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## **Assumption in Development of Intermodal Transport Systems**

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### **1. Current state of analyzed problems**

Historical development of combined transport begins in the World War II when unified transport units were used to supply American army (1). Since then the character and importance of combined transport changed significantly. Not only it started being used for peace purposes but it also became an integral part of supplier-consumer chains. Because the technology of combined transport was created in different parts of the world, the terminology was disunited. Therefore the United Nations set a goal to create a multilingual vocabulary of combined transport (2). Economic Commission for Europe, European Commission and European Conference of Ministers of Transport were authorized to compile this vocabulary. It was published in 2001 and the basic terminology used in this dissertation work comes from this vocabulary. Among fundamental terms in the area of combined transport are:

- multimodal transport,
- intermodal transport,
- combined transport.

Current state of combined transport in CR was analyzed by looking at used kinds of combined transport and their volumes. Ways of support of combined transport in CR and the whole EU were also summarized. The summary of the whole analysis is that it is obvious that the importance of combined transport is increasing. This is caused not only by subsidy politics of EU and CR but also specific characteristics of combined transport.

The analysis shows that a lot of authors deal with the problematic of combined transport. There are a lot of contributions and projects concerning implementation of CT (combined transport) systems in door-to-door mode. We are however missing the point of view of CT operator who would save significant amount of financial funds and time by "inserting" railroad transport which would mean implementing a CT system.

Therefore we need to create mathematical model of such a system that would be able to economically motivate operators to use it for long distance transportation purposes.

There are also a lot of publications that deal with optimum position of depot in the network. These algorithms will be described and modified for usage in CT form operator's point of view which means that before the actual algorithm of location-allocation problem will be inserted a newly designed algorithm for determination of optimum delivery distance along with cluster analysis.

No one was yet able to calculate the external costs of individual kinds of transport. This problematic is so far stand in by financial subsidies into CT. The goal of future CT is to help the overloaded road network and to offer to the transporters a more economical, reliable and ecological way of transporting deliveries over our area taking consideration to the fact that capacities of railroad traffic road are also limited.

## **2.Aim of the written dissertation work**

The aims that came out of the analytical part of the dissertation work were:

- to create a new method designed by author for determination of optimum delivery distance,
- to draft a mathematical model of maximizing financial savings with changing delivery distance,
- to set up a scheme of decision process of initiating a CT line.

## **3.Methods of analysis and solution of the problem**

During identifying ways of possible future development of CT the author focused on options set in conditions of EU and CR. For solution were used methods of operations analysis (location-allocation problem, VRP) and costs modeling.

### **Location-allocation problem**

Location-allocation problem is used in praxis very often. It is used for solving problems where we operate the peaks from more depots. The problem is where to place the depots so that the peak service can be as efficient as possible (with lowest costs or within the shortest time).

Name of this problem consists of two words that characterize its use, location meaning finding the best place, and allocation meaning regionalization tasks. The goal of location task is to place a specified number of depots in traffic network. The goal

of allocation task is to set service areas of each depot. High correlation of these two problems lead to the fact that in current literature they are usually used together under the title "location-allocation problems".

Solution of this problem has several requirements:

- traffic network has evaluated edges (length of individual routes) and peaks (number of services of the peak in given time),
- depot can be placed only in peak,
- number of depots is a number known in advance lesser than number of peaks  $n$ ,
- all depots have the same characteristics making them mutually substitutable,
- by servicing the junction we mean shuttle service depot-peak-depot,
- number of services in each peak will not be changed during the calculations,
- depot capacity is sufficient enough for the service.

This method does not take into account different types of vehicles that are used for servicing. Therefore in the dissertation work was put a new algorithm designed by author before this location-allocation problem that help us to set an optimum range of attraction perimeter or the average delivery distance.

### **Vehicle routing problem**

Vehicle routing problem (VRP), is a set of methods belonging to methods resolved by optimization and linear programming. It is mostly used for traffic problems for different number of customers and inhomogeneous car park. Origin of these methods comes from Dantzig and Ramser in 1959. Currently it is used in many modifications for solving traffic and delivery problems of logistic chains or haulage-distribution problems. Here is the list of VRP modifications:

- travelling salesman problem (TSP),
- capacitated vehicle routing problem (CVRP),
- split delivery vehicle routing problems (SDVRP),
- vehicle routing problem with time windows (VRPTW),
- multi-depot vehicle routing problem (MDVRP),
- periodic vehicle routing problem (PVRP),
- stochastic vehicle routing problem (SVRP),
- vehicle routing problem with backhauls (VRPB),
- vehicle routing problem with pickup and delivery (VRPPD),
- vehicle routing problem with satellite facilities (VRPSF).

For solving all VRPs the newly author designed algorithm can be used as the first step.

## Cluster analysis

Original definition of the term cluster dates to the year 1939 from Van Rijsbergenov and sounds: „Cluster analysis is a common consecution formulated as a procedure through which we objectively group some subjects into groups on the basis of their resemblance and variance“. Basic term of the cluster analysis is a cluster. Its definition has been made again by Van Rijsbergenov as: „We have a set of objects  $X = \{x_1; x_2; \dots; x_n\}$  and any coefficient of objects dissemblance  $D$ . Cluster is called a subset of the set  $X$  for which is valid figure 3-1“. This condition is well known as a L1-condition.

$$\max D(x_i; x_j) < \min D(x_i; x_j) \quad (3-1)$$

where:

$$\begin{aligned} x_i, x_j, x_l &\in A \\ x_k &\notin A \end{aligned}$$

Each method of a cluster analysis can be described by defined goals towards them it leads to the solution. In principle, there are just two main groups of methods. These are hierarchic methods and nonhierarchic methods or monothetic and polythetic methods:

- Hierarchic methods – common feature of those methods is that clustering process is a series of steps of objects decomposition. We can divide them on agglomerative methods (Each object is initially placed into its own group) and divisive methods (At the beginning is just one cluster with all of the objects, which is than spreaded into separate disjoint sets),
- Non-hierarchic methods – resolve basic set into subsets to satisfy some criterion. The first decomposition isn't constant and changes up to the optimal solution. Non-hierarchic methods can be divided onto optimization methods and relocation.

Beside concrete methods of cluster analysis belong Simple linkage, Complete linkage, Weighted group method, Average linkage method, Unweighted group average, Ward-Wishat method (Ward's error sum of squares method), MacQueen method of  $k$ -means, PAM (Partition around metoid) and Bagged clustering (Bootstrap aggregating clustering).

This is just a small enumeration of some cluster analysis methods. However solving of cluster analysis wasn't a primary goal of the dissertation work. Therefore was for the solution used a software product STATISTICA 8.0.

### *MacQueen's method – k-means clustering (3), (4)*

This method is one of the most well known non-hierarchic methods of cluster analysis. For the first time it was published by MacQueen in 1967. The method disarticulates engaged matrix on predefined (expected) number of clusters by maximization of some criterion by Euclidean distances. Most frequent criterion is used a value of matrix memory interior variability  $st(T)$ . This criterion is stipulated in figure 3-2.

$$T = \sum_{h=1}^k \sum_{i=1}^{n_h} (x_{hi} - \bar{x}_h) \cdot (x_{hi} - \bar{x}_h)^T \quad (3-2)$$

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where:

- $k$ .....total volume of clusters [number],
- $n_h$ .....number of objects in cluster  $h$  [number],
- $x_{hi}$ .....object  $i$  in cluster  $h$ ,
- $\bar{x}_h$ .....array of averages of cluster  $h$ .

This method has one significant problem. If we want to find optimal solution, we will have to skirt large volume of possibilities  $\binom{n-1}{k-1}$  exactly. Where  $n$  is a number of values in a matrix and  $k$  is a number of clusters. Therefore is online solution possible just over heuristic algorithms with well known disadvantage in suboptimal solution.

MacQueen algorithm of k-means in four steps::

1. Place  $D$  points into the space represented by the objects that are being clustered. These points represent initial group centroids.
2. Assign each object to the group that has the closest centroid.
3. When all objects have been assigned, recalculate the positions of the  $D$  centroids.
4. Repeat steps 2 and 3 until the centroids no longer move. This produces a separation of the objects into groups from which the metric to be minimized can be calculated.

#### *Ward – Wishhart’s method (3),(4)*

Original name of this method is Ward’s error sum of squares method. Basic principle of this method is a data dump which results from joining of objects into clusters and total square sum of error of each value from array of averages. This average is called centroid of a cluster. The method uses as a quality criterion increment of total sum of each sum of squares. This increment is stipulated by sum of squares of a new cluster  $S$  ( $S = A \cup B$ ), minus sums of squares of evanescent clusters  $A$  and  $B$ . Mathematical expression of this procedure is in figure 3-3.

$$\Delta C = \sum_{i=1}^{n_S} \sum_{j=1}^p (x_{sij} - \bar{x}_{sj})^2 - \sum_{i=1}^{n_A} \sum_{j=1}^p (x_{ajj} - \bar{x}_{aj})^2 - \sum_{i=1}^{n_B} \sum_{j=1}^p (x_{bij} - \bar{x}_{bj})^2 \quad (3-3)$$

where:

- $x_{sij}$ .....value of  $j$  variable in cluster  $S_i$ ,
- $n_S$ .....number of objects in cluster  $S$ ,
- $\bar{x}_{sj}$ .....average value of cluster  $S$ ,
- $\bar{x}_{Aj}$ .....average value of cluster  $B$ ,
- $\bar{x}_{Bj}$ .....average value of cluster  $B$ .

This consecution joins clusters whose connection brings minimization of  $\Delta C$  criterion. These ways are eliminated small clusters and set clusters of equivalent size. Criterion  $\Delta C$  is be stipulated in figure 3-4.

$$\Delta C = \frac{n_A n_B}{n_A + n_B} \sum_{j=1}^p (\bar{x}_{aj} - \bar{x}_{bj})^2 \quad (3-4)$$

where:

- $n_A$ .....number of objects in cluster A,
- $n_B$ .....number of objects in cluster B,
- $\bar{x}_{A_j}$ .....average value of cluster A,
- $\bar{x}_{B_j}$ .....average value of cluster B.

According to figure 3-4 are stipulated products of Euclidean distances between centroids of clusters, all of which is formed one cluster and coefficient depending on size of a cluster or number of objects in that cluster.

### Modelling of expenses

The second goal of written dissertation work needed beside precise analysis of expenses mainly mathematical modelling for determining costs of transport. Author observed costs by changing hauling distance. This way was found a range of economically performed distances as well as optimal hauling distance.

Into the comparison were added such kinds of intermodal transport which are most widespread in Europe. There fall ISO 1 containers (swap bodies), semitrailers and Ro-La system. Expenses of those kinds are compared with direct road transport. In the table 3-1 we can find just such type of an expense with direct impact upon variable costs. That corresponds with presumptions from analysis. Overview of expenses for each kind of transport is in table 3-1. Modelling of costs will answer for the question which system is the most tenderable to direct road transport.

**Table 3-1: Overview of costs for different kind of transport**

Type of expense	ISO 1 containers	Semi trailers	Ro-La	Direct road transport
Damage liability	No	Yes	Yes	Yes
Road Tax	No	Yes	Yes	Yes
Depreciation	No	Yes	Yes	Yes
POL <sup>1</sup>	No	Ne	Yes	Yes
Toll	No	Ne	Yes	Yes
Driver wage	No	Ne	Yes	Yes
Tires	No	Ne	Yes	Yes
Transport unit rent	Yes	No	No	No
Railroad transport	Yes	Yes	Yes	No

Source: author

### 4.Achieved results

In the dissertation work was designed a new algorithm for calculating of optimal delivery distance. Mathematical modelling of variable costs and direct road transport was made and a scheme of decision processing of initiating a CT line was set up.

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<sup>1</sup> POL – shortcut of Petroleum, Oils and Lubricants

### Newly designed algorithm

Author's newly designed algorithm for calculating optimum delivery distance with variable number of vehicle turnarounds and time of manipulation operations. Designed algorithm consists of input data, A – E matrices and mathematical apparatus connecting individual matrices. Brief description of individual matrices:

- **Matrix A** - after entering input data illegal solutions for driving times that exceed restricting conditions (maximum driving time) are filtered out.
- **Matrix B** - driving times are decreased by legal pauses.
- **Matrix C** - using values from matrix B average distances are calculated.
- **Matrix D** - uses values from matrix B and calculates individual tariff rates in financial units per kilometer for different driving times.
- **Matrix E** - by setting a required interval of allowed tariff rates this matrix eliminates the solution by further values so there are only valid solutions left.

For application the newly designed algorithm the basic and key step is to set the input parameters which influence the whole process and relevance of the results. Among the input data that were described as constant are:

- daily tariff rate for one vehicle  $P = 355 \text{ €}^2$ ,
- average speed of vehicle  $v_{pr} = 1,08 \text{ km} \cdot \text{min}^{-1}$ ,
- maximum daily work time  $T_{max} = 720 \text{ min}$ ,
- maximum daily time spent by driving including legal pauses  $T_{\bar{R}max} = 600 \text{ min}$ .

Algorithm was made for two options of manipulating times and number of turnarounds. The result of the algorithm is matrix E that is below in table 4-1. Because option 2 was chosen all the further results are for option 2. Using cluster analysis all the values from table 4-1 can be transformed to intervals. Process of cluster analysis is on picture 4-1, interval results in table 4-2.

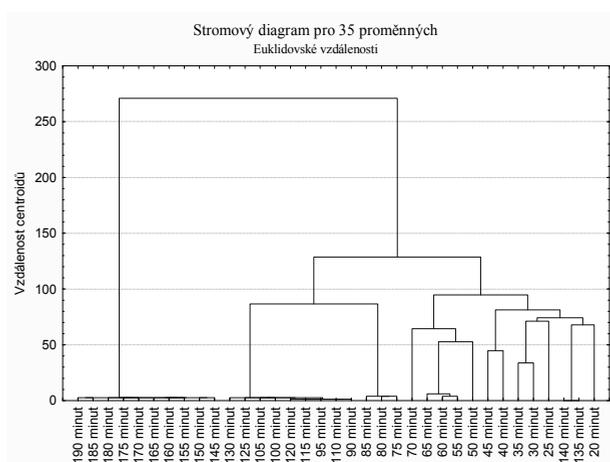
**Table 4-1: Part of matrix E (Option 1)**

$n_o$	$T_{NV}$	20	30	40	50	60	70	80
1								
2								143,54
3					97,50	92,08	94,79	89,38
4				71,77	72,45	67,03		
5			58,50	57,96	52,54			
6			46,04	44,69				

<sup>2)</sup> value of the daily tariff rate set upon consultation with Hangartner AG company

$n_o$	$T_{NV}$	20	30	40	50	60	70	80
7			40,63					
8	35,89	33,52						
9	30,69							
10	28,98							
11	25,36							
12	22,34							

Source: author



Source: author

**Picture 4-1:** Cluster analysis of matrix E for option 2

**Table 4-2:** Manipulation time intervals for option 2

Manipulation time interval [min]	Average delivery distance [km]
<20, 70)	53,52
<75, 130)	128,65
<145, 190)	283,02

Source: author

From the newly designed algorithm also results that optimum delivery distance is proportional to manipulation time with the vehicle. Among the most common types of manipulation belong loading and unloading. Therefore it can be said that optimum delivery distance is proportional to loading and unloading time. Every subject is trying to reduce the manipulation time. In case of combined transport the time is usually between 10 and 30 minutes. This is however based on presumption that in the terminal is processed only loading of transport unit onto road vehicle and dispatching of transport documents. On the consumer side it is more difficult to determinate the manipulation time

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because of different type of subjects with different manipulation machinery and technology. Generally we can divide the customers to three basic types: terminal, logistic warehouse and general customer. Each of these types has its own specifics.

### Mathematical modeling of costs

On the basis of mathematical calculations it was theoretically found out that it is possible to fulfill the presumption mentioned in analytical part of the dissertation work about relationship between variable costs of accompanied CT and direct road transport. Distances have been calculated that set bounds to the area of allowed solutions including optimum distance. These distances are in equations 4-1 to 4-3. They also help to reveal on what does depend the length of these distances.

$$l_{\min} = \frac{c_{m\ddot{y}to} + c_{pneu} + c_{mzda} + c_{PHM}}{c_{SD} + 2 \cdot (c_{m\ddot{y}to} + c_{pneu} + c_{mzda} + c_{PHM}) - c_{\ddot{z}D}} \cdot v_{vlak} \quad (4-1)$$

$$l_{opt} = d.d.o. \cdot v_{vlak} \quad (4-2)$$

$$l_{\max} = \frac{c_{mzda} \cdot d.d.o.}{c_{\ddot{z}D} - c_{m\ddot{y}to} - c_{pneu} - c_{SD} - c_{PHM}} \cdot v_{vlak} \quad (4-3)$$

On the basis of this theoretical mathematical modeling of costs in the application part there are set factual values from praxis into these relationships so that the functionality and validity of this modeling can be verified. In table 4-3 is a summary of used rates.

**Table 4-3: Calculation formulas [Kč·km<sup>-1</sup>]**

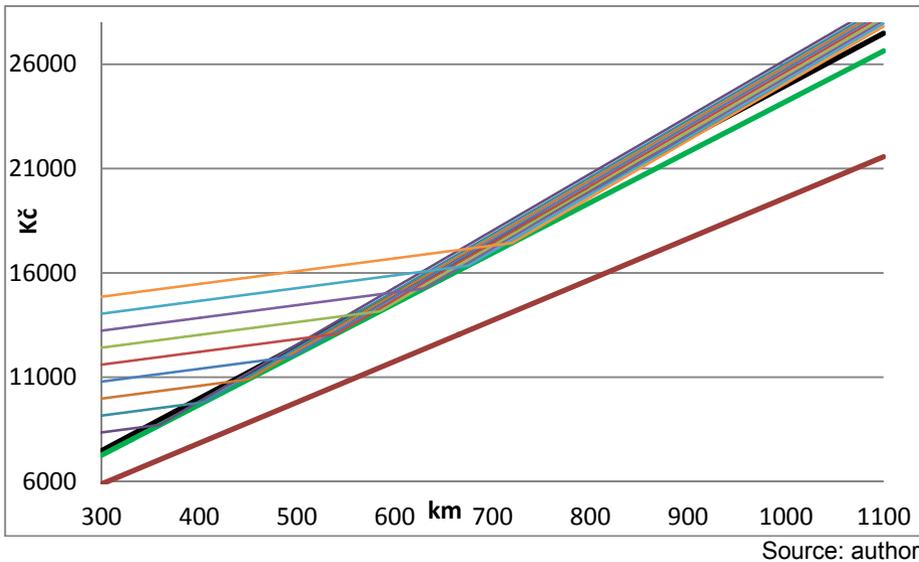
Type of load	ISO 1 containers	Semi-trailers	Ro-La	Direct road transport
Damage liability	0	0,54	0,54	0,54
Road tax	0	0,23	0,23	0,23
Depreciation	0	6,15	6,15	6,15
POL	0	0	9,81	9,81
Toll	0	0	4,20	4,20
Driver wage	0	0	3,08	3,08
Tires	0	0	1,00	1,00
Transport unit rent	2,11	0	0	0
Railroad transport	17,50	17,50	17,50	0
<b>TOTAL</b>	<b>19,61</b>	<b>24,24</b>	<b>----</b>	<b>25,01</b>

Source: author

Total value is missing for accompanied CT because the relationship for its calculation and therefore the value of individual cost items is changing with delivery distance. Putting  $c_i$  values from table 4-3 for all intervals it is possible to set how costs of accompanied CT will be changed with different delivery distance. Mathematically it can be said that the costs of accompanied CT not only depend on length of CT line but also depend on speed of the train.

$$\begin{aligned}
\forall l \in (0; d.d.o \cdot v_{vlak}); C_{RoLa} &= 6,123 \cdot l + 162,81 \cdot v_{vlak} \\
\forall l \in \langle d.d.o \cdot v_{vlak} \rangle; C_{RoLa} &= 24,213 \cdot l \\
\forall l \in (d.d.o \cdot v_{vlak}; \infty); C_{RoLa} &= 27,293 \cdot l - 27,72 \cdot v_{vlak}
\end{aligned}
\tag{4-4}$$

For other types of transport the costs function is directly proportionate to the length of the line. TOTAL values from table 4-3 are used as tangent of the costs function. Graph 4-2 was made by inputting values  $c_i$  and modeling costs of accompanied CT for different  $v_{vlak}$ .



**Picture 4-2:** Graph of dependence of costs on travelled distance for different types of transport

Hypothesis that an area of allowed solutions exists where the variable costs of accompanied CT are lower than costs of direct road transport was confirmed by visualization of the modeling. Interval of allowed solutions and optimum solution can therefore be mathematically interpreted. Minimum interval  $l_{min}$  and maximum interval  $l_{max}$  of allowed distance are in the intersections of first and third function from formulas 4-4. Optimum  $l_{opt}$  can be found at maximum of first and third function difference. None of these functions is defined in this point but the intersection can be searched as limit of these both functions heading towards this point. The results are in formula 4-5.

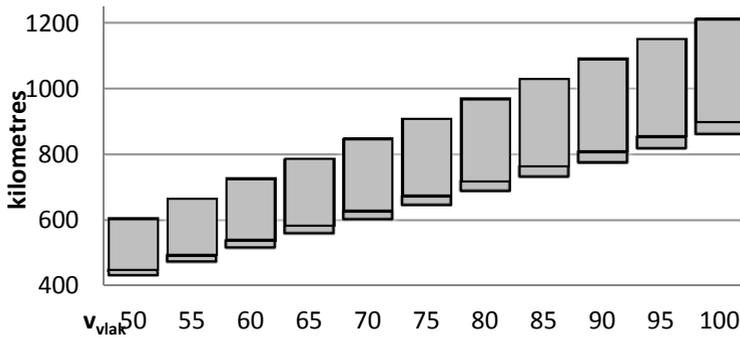
$$\begin{aligned}
l_{min} &= 8,62 \cdot v_{vlak} \\
l_{opt} &= 9 \cdot v_{vlak} \\
l_{max} &= 12,14 \cdot v_{vlak}
\end{aligned}
\tag{4-5}$$

If we transfer these formulas into the table 4-4 we can make a graph of the interval of allowed solutions depending on speed of the train of accompanied CT  $v_{vlak}$ . That is in picture 4-3 and it covers the area of allowed solutions  $l_{min}$  to  $l_{max}$  (grey area). Value  $l_{opt}$  is the black line in each of the columns.

**Table 4-4:** Calculation of the interval of allowed solutions for different speeds of train [km]

$v_{vlak} [km \cdot h^{-1}]$	50	55	60	65	70	75	80	85	90	95	100
$0 - l_{min}$	431	474	517	560	603	647	690	733	776	819	862
$l_{min} - l_{opt}$	450	495	540	585	630	675	720	765	810	855	900
$l_{opt} - l_{max}$	607	668	728	789	850	911	971	1032	1093	1153	1214

Source: author



Source: author

**Picture 4-3:** Graph of optimal distances for different speeds of train of accompanied CT [km]

Using modeling it was proved and quantified under what conditions can be the accompanied CT profitable. Distances from formulas 4-5 are the initial clue for the CT operator deciding about establishing a new line accompanied by CT. Another important step is to identify the peaks suitable for placing CT terminals. These peaks should satisfy these conditions:

- the peak is on a track which is part of European Agreement AGTC.
- the peak is connected to network of highways and 1st class roads that are suitable for operation of heavy goods vehicles (vehicle combinations up to 40 tons).
- the peak must be internally dimensioned for technological and manipulation tasks of road and rail vehicle combinations,
- sufficient demand for transport services in the peak.

Based on this procedure described in this chapter and on the mathematical modeling a scheme of decision making process for establishing a new CT lien was drawn up. For accompanied CT would the founded terminals work as final ones in terms of changing the type of transport. If we however enlarge this decision making process by newly designed algorithm for calculating optimum delivery distance we can use these terminals as final ones in terms of final cargo delivery.

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## Resumé

### Předpoklady vývoje intermodálních přepravních systémů

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Článek sumarizuje autorovu disertační práci, která se zabývá matematickým modelováním variabilních nákladů vybraných druhů kombinované dopravy a přímé silniční dopravy. Pomocí aplikace matematického modelu je stanoven interval přípustných vzdáleností, kde doprovázená KD dosahuje nižších variabilních nákladů než přímá silniční doprava. Disertační práce se dále zabývá vytvořením nového autorem navrženého algoritmu pro výpočet optimální rozvozní vzdálenosti. Tento výpočet je založen na principu, že silniční vozidlo je najímáno za paušální částku (denní paušál). Součástí řešení je i vývojový diagram tohoto algoritmu.

## Summary

### Assumption in Development of Intermodal Transport Systems

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Presented paper is an abstract of author's dissertation thesis on theme The Assumptions in Development of Intermodal Transport Systems, which deals with trend this will be observed in the future on the field of intermodal transport in Czech Republic and EU. Its goal is in finding ways, how to make intermodal transport more attractive for wider spectrum of haulers. Dissertation thesis is divided into five main chapters.

In the first chapter is a state-of-the-art analysis of intermodal transport in Czech Republic as well as in EU. Emphasis is placed on technological respect of intermodal transport and its specifics in confrontation with direct road transport. There is propounded a hypothesis that variable costs of intermodal transport including accompanied might be lower than for direct road transport. This hypothesis is supported by expected mathematical curve of variable costs for accompanied intermodal transport and direct road transport. Another important part of the analysis is focused subvention support of intermodal transport on national and European level. Matter of common disadvantage of intermodal transport is very high costs for infrastructure development and buying of vehicles. Those costs are shown up in final price of the service, so that most dynamic development has nowadays types of intermodal transport with less input costs. Presumption of dissertation thesis is, that if intermodal transport systems will be free of input costs, than intermodal transport can be profitability. The input costs can be financed from European funds or national donation. One of the conditions for European projects is sustainability after the end of subsidy, so in the field of variable costs.

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On the basis of the analysis were set goals of the dissertation thesis:

- set up of new author's proposed method for calculation of optimal hauling distance,
- proposal of mathematic model which maximize financial savings by changing hauling distance,
- set up of decision process diagram for put of line of intermodal transport into service.

Those goals led to choice of mathematical apparatus, which was in necessary cases modified for needs of dissertation thesis. Through the use of chosen and modified methods all aims of dissertation thesis were fulfilled. The contribution of the dissertation thesis is in:

- set up of new author's proposed method for calculation of optimal hauling distance, through which can be determined optimal hauling distance. This algorithm is coupled with flowchart,
- mathematic modelling of costs is looking for changing of variable costs with growing hauling distance for different types of intermodal transport and direct road transport. The proposed hypothesis that accompanied intermodal transport might have lower variable costs than direct road transport was acknowledged,
- set up of decision process diagram for put of line of intermodal transport into service.

## **Zusammenfassung**

### **Assumption in Development of Intermodal Transport Systems**

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Der Artikel summiert Autors Dissertation, die sich mit mathematischem Model der veränderlichen Kosten der ausgewählten Arten des kombinierten Transports und des direkten Automobilverkehrs beschäftigt. Mithilfe der Applikation des mathematischen Modells ist Intervall zulässigen Entfernungen festgelegt, wo begleitete KD niedere veränderliche Kosten erzielt als direkter Automobilverkehr. Die Dissertation durchnimmt weiter von der Bildung des neuen Algorithmus für Berechnung der optimalen Lieferentfernung, mit dem Autor vorgeschlagen. Diese Berechnung ist auf dem Prinzip gegründet, dass Straßenfahrzeug ist für Pauschalsumme (tägliches Pauschale) erworben. Bestand der Lösung ist auch Flussdiagramm dieses Algorithmus.