehicles, even in automatic mode. Since modern container handling has low unit costs (transhipment price per container is around 20% of the current price), it can be used as a new basis for rail-road intermodal freight transport. The technical advantages offered by the new machine have made it possible to develop the freight transport model, which is environmentally sustainable because it is essentially rail-based.

Thesis 2: I have determined that container handling equipment that can be used under the catenary can help the competitiveness of rail-road intermodal freight transport, but only if it does not require the simultaneous presence of technical means of transport, is capable of stacking containers on the storage side, and is suitable for unattended, automatic operation. I conclude that, in addition to the development of container handling, rail traffic management and legislative measures are needed to reduce the competitive disadvantage. [S2] [S3] [S4]

I have analysed and identified the reasons for the competitive disadvantage of rail-road intermodal freight transport, which has both time and price dimensions. An important element of the causes is the simultaneous presence of the means of transport (rail wagon, road transport vehicle, container transhipment technology). To investigate the possibility of reducing the competitive disadvantage in terms of time, I prepared a timetable for the Budapest-Nyíregyháza-Miskolc-Budapest route. On this basis, I have concluded that there is no rail capacity constraint to the development of rail freight. An effective rail traffic management measure could be to run container trains in a roundabout. In order to examine the possibility of reducing the competitive disadvantage in terms of price, I have made a cost and revenue calculation for a specific route (Záhony-Sopron). On the basis of this calculation, I found that rail-road intermodal freight transport can be developed to be competitive with road prices. Based on literature data, I studied different container handling procedures and container transhipment equipment. I have identified the technical requirements and characteristics that modern container handling must have in order to develop rail freight transport.

I found that there are not only technical but also legal obstacles to the development of intermodal freight transport. By examining the legislation (laws, government decrees, sectoral regulations) governing and influencing the operation of public and private organisations involved in rail freight transport, I have highlighted the legal provisions which are outdated in terms of the state of the art and which are hindering the development of the sector. I have identified the most important legal provisions which, despite technical progress, cannot be developed without revision or amendment.

Thesis 3: I have developed the design of an intermodal transfer point using modern container transfer equipment, which allows the deconcentration of intermodal traffic to match the deconcentration of industrial production. It is specified that intermodal transfer points should have a catenary overhead passing railway track. [S6] [S7]

By applying the new container handling technology I have developed, it is possible to go beyond current terminal construction practices. Linked to the theory of the physical Internet, I have identified ITP (Intermodal Transhipment Point) constructions that can provide a new basis for rail-road freight transport. Using the new container handling equipment, I developed a new intermodal transhipment point design, which can be used for efficient container handling under the catenary. I have developed the proposed layout of ITPs, which require a small space.

I pointed out that the application of the new container handling technology will not only make freight transport sustainable, but also reduce the fossil fuel exposure of the national economy.

6. Description of the application and further development possibilities of the developed container management technology

The application of the intermodal freight transport system developed during the research may lead to the creation of a new door-to-door intermodal freight transport service that can operate under market economy conditions. The service can be provided by both new and existing economic operators. Intermodal transhipment points may be created in the unused rail freight yards of major cities and in the vicinity of larger industrial centres, which ensure the competitiveness of intermodal freight transport in terms of time and price.

A research project is considered to be successful if it ultimately leads to social benefits as well. The container handling technology described in this dissertation and the rail-road intermodal freight transport system that can be developed on its basis can have societal benefits in several aspects:

- The promotion of environmentally friendly modal shift from road to rail (modal shift) has significant environmental benefits, as the ecological footprint of rail freight is significantly smaller than the ecological footprint of road freight, which means sustainable freight transport.
- The reduction in heavy goods vehicle traffic by road reduces the deterioration of major roads, which in turn reduces the public resources to be spent on them.
- The intermodal freight transport system presented in this thesis is more cost-effective than road freight transport. It follows that the competitiveness of sectors with hight logistics costs will improve as a result of the new freight transport system.
- Utilization of currently underused rail infrastructure may increase, resulting in a reduction in the need for budgetary support for the rail sector.

7. Scientific publications on the topic of the present dissertation

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[S2] **László Vida**: HCT: New ideas in land-based intermodal logistics LOGISTICS YEARBOOK (1218-3849): 2013 pp. 260-270., (2013), Announcement: 30774602; Public; Journal article (Article)

[S3] **László Vida**: New ideas for continental intermodal freight transport LOGISTICS TRENDS AND BEST PRACTICES (2416-0555) V. grade: N. 1. pp. 29-35., (2019), Announcement: 30774610; Public; Journal article (Article)

[S4] Béla Illés; Antal Véha; **László Vida**: New ideas for inland intermodal transport; TRANSPORT PROBLEMS / PROBLEMY TRANSPORTU: INTERNATIONAL SCIENTIFIC JOURNAL (1896-0596 2300-861X) 15 1 pp 117-130 (2020), Announcement: 30917948; Public; Journal article (Article)

[S5] **László Vida**; Béla Illés; Ágota Tóth Bányainé: Special handling machine for transshipment of rail-road intermodal units; MULTIDISCIPLINARY SCIENCES: PUBLICATION OF THE UNIVERSITY OF MISKOLC (2062-9737) 10: 3 pp. 24-29., (2020), Announcement: 31389834; Public; Journal article (Article)

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