RIGA TECHNICAL UNIVERSITY

Aivis GRISLIS

ANALYSIS OF POSSIBLE USE OF LONG COMBINATION VEHICLES FOR DIVISIBLE CARGO TRANSPORT

Summary of Doctoral Thesis

Riga 2010

RIGA TECHNICAL UNIVERSITY
Faculty of Transport and Mechanical Engineering
Department of Automobile Transport

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DOCTORAL THESIS
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Thesis for Doctor of Engineering Degree will be defended on December 29th, 2010, at 14:30, in Riga Technical University, Faculty of Transport and Mechanical Engineering, Institute of transport Vehicle Technology. Address: Riga, Lomonosova Street 1, Building V, room 218.

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CONFIRMATION

I confirm that I have developed the Doctoral Thesis submitted for defense of Scientific Degree of Doctor in Engineering at Riga Technical University. The Doctoral Thesis has not been submitted to any other University for obtaining the scientific degree.

Aivis Grislis
Date: September 15, 2010.

Doctoral Thesis is written in Latvian, it consists of four chapters. The bibliography includes 130 sources; there are 62 figures and 24 tables to illustrate the conception of the research. The Doctoral Thesis contains 184 pages; it is supplemented with nine attachments. The total volume is 243 pages.

ABSTRACT

Doctoral Thesis “Analysis of Possible Use of Long Combination Vehicles for Divisible Cargo Transport” is designed to analyze the possible impact of long combination vehicle usage for divisible cargo transport on road safety and transport efficiency. Long combination vehicles (LCV) complying with the European Modular System (EMS) concept has been chosen for research object. These LCVs are allowed in some Member States of European Union.

The Doctoral Thesis accomplishes seven tasks in four research areas: legislation, road infrastructure, and road safety. An analysis of legality to use LCVs for commercial transport operations is done by detailed classification of long combination vehicles; analysis of legislative acts of the European Union, Republic of Latvia and other Member States. The evaluation of efficiency parameters is done by determination of the estimated amount of long combination vehicle usage in Latvia; creating a methodology of simulation model for analysis of road haulage business projects. Prognosis of benefit for Latvian road transportation companies if typical combination vehicles (widely used truck with semi-trailer and truck with trailer) would be replaced with LCVs and comparative financial analysis of road haulage business projects (road haulage projects realized by using typical combination vehicles and LCVs) is conducted by using simulation model.

An analysis of maneuverability characteristics of long combination vehicles and determination of opportunities to use the existing road infrastructure are done in the Doctoral Thesis. The analysis of road safety issues related to the usage of LCVs is done by theoretical calculations, graphical simulations, and mathematical prediction model. Theoretical calculations results of overtaking maneuvers are compared with experimental measurements on roads. Developed mathematical model identifies the associated factors for large truck accidents on two-lane rural highways and provide useful recommendation for the improvement of highway safety

Key words: long combination vehicles (LCVs), effectiveness analysis of road haulage projects, mathematical models, maneuverability of the LCVs, overtaking maneuvers, causes of truck accidents.

CONTENTS

1. TOPICALITY OF RESEARCH

In 2004, public organization representing several international road transportation/haulage companies in Latvia contacted Department of Automobile Transport at Faculty of Transport and Mechanical Engineering (Riga Technical University) with an offer on cooperation to conduct research about national and international restrictive legislative norms on vehicle dimensions, axle loads and total mass of vehicles. Latvian transport companies wanted to know why they feel there are unfair competition conditions in the international freight market. The perception of unfair competition formed provisions in the national legislation of Sweden and Finland allowing cargo transport services within the 25.25 meters long vehicle combinations for divisible cargo in the domestic freight market. In this way, Latvian hauliers have been denied from equal opportunity. Currently, Denmark and the Netherlands allow the use of LCVs on the main roads. As a result, international freight traffic from the western ports to Russia is transported through the North European countries. The interest of Latvian road haulage companies to use Long combination vehicles for commercial transport operations underlined the need for a thorough study of the problem.

An initiated discussion of the European Commission and several European Union Member State governments as well as a number of research projects on the availability of LCVs for commercial transport operations confirms the topicality of the conducted research and the developed Doctoral Thesis. Regional studies implemented in several Member States of the EU obtained different results on the relative benefits, environmental pollution reduction, modal dominance on the market and parameters of road safety caused by use of Long combination vehicles. In 2009, several interest groups have emerged in Europe to express the both views for and against the introduction of Long combination vehicles.

An engineering research of the potential impacts of the LCVs usage has not been conducted in Latvia so far. The Doctoral Thesis was carried out just for transport research purposes. The author sets out only the study results. The content of the Doctoral Thesis is not an attempt to defend a particular view of society, nor is it an attempt to promote or hinder the use of Long combination vehicles on Latvian roads.

2. OBJECTIVE AND TASKS OF RESEARCH

The aim of the Doctoral Thesis is to analyze the projected impact on road safety and transport efficiency resulting from the possible use of long combination vehicles for commercial freight services of divisible cargos. Several tasks have been set to achieve the objective; an overview of study progress, results and conclusions are summarized in the Thesis subchapters. Each subchapter is devoted to one particular task.

The main tasks for research are:

1. To analyze types of long combination vehicles (longer than the standard European combination vehicles); to develop classification, to define the research object for Thesis (configurations of analyzed LCVs).
2. To determine restrictions in legislative acts of Republic of Latvia and European Union on the use of long combination vehicles for transporting divisible cargoes and LCVs could be used in traffic on general-purpose roads, to make proposals for solving problems and for possible revisions of legislation.
3. To determine the possible extent of use longer combination vehicles (potential to replace typical/standard combination vehicles with LCVs by not to exceeding the axle load and total weight limits) in the international road haulage sector serviced by Latvian haulage companies.
4. To determine the maneuverability parameters of longer combination vehicles at low speed, when different configurations of LCVs are turning to the opposite direction or turning by 90 degrees, or entering/exiting the parking lot designed for trucks and trailers.
5. To determine the effect of length of road combination vehicles on overtaking maneuver parameters (length and duration of overtaking maneuver) and on potential risk of road traffic accidents.
6. To determine a quantitative relationship between the probabilities of road traffic accidents occurrence involving commercial road vehicles, road geometric, and road traffic characteristics/parameters of two-lane rural highways. To analyze the relationship between single-vehicle large truck accidents (accidents where only one vehicle is involved) and design features as well as traffic flow parameters of two-lane rural highways.
7. To determine the potential effectiveness (changes of operating costs, commercial project's economic and financial parameters) of longer combination vehicles by analyzing haulage commercial projects where typical/standard European combination vehicles are replaced by LCVs.

3. RESEARCH METHODOLOGY AND USED METHODS

The Doctoral Thesis is the first transport research work in Latvia where a detailed evaluation of possible consequences of long combination vehicle usage is realized. The selected research methodology is appropriate for conventional research norms and principles: all used research data are identified, each part of the research methodology is described, the research work sequence is successively explained, and the research process is repetitive.

Research methodology and research methods used:

1. Individual research methods (information gathering and processing) and cognitive techniques (grouping of information, analysis and synthesis) are used to analyze types of longer combination vehicles, to develop classification of types, and to define the Thesis object. Previous studies and reports, vehicle manufacturers' technical documentation and legal documents (standards, laws) are used for solving the research task.
2. Individual research methods (collecting and processing information) and cognitive techniques (grouping of information, analysis and synthesis) are used to determine restrictions on usage of longer combination vehicles in legislation of the Republic of Latvia and the European Union, and to make proposals for possible amendments to legislation acts. Legal documents of Latvia and European Union (standards legitimated in definite national territories, national and international legislation), and previous research results are used for solving the second research task. Possible guidelines and amendments for legislation (if there would be positive decision on usage of LCVs in Latvia) are conducted by using method of induction and synthesis of information.
3. Methods of statistical analysis are applied to determine the possible extent of use longer combination vehicles by Latvian companies operating in the international road haulage market. The statistical analysis of freight flow parameters in road transport sector is conducted using data sample (data base created for study) of records/documents accompanying the consignment on the trips of Latvian haulage companies in the international freight transport market to and from third part countries (TIR carnets). Data from Latvian Central Statistical Bureau, the European Union's statistical office *Eurostat* and information from previous research projects are used in addition. Sample data classification and comparison, descriptive statistical analysis, calculations of the mean and relative values of parameters are conducted. Parameters restricting the maximum cargo volume transported by one road vehicle are determined using data sample. The possible extent of use longer combination is calculated in accordance with the dataset processing results.
4. Experiments are made using PC-Crash 8.0 computer program for graphical models to determine the maneuverability characteristics of long combination vehicles at low speed. Through computer simulation experiments, maneuvering characteristics of LCVs at low speed are calculated in various road situations: turning maneuver to the opposite driving direction, turning at intersection of 90 degrees with small and large rounding, parking at commercial vehicles parking place. Experiments of maneuverability parameters of long combination vehicles are conducted in the accordance with regulatory restrictions. To perform computer simulations and experimental data processing, an analysis method is developed for determination of maneuverability parameters of LCVs by measuring driving corridor width and length at 90 degrees turn. Experiments are conducted using road infrastructure in accordance with standards: LVS 190-3:1999 and LVS 190-7:2002. Experiments of maneuverability parameters of typical combination vehicles are conducted to approve

results. The obtained experimental data are processed with statistical analysis methods; they are compared to similar research results and legislative requirements.

5. Experiments are made on general-purpose roads in Latvia to determine the impact of length of road transport vehicles on overtaking maneuver parameters. Road users were not warned about experiments to avoid incorrect measuring results. The methodology of experiments is adapted to Latvian circumstances. The experimental data acquisition is done by filming traffic flow from the moving car, which was following a long combination vehicle at visually constant distance. The additional overtaking maneuvers' parameters are set by a timer and by processing recorded live images (analyzing road markings). After performing experiments, all results are combined in the database, where statistical analysis is conducted by data classification and comparison, nonparametric statistical analysis and determination of relative values. Results of experimental measurements are compared with the results of theoretical calculations carried out in accordance with road safety theory.
6. Road traffic accidents, which are occurred on a single carriageway two-lane road (one traffic lane to each direction) sections outside urban areas, and which are involved one transport unit (truck or combination vehicle), are analyzed to determine the significance of road geometric parameters and traffic flow parameters affecting road traffic accident risk. A mathematical simulation modeling is performed to analyze the influence of traffic flow parameters and the importance of road geometric parameters on road accident occurrence with long combination vehicle involvement. The information about road traffic accidents occurred in the Washington State (USA) provided by the U.S. Highway Safety Information System database on road traffic accidents (scene, vehicles involved, road geometric and traffic characteristic parameters) is used to perform research. At first, the adequacy/suitability of several mathematical distributions to give realible results for predicting traffic accident occurance are determined by applying methods of mathematical statistics. The Poisson, the Negative-Binomial, the Zero-Inflated Poisson (ZIP) and the Zero-Inflated Negative Binomial (ZINB) regression models are compared by determining the t-statistics and by comparative analysis (Vuong test). Statistical data analysis and suitability test of theoretical mathematical distributions are conducted using MS SQL 2005 and SYSTAT 11 software. The Zero-Inflated Negative Binomial mathematical prediction model is determined as the most appropriate. The significance of road geometric parameters and road traffic parameters, and probability density function is determined by developing the mathematical prediction model. The mathematical prediction model is developed by using the software R 2.7.1 and the statistical module "pscl".
7. An analysis of international road haulage commercial project costs including breakdown by cost items and a comparative analysis of Latvian company's commercial road project performance indicators (typical and long combination vehicles are used to provide road haulage operations) is conducted to determine the possible effectiveness of road transport companies' commercial road projects, where typical combination vehicles are substituted by LCVs. Effectiveness parameters of road haulage business projects are estimated by using a computer simulation model.

The model is developed for analyzing specifically road haulage projects (financial performance prediction and analysis). Statistical analysis and mathematical economic methods are used in the computer simulation model. Data processing and determination of system parameters over a specified period is performed by using the MS Excel software and a management program in the VBA environment. An example of road haulage project is used to solve the task of Doctoral Thesis (initial values for project are estimated by expert analysis). The possible effectiveness of long combination vehicles is determined by comparing simulation results of road haulage commercial project parameters, where typical and long combination vehicles are used in equal external conditions.

4. SCIENTIFIC NOVELTY

The main scientific novelty of the conducted Doctoral Thesis research is:

1. The method for quantitative comparison of maneuverability parameters of different configurations of long combination vehicles has been developed; the method has been applied to evaluate the maneuverability parameters LCVs taking a turn by 90 degrees (with different corner radius of curvature). Measurable and comparable turning maneuver parameters have been established.
2. A mathematical forecasting model has been developed to identify significantly affecting highway geometric and traffic flow parameters and to evaluating their influence on the potential risk of traffic accidents involving only one transport unit (truck or combination vehicle).
3. A computer simulation model has been created for measuring and prediction an efficiency of road transport companies' business projects.

5. PRACTICAL IMPORTANCE

Practical importance of the carried out research is characterized by:

1. The research results are used for constructive dialogue between representatives of Latvian haulage companies and Ministry of Transport of Latvia about possibilities to start useing LCVs for commercial transport on roads.
2. Proposals and practical recommendations developed in the Thesis work for possible harmonization of legislation in order to avoid discrepancies and inconsistencies in the area of long combination vehicle useage have been submitted for further consideration to the association "Road Carriers Association "Latvijas auto"'.
3. The results of carried out engineering studies for maneuvering capabilities of longer combination vehicles according to the Latvian road infrastructure have been included in a number of infrastructure research projects, specific recommendations will be used in developing futher road design project recommendations.

4. Developed computer simulation and forecasting model for evaluating haulage business projects' effectiveness is used for forecasting efficiency and for analyzing performance of both passenger and freight transport business projects (both international and local) in research and advisory work.

6. APPROBATION OF RESEARCH RESULTS

Conferences:

1. The 45th Scientific Conference of Riga Technical University. Section: "Production Engineering and Transport". Riga, Latvia, October 14, 2004. Report: "Permissible Length of Road Freight Vehicles and Composition Vehicles", Author: Grislis A.
2. The 63rd Conference of University of Latvia. Conference section: "Management Science", Subsection "Marketing and Logistics". Riga, Latvia, February 3, 2005. Report: „Transportation in Supply Chains", Author: Grislis A.
3. The 46th Scientific Conference of Riga Technical University. Section: "Production Engineering and Transport", Subsection "Road Transportation". Riga, Latvia, October 13 – 15, 2005. Report: "Overtaking of Combination Vehicles", Author Grislis A.
4. The 9th International Conference of Kaunas University of Technology; "Transport Means – 2005"; Section: "Automotive Transport". Kaunas, Lithuania, October 20, 2005. Report: "Efficiency Improvement of Road Haulage Using Long Vehicle Combinations", Authors Grislis A., Kreicbergs J.
5. The 47th Scientific Conference of Riga Technical University. Section: "Production Engineering and Transport". Riga, Latvia, October 13, 2006. Report: "The Modeling of Maneuverability Situations of Long Combination Vehicles", Author: Grislis A.
6. The 10th International Conference of Kaunas University of Technology. Section: "Automotive Transport". Kaunas, Lithuania, October 19, 2006. Report: "Maneuvering Situations Modeling of Long Combination Vehicles", Author Grislis A.
7. The 49th Scientific Conference of Riga Technical University. Section: "Production Engineering and Transport". Riga, Latvia, October 13, 2008. Report: "Research of Road Traffic Accidents Involving Freight Transport Vehicles", Author Grislis A.
8. The 50th Scientific Conference of Riga Technical University. Section: "Production Engineering and Transport", Subsection "Road Transportation". Riga, Latvia, October 13, 2009. Report: "The Analysis of International Commercial Cargo Transport Volume Provided by Latvian Haulage Companies: Possible Usage Analysis of Long Combination vehicles", Author: Grislis A.
9. The 51st Scientific Conference of Riga Technical University. Section: "Production Engineering and Transport", Subsection "Road Transportation". Riga, Latvia,

October 14, 2010. Report: “Analysis of Economical Effectiveness of the Usage of Long Combination Vehicles”, Authors Grislis A., Kreicbergs J.

10. The 51st Scientific Conference of Riga Technical University. Section: “Production Engineering and Transport”, Subsection “Road Transportation”. Riga, Latvia, October 14, 2010. Report: “Comparison of Commercial Road Transport Project Economic Efficiency”, Authors Kreicbergs J., Grislis A.

Publications:

1. Grislis A., Liberts G., Kreicbergs J.. Efficiency Improvement of Road Haulage Using Long Vehicle Combinations // Kaunas University of Technology, Proceeding of the 9th International Conference “Transport Means 2005”. – Kaunas, Lithuania: “Technogija”, 2005, pp. 56 – 58.
2. Grislis A., Liberts G., Kreicbergs J.. Investigation of Haulage by Long Vehicle Combinations in Latvia //, Proceedings of the 12th International Conference “trans & MOTAUTO’05+”, Volume II. – Sofia, Bulgaria: “Scientific-technical union of mechanical engineering”, 2005, pp. 266 – 270.
3. Čivčiša G., Grīslis A., Janauska J., Liberts G., Rudņevs J., Salenieks N. Engineering/Managerial Education for International Business Knowledge in European Small Countries // “Latvijas Lauksaimniecības universitāte” “Inženierproblēmas lauksaimniecībā” Proceedings of the International Scientific Conference. – Jelgava, Latvia: 2005, pp. 6 – 14.
4. Grīslis A. Produktu transportēšana piegāžu ķēdēs // Latvijas Universitātes raksti; Ekonomikas vadības zinātnes sērija; Volume 696. – Riga, Latvia: “Latvijas Universitāte”, 2006, pp. 112 – 122.
5. Grīslis A., Liberts G.. Dalāmu kravu pārvadājumi ar gariem autotransporta līdzekļu sastāviem // “RTU zinātniskie raksti”, Series 6, “Mašīnzinātne un transports” Volume 25; – Riga, Latvia: Izdevniecība “RTU”, 2007, pp. 75 – 84.
6. Grīslis A., Liberts G.. Autotransporta līdzekļu sastāvu apdzīšana // “RTU zinātniskie raksti”, Series 6, “Mašīnzinātne un transports” Volume 25; – Riga, Latvia: Izdevniecība “RTU”, 2007, pp. 65 – 74.
7. Grislis A.. Longer Combination Vehicles and Road Safety. Transport, Journal of Vilnius Gedeminas Technical University and Lithuanian Academy of Sciences. – Nr. 25 (3), 2010, pp. 336 – 343. doi: 10.3846 / transport.2010.41.
8. Grīslis A.. Kravas autotransporta līdzekļu sastāvu ceļu satiksmes negadījumu rašanās risku ietekmējošo parametru analīze // RTU zinātniskie raksti, Series 6, „Mašīnzinātne un transports” - Riga: Izdevniecība „RTU” *(article accepted for publication in the November, 2010).*

7. STRUCTURE OF DOCTORAL THESIS AND SUMMARY OF RESEARCH RESULTS

The Doctoral Thesis consists of introduction, four chapters, conclusions, bibliography and seven appendices. Lists of images and tables, list of used abbreviations, and acknowledgments available in the content of the Thesis work.

Chapter 1. State of the Art Review

The first chapter of the Doctoral Thesis defines research problem and gives a chronological overview of development, it describes the process of strategy and systematic approach to research. By analyzing dynamics of historical growth of road transportation and problems related to this issue, it appears that there is need to seek new solutions to meet growing demand for cargo transport. One of the possible problem solving solutions is usage of longer combinations of freight transport vehicles for long distance cargo transport.

Chapter 2. The Classification of Long Combination Vehicles and Analysis of their Possible Usage

The second chapter of Thesis has two subchapters, each addressed to separate pre-defined task. Each subchapter describes one completed part of research.

Subchapter 2.1. Classification and Analysis of the Long Combination Vehicles' Types

Subchapter identifies long combination vehicles' types, classifies them, and defines the configurations of the long combination vehicles. A comparative analysis of technical parameters of combination vehicles with increased total length used in the North America, South America, Asia and Australia was carried out in this study.

The specificity of Doctoral Thesis research is associated with long combination vehicles. Detailed classification of long vehicle combinations (with increased total length) is done to define the research object of the Thesis. In this classification, a combination vehicles with increased total length used in the Europe, North America, South America, Asia and Australia is included. The classification divides the long combination vehicles (with increased total length) into three parts:

1. Extend vehicle configurations - one of the vehicles forming combination vehicle is longer than standard road combination vehicles in the geographic region; In some cases, combination vehicle does not exceed the maximum length of combination vehicles allowed for other type combination vehicles in the definite region.
2. Bulky vehicle configurations – combination vehicles designed for special and indivisible freight transportation; some of vehicles are longer than permitted in the region.

3. Long configurations vehicles – combination of road vehicles where each of separate vehicles individually meets all regional legislative provisions relating to vehicle sizes and allowable axle loads, and total mass, but the combination of these vehicles is longer (in some cases there is also heavier) than the maximum permitted parameters (see Figure 1).

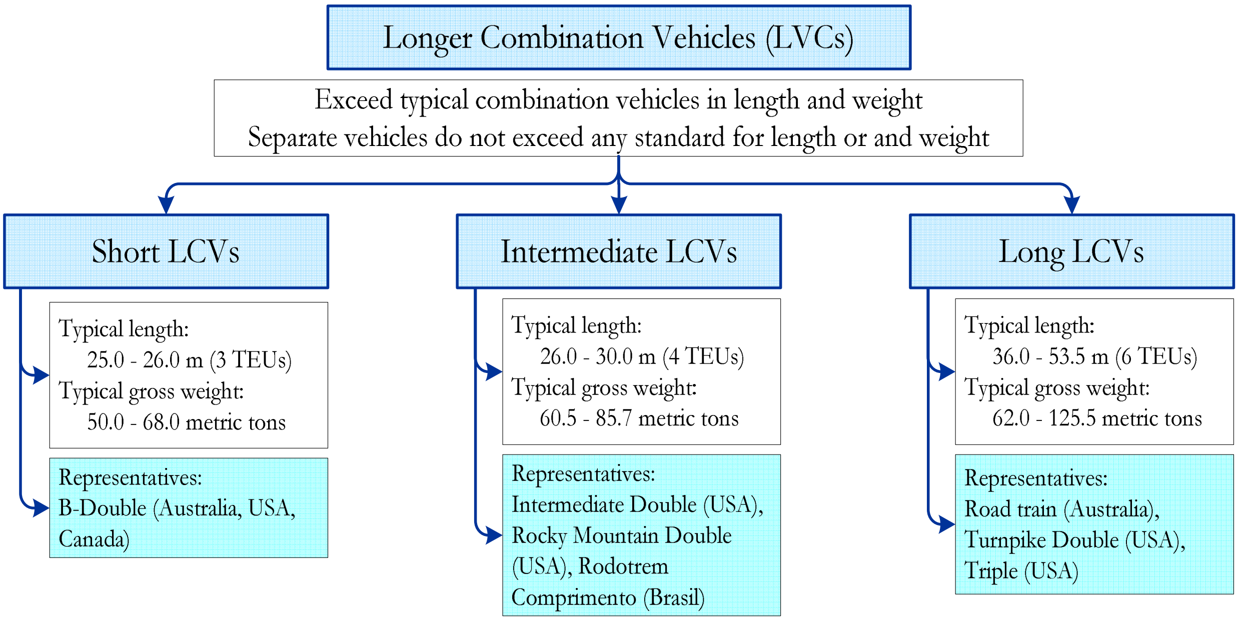
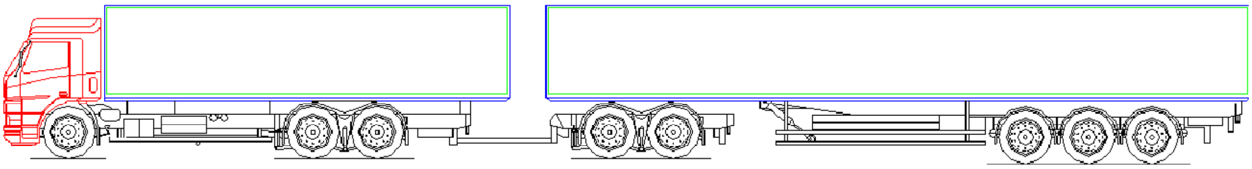


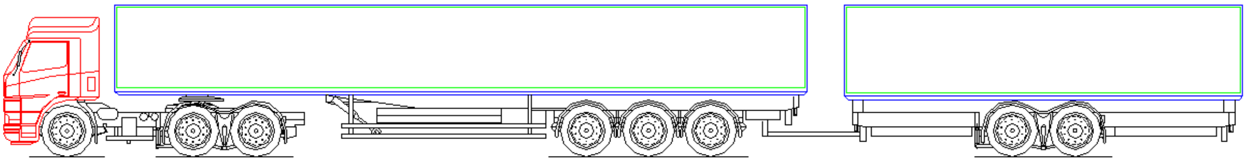
Figure 1. Classification of Long Combination Vehicles

Long combination vehicle with the maximum total length of 25.25 meters (transport capacity 3 TEU) has been chosen as research object. Selected type of long combination vehicles is defined in Directive 96/53/EC as the European Modular Concept combination vehicle. The principal schemes of most frequently used LCVs configurations in the Europe are given in the Figure 2.

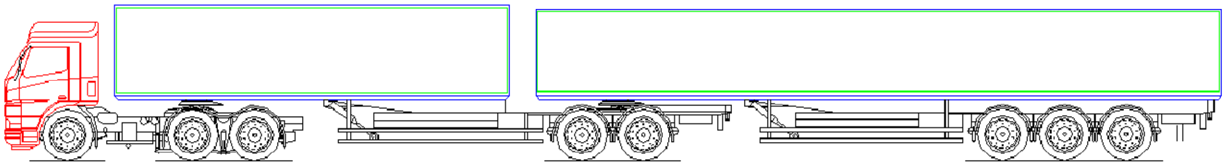
Configurations of long combination vehicles, which do not comply with the European Modular Concept ("D", "E" and "F" configuration), have been analyzed in the work as well.



Conceptual scheme of „A configuration” long combination vehicle (lorry coupled with a standard semitrailer)



Conceptual scheme of „B configuration” long combination vehicle (a truck coupled with semitrailer and central-axle trailer)



Conceptual scheme of „C configuration” long combination vehicle (a truck coupled with specific construction semitrailer and standard semitrailer)

Figure 2. The most common configurations of long combination vehicles in Europe; all configurations comply with European Modular Concept principle

Analysis of possible technical parameters and cargo load capacities of all indicated configurations of LCVs has been analyzed in the Thesis: determined potential volume and weight of transported cargo. All configurations relevant to European Modular Concept principle hold freight area volume up to 30% higher than the standard combination vehicles.

Subchapter 2.2. Analysis of the Legislation Regulating the Usage of Long Combination Vehicles

Subchapter examines the requirements of legislation of the European Union, Republic of Latvia and other Member States for the technical requirements of single vehicles and combination vehicles in order to be permitted to use them for divisible cargo transportation operations, and to be allowed for road traffic on public roads. Legislative rule discrepancies, prompting proposals and practical recommendations for legislative action to harmonize laws have been identified in the study.

After research of the national legislation of several European Union Member States (Latvia, Finland and Sweden) and European Union regulatory directives and regulations has been stated:

1. The legislation of Latvian Republic has equal norms to the European Union documents. Specific exceptions for the dimensions of vehicles, axle load and total weight have not been set out in the existing legislation of the Latvian Republic;
2. The combination vehicles relevant to the European Modular Concept are not permitted in territory of the Republic of Latvia;
3. In the national legislation of Latvian Republic, the specific coupling trolley (dolly) has not been defined, there are no possibilities for their use;
4. The transportation of indivisible bulky goods are allowed in the Latvia;
5. The legislation of EU allows Member States to use the modular concept long combination vehicles for national transport of divisible cargo: Finland and Sweden are using these possibilities in their national legislation;
6. The legislation does not strictly define the EU's position in situations where two or more States bordering to each other allow the European Modular Concept vehicles usage for the domestic market of each Member State. Finnish and Swedish transport companies have a chance to make transport operations (shipping divisible cargoes) to/from Russia with the European Modular Concept combination vehicles;
7. European Union Member States may make test trips/transportation by road vehicles or combinations that do not meet one or more requirements of the European Union Directive. Series of experimental transportation operations and tests have been accomplished using different configurations of vehicles including long combination vehicles in the Netherlands;
8. The coupling trolley (dolly) has not been precisely defined in the European Union regulatory documents. According to Directive 97/27/EC, dollies are considered as a part of vehicle converting a semi-trailer to the drawbar trailer. There is no clearly defined, is dolly a vehicle or a part of other vehicle;
9. In some European countries (e.g. Great Britain, Germany, and the Netherlands), series of pilot transportation services have been carried out for the assessment of long combination vehicles, which do not comply with the principles of the European Modular Concept.

There are several discrepancies and inconsistencies between Latvian Republic, the European Union and other Member States' national legislation in areas of long combination vehicle technical requirements and their usage, there is no common understanding on several technical and legal matters. Before the possible introduction of long combination vehicles on Latvian territory (experimental traffic permitting), it is necessary to amend the national normative documents, coordinating changes to European Union legislation.

Chapter 3. Effectiveness Analysis of the Usage of Long Combination Vehicles

The third chapter of Doctoral Thesis has two subchapters, each addressed to separate pre-defined task. Each subchapter describes one completed part of research. Chapter deals with analysis of predicted amount of usage of long combination vehicles for transporting cargoes internationally and analysis of predicted benefit for road haulage company by switching from typical combination vehicles to LCVs in haulage service operations.

Subchapter 3.1. Analysis of Road Freight Transportation and Determination of Possible Volume of Long Combination Vehicles' Usage

Subchapter examines the cargo transport volume and turnover carried by Latvian haulage companies in both national and international markets; it provides freight transportation (tons) and cargo turnover (tons-km) breakdown by commodity groups (according to NST/R recommendations). Study was carried out using specially designed database compiled with information from accompanying documents (TIR Carnet) of international freight to/from third-party countries (documents provided by National Association of Road Hauliers "Latvijas Auto"), and using publicly available databases. Statistical test results indicate that the sample size used for analysis is sufficient to assess objectively the possible usage volume of long combination vehicles for international freight transportation to and from third-party countries. It has been found that the length of vehicle cargo space is the primary-limiting factor for transported cargo volume by one road vehicle unit. The freight transportation volume has been determined where typical or standard combination vehicles could be substituted with long combination vehicles. According to the methodology of research, in that way, the transported cargo volume could be increased per unit of freight transport without violating the restrictive rules of vehicle total mass and axle load.

The following results of freight transport analysis and the volume analysis of possible use of long combination vehicles have been obtained:

1. Structure and distribution of the transported products is significantly different for domestic and international traffic. Transported products and goods in international transport over long distances often are low volumetric (cargo space of combination vehicles are not fully used). Haulage companies are using full vehicle load (above 90% of the allowable cargo weight) just in 13% of cases.
2. About 39% of cases cargo is transported on 28 and more cargo pallets by the Latvian road haulage companies to/from third party countries. This corresponds to occupancy of cargo area above 80%. 33 or 34 cargo pallets (completely filled cargo space of standard combination vehicle) have been transported in most cases.
3. Detailed cargo traffic analysis shows that the composition of cargo space fulfillment with goods of different groups is different. The most transported goods by Latvian international road haulers to and from third countries are (by commodity group):

a. Machinery, transport equipment, miscellaneous manufactured articles: 30% of the relative movement of vehicles cargo weight is higher than 80% and 41% of cases, the cargo space fulfillment with cargo pallets are above 80%.

b. Food and livestock feed: 80% of shipments are with fully used cargo space (more than 80%) and 37% of cases, the relative length fulfillment of vehicle cargo space with cargo pallets is above 80%.

c. Chemicals: 56% of the relative movements the cargo weight is higher than 80% and 60% cases a load space length of transport vehicles is filled with cargo pallets more than 80%.

4. The long combination vehicles (with increased cargo space length) are effective in improving the efficiency of freight transport. Volumetric characteristics of goods by group are restricting the degree of LCVs usage.

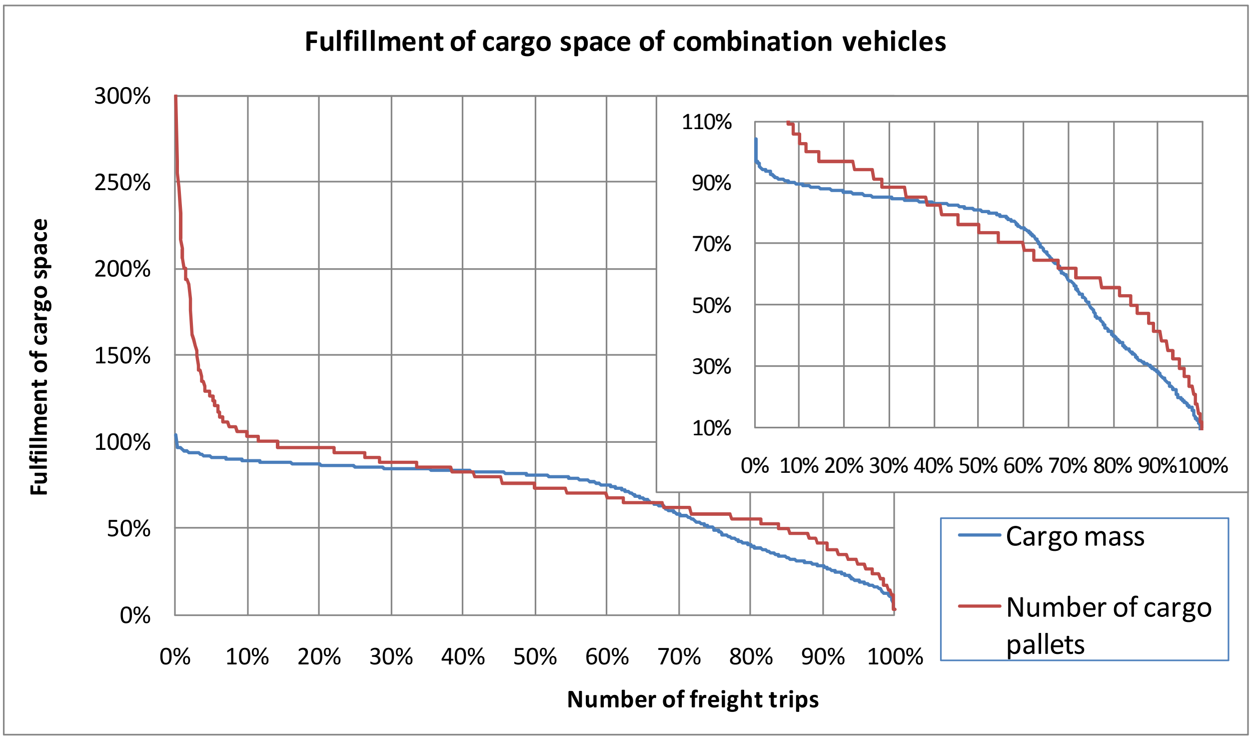


Figure 3. The relative fulfillment (number of cargo pallets) of the length of cargo space of combination vehicles (cargo pallets could be placed up to three one over the other)

5. According to accompanying detailed analysis of transport documents, 24% of all freight transport by combination vehicles could be substituted with the long combination vehicles (see Figure 3). This is a way to increase the transported cargo volume per freight unit (one vehicle) without violating the restrictive rules of total mass. The length of a cargo space of combination vehicles is primary limiting factor of transported cargo volume.

Subchapter 3.2. Analysis of Effectiveness of the Usage of Long Combination Vehicles

Subchapter analyzes the predicted benefit of Latvian transport companies, typical combination vehicles partially or totally replaced by the LCVs in transportation operations. The analysis is done by developing simulation model for forecasting efficiency parameters of commercial haulage project realized by Latvian freight transport company. The computer-forecasting model is developed in *MS Excel* as a number of electronic data tables with scenarios controlled by *Visual Basic for Applications* programming. Simulation model is developed for analyzing commercial road transport projects; it could be used for forecasting efficiency and performance of both passenger and commercial freight transport projects.

The feasibility evaluation of long combination vehicles and comparative analysis of commercial road project efficiency indicators has been conducted in two phases. The first stage: analysis of costs and general breakdown by cost items for international road haulage company (providing road haulage operations using typical combination vehicles and long combination vehicles). The second phase is done by identification and comparative analysis of efficiency indicators of commercial road haulage project carried out by Latvian company.

The cost analysis of business project realization of road haulage providing transportation operations with the standard combination vehicles and LCVs results:

1. In the equal conditions of economic activity, commercial road transport projects where standard combination vehicles will be substituted with the LCVs the total costs of one traveled kilometer will increase by 24%. The results determined that the efficiency of business project would sharply decline with increase of empty running of vehicles.
2. In the equal conditions of economic activity, commercial road transport projects where standard combination vehicles will be substituted with LCVs the total costs per unit of cargo turnover (ton-km) would be reduced by 23% (see Figure 4). Finding justifies that the usage of long combination vehicles for divisible cargo transport could lead to benefit of road transport companies.
3. The largest percentage of costs is expenditure for fuel (37% - 40%), labor costs (20% - 22%) and vehicles and other fixed assets depreciation (15% - 16%). The cost percentage breakdown of subgroups for haulage business projects realized with standard road combination vehicles and long combinations does not change significantly (about 3%).

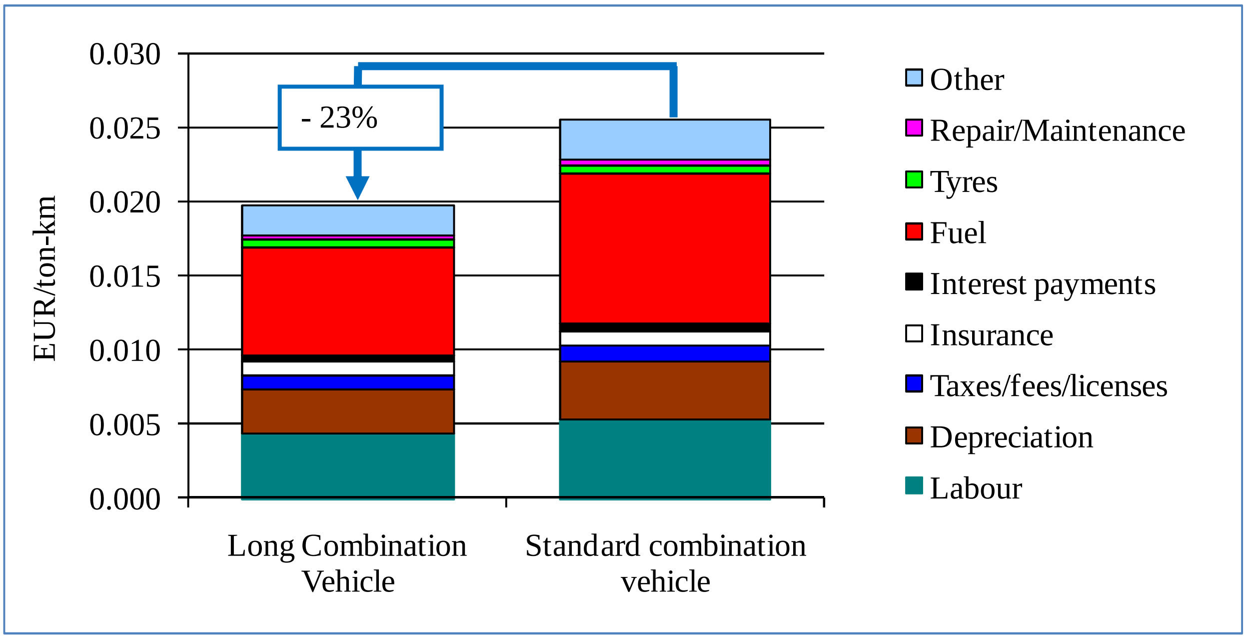


Figure 4. The total costs per unit of cargo turnover (EUR/ton-km) of business project of road haulage; comparison of business projects realized with typical/standard combination vehicles and longer combination vehicles (LCVs)

4. Business project realized by using typical/standard combination vehicles for haulage operations has higher liquidity ratio comparing to identical projects realized by using LCVs. This could be explained by the need to attract less capital investments (lower vehicle price) at the beginning of implementation of the project.
5. It is expected that the commercial road haulage project will have higher efficiency (at similar economic environment used in the developed simulation model), if it will be realized by using long combination vehicles. The statement is done by analyzing predicted efficiency parameters for five-year period. See Figure 5 and Figure 6 as example of graphical view of balance sheet of haulage project realized in equal economic environment and carried out by using standard/typical road combination vehicles and LCVs.
6. Simulation model developed for commercial road haulage project efficiency analysis works correctly. Parameters' values selected by expert method are eligible for real business environment. The simulation model results are reliable and usable for evaluation of commercial haulage projects and road transport cost structure analysis (see Figure 5 and Figure 6).

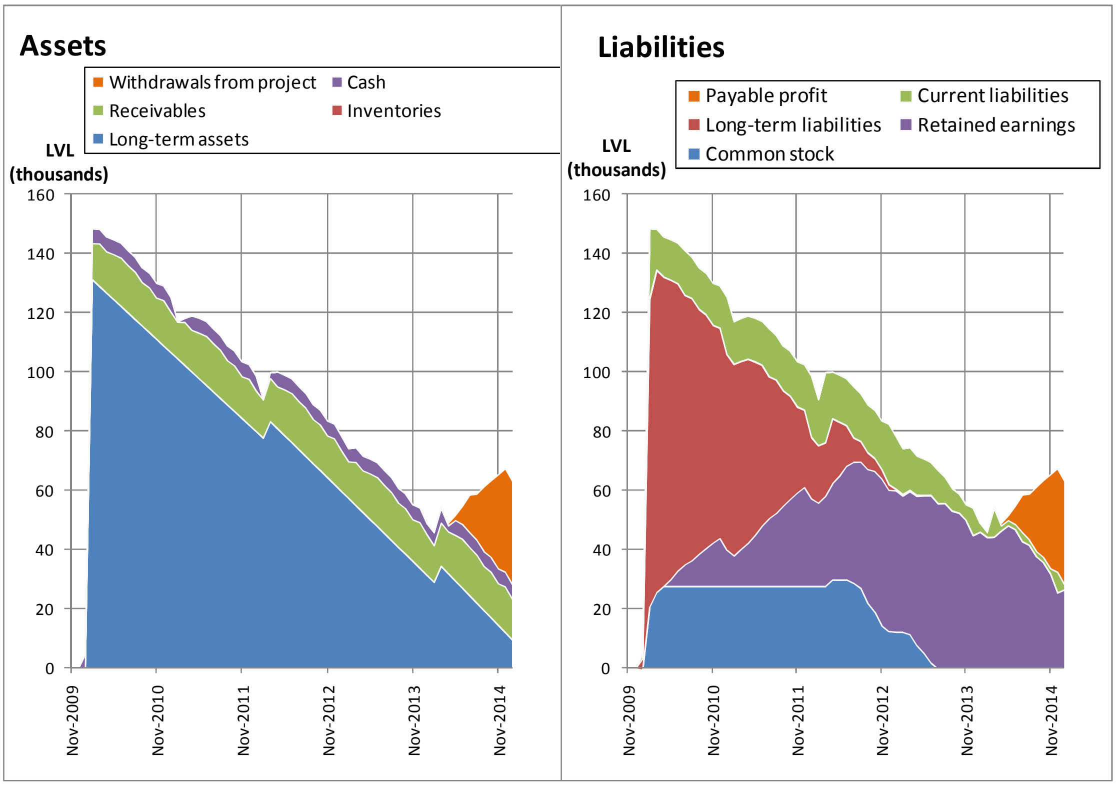


Figure 5. An example of predicted balance sheet in graphical form for international haulage business project (using standard/typical combination vehicles)

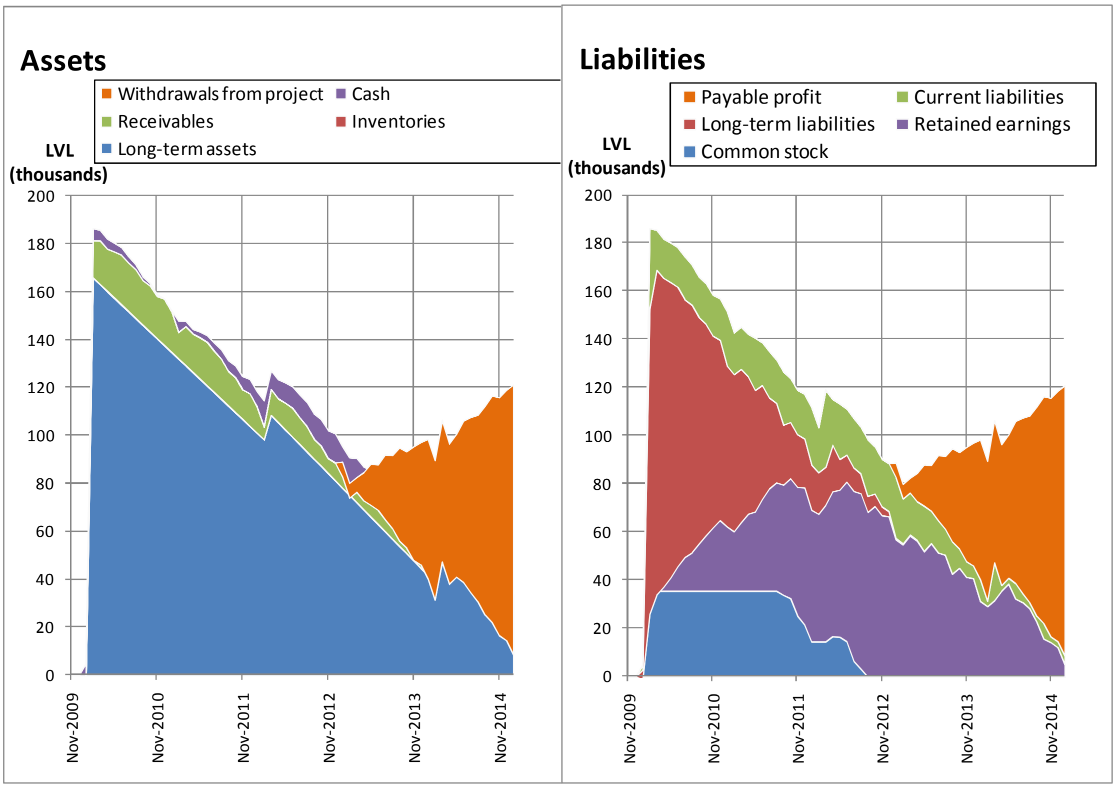


Figure 6. An example of predicted balance sheet in graphical form for international haulage business project (using long combination vehicles)

Chapter 4. Analysis of Road Safety Elements Influenced by the Usage of Long Combination Vehicles

The fourth chapter of Doctoral Thesis has three subchapters, each addressed to separate pre-defined task. Each subchapter describes one completed part of research.

Subchapter 4.1. Analysis of Maneuverability of Long Combination Vehicles

The maneuverability parameters are analyzed for long combination vehicles moving at low speed. Using the graphical computer simulations created with *PC-Crash 8.0*, the inner and outer radius) of U-turn (turn to opposite driving direction) and the parameters of turn to the right (with the internal rim rounding of 8 and 12 meters) has been modeled for six different configurations of typical combination vehicles and LCVs. The compliance of LCVs maneuverability with the legislative requirements has been determined. The possibilities to use existing service zones (parking lots, warehouses, petrol stations, etc.) for LCVs have been analyzed in this research part as well. Computer simulation results are compared with results obtained in the previous studies.

Research results of maneuverability parameters of long combination vehicles:

1. Long combination vehicles are allowed for use on public roads in several European Union countries; National legislation in these countries defines different from Directive 96/53/EC values of vehicle maneuverability parameters of LCVs.
2. Computer modeling results show that none of the long combination vehicles (analyzed "A", "B", "C" and "D" configurations of LCVs) cannot make U-turn (turn to opposite driving direction) in borders of set of concentric circle defined in the Directive 96/53/EC (see Table 1). The “A” configuration of long combination vehicles (without without the steerable axles) has the narrowest (7.9 meters) corridor for turn to opposite direction. The “C” configuration of long combination vehicles (without without the steerable axles) has the widest (10.2 meters) corridor for turn to opposite direction.
3. Computer modeling results show that the out-swing of vehicle rear part for all analyzed long combination vehicles is less (from 0.1 meters to 0.3 meters) than maximum permitted value (see Table 1).

Table 1. Summary of parameter values for long combination vehicles turning to the opposite driving direction

Combination vehicles are turning to the opposite driving direction in the circle radius of 12.5 meters	Results of previuos studies	Results of PC-Crash modeling		Complies with maneuverability requirements in the Directive 96/53/EC
	Corridor width (meters)	Corridor width (meters)	Rear out-swing (meters)	
Articulated vehicle (16.5 meters)	6.74* - 6.84	7.2	0.2	YES
Lorry with a two-axle trailer (18.75 meters)	<7.2	6.5	0.1	YES
"A configuration" long combination vehicle (25.25 meters)	7.2* - 10.5	7.9	0.1	NO
"B configuration" long combination vehicle (25.25 meters)	<10.5	9.3	0.1	NO
"C configuration" long combination vehicle (25.25 meters)	7.51*	10.2	0.1	NO
"D configuration" long combination vehicle (18.75 meters)	>7.2	9	0.3	NO

4. Computer modeling results show that all investigated long combination vehicles (analyzed the "A", "B", "C" and "D" configuration of LCVs) making a ninety-degree turn to the right (corner rounding of 8 and 12 meters) would take a longer and wider turning lanes compared to the standard combination vehicle making an identical maneuver. "A" configuration of long combination vehicles shows good maneuverability at turn to the right (corner rounding of 8 meters) taking about 14% more turning lanes compared to a standard vehicle composition (tractor with semitrailer). Computer modeling shows a poorer maneuverability for the "C" configuration of long combination vehicles, which makes a turn to the right (corner rounded to 8 meters) by 5.1 meters longer and 3.1 meters wider corridor compared to standard combination vehicle.
5. The computer modeling results of long combination vehicles turning to the right at large corner rounding (R = 12 meters and more) show that difference between maneuverability parameters of standard combination vehicles and long combination vehicles is relatively low. Maneuverability characteristics of the European Modular Concept vehicles are 10% to 23% (+0.6 meters to +2.7 meters) worse as for standard combination vehicles (results of computer modeling.
6. Computer simulations show that in the service areas designed for servicing standard vehicle combinations, it is impossible to drive in and to park long combination vehicles (See the Figure 7 for graphical example of trajectory of LCVs in typical parking lot). During arrival and departure maneuvers, long combination vehicle is using parking places and safety zones of other vehicles. Leaving the long combination vehicle at parking, it will reduce parking lot capacity.

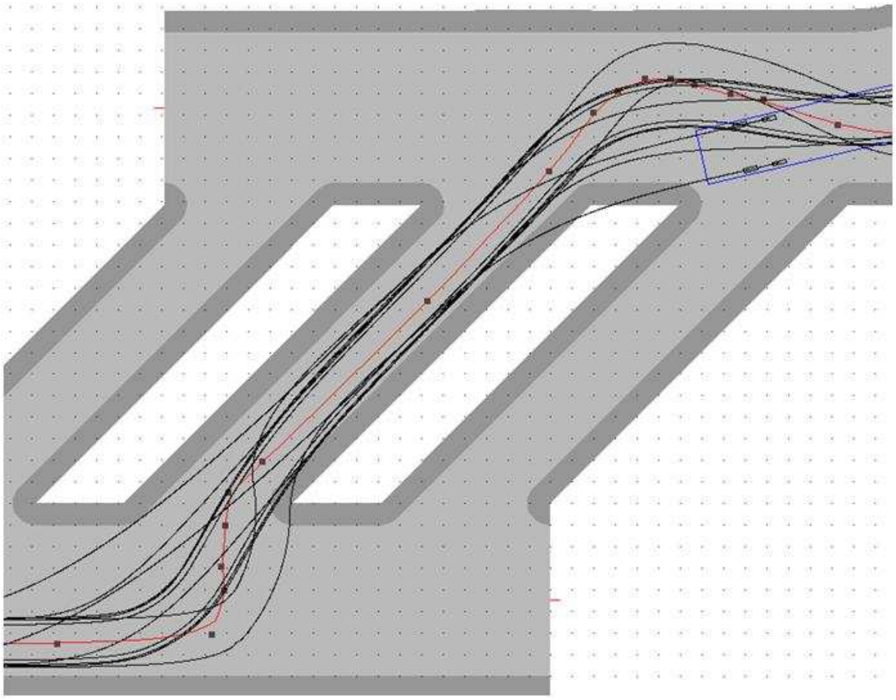


Figure 7. The maneuver scheme of "A configuration" long combination vehicle entering and leaving the parking lot

Vehicle models are used without the steerable axles in computer simulations. Improved design of vehicles with steerable axles and edited the wheel axle position can improve maneuverability of LCVs.

Subchapter 4.2. Analysis of Overtaking Maneuvers of Combination Vehicles

The effect of total length of combination vehicles on characteristics of overtaking maneuver and road accident risk has been determined in the subchapter. The number of overtaking maneuvers and evaluation of overtaking maneuvers depending on the difference of speeds of vehicles has been estimated in this part of research.

Analysis of overtaking maneuver of combination vehicles has been performed in several stages. At first, theoretically necessary overtaking maneuver parameters have been calculated for all configurations of long combination vehicles at different speeds; calculations based on past studies and mathematical relationships of traffic safety. Experimental measurements of overtaking maneuvers of long combination vehicles on major Latvian roads on daily traffic (without any restrictions) have been made at the second phase of the study. The experimental measurements made using video captured from car following LCVs. Filming was done through windscreen of the car. Passenger car with camera drove behind (with distance of about 100 meters) different configuration of combination vehicles with the total length of 16.5 meters, 18.75 meters and 24.00 meters. Overtaking maneuver experiments were conducted in 2005, when 24.00 meters long combination vehicles were legally used for transporting divisible cargoes in Latvia (legal exception for short time period).

Results of processed videotaping have been entered in the database; descriptive statistical analysis of experimental data has been performed. Main results of analysis of road combination vehicles overtaking maneuvers are:

1. By comparing the overtaking maneuvers made at legal speed regime on rural roads, calculated length of the overtaking maneuver, where car is overtaking 25.25 meters long combination vehicle, will be up to 13% longer compared to overtaking maneuver, where typical combination vehicle (18.75 meters length) has been overtaken (see Figure 8).

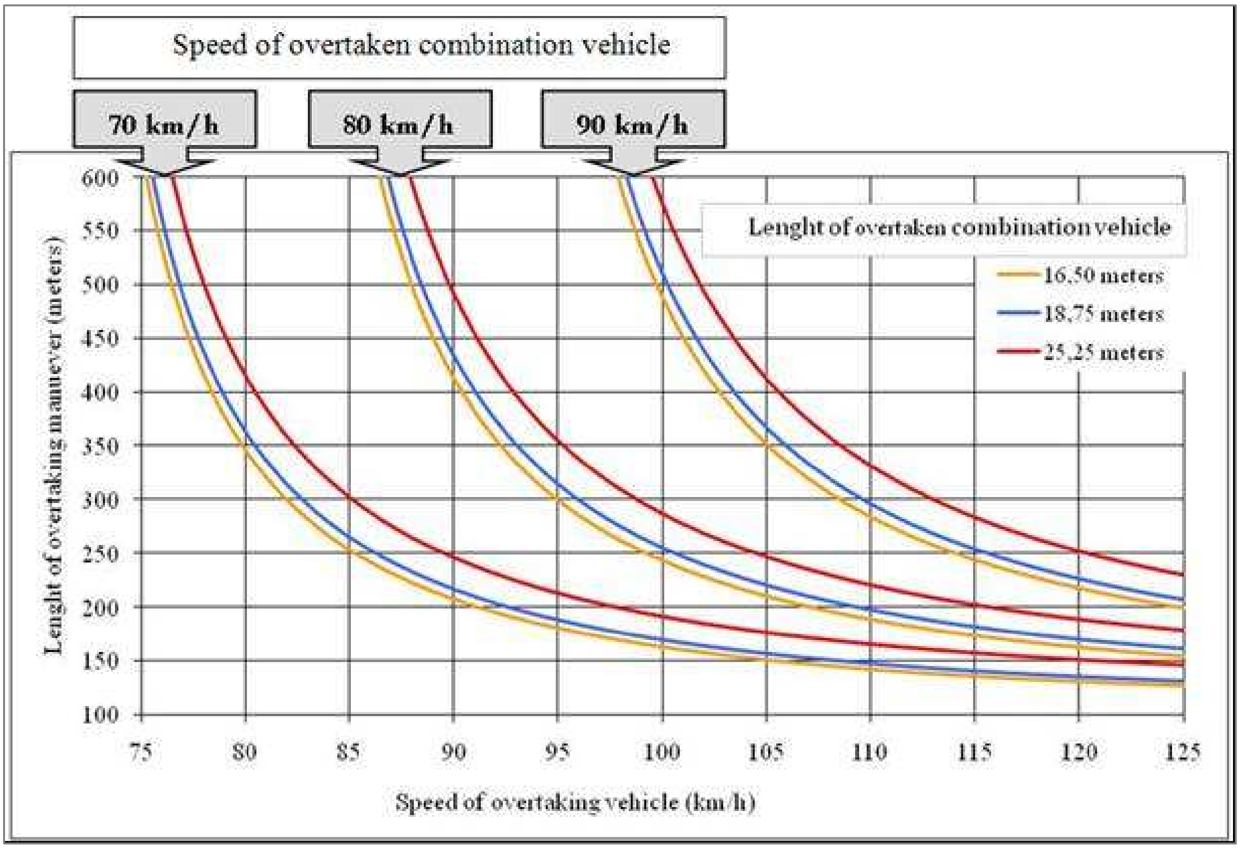


Figure 8. The length of overtaking maneuver depending on the length of combination vehicle, speeds of combination vehicle and the speed difference between overtaking car and overtaken combination vehicle

2. Determined that 25.25 meters long combination vehicle speed should be 78.7 km/h to get the equal overtaking maneuver length to the length of the overtaking maneuver, in which car overtakes the 18.75 meters long combination vehicle. The speed difference between overtaken combination vehicles – 18.75 meters long truck with a trailer and 25.25 meters long LCV 1.3 km/hour (1.6%).

3. The length of overtaking maneuver is significantly affected by speed of traffic flow and by speed difference between overtaken and overtaking vehicle. The effect of LCVs total dimensions on length of overtaking maneuver has secondary importance. It could not be said that the length of the long combination vehicle is the primary influencing road safety factor. The impact of road vehicles length on the overtaking

maneuver length decreases with increasing speed difference between overtaken and overtaking vehicle.

4. Legal maximum speed reduction of long combination vehicles (e.g. up to 70 km/h) will increases the number of overtaking maneuvers of LCVs. Traffic flow creates high safety risk in which heavy cargo transport units are moving at different speeds and are doing reciprocal overtaking maneuvers.
5. Results of experimental measurements of overtaking maneuvers on Latvian roads are close to theoretical results. A correlation between speed difference of vehicles involved in overtaking maneuver and length of overtaken road combination vehicle has not been observed in the measurement results.
6. Drivers of overtaking cars are choosing speed according to specific traffic situation; about 70% of the overtaking maneuvers are performed with up to 20 km/h speed difference between overtaking car and overtaken combination vehicle (see Figure 9). By comparing parameters of overtaking maneuvers, it could be observed that the difference of average duration of overtaking maneuvers involving 18.75 meters and 24.00 meters long combination vehicles is 1.7 seconds.

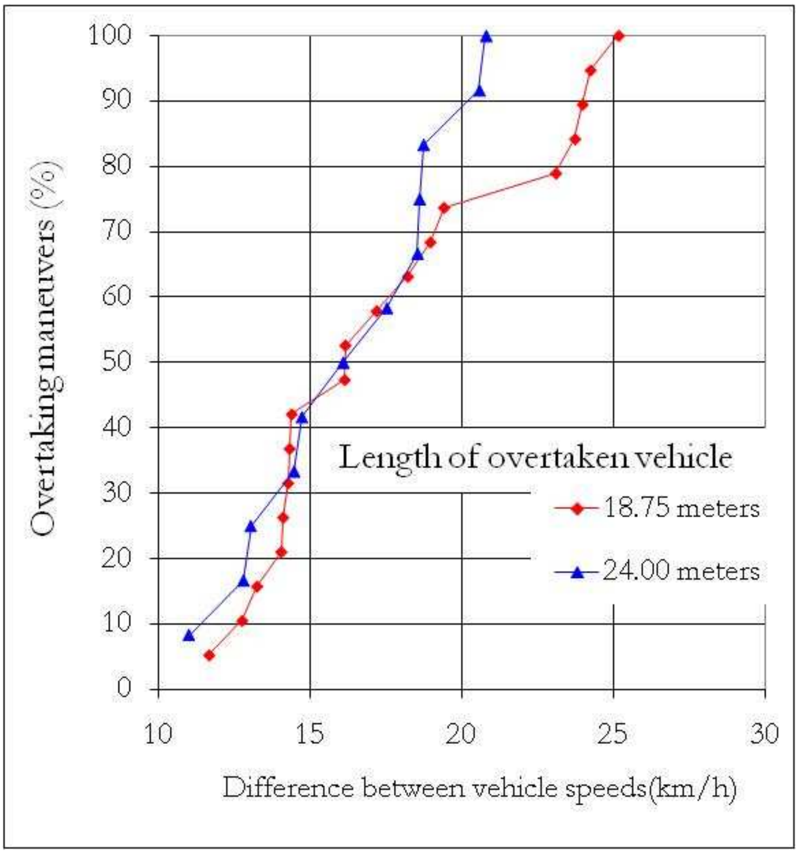


Figure 9. Results of road experimental measurements: the number of overtaking maneuvers depending on the difference of vehicle speeds

7. Overtaking maneuvers of each individual long combination vehicle are longer and could be more dangerous. According to conclusions of other chapters of the Thesis work and results of past research findings done by other authors, the total number of road vehicle units (number of heavy cargo vehicles) may be reduced on road by using

long combination vehicles. Thus, it is possible to reduce number of slower moving vehicles in traffic flow and it is possible to reduce total number of overtaking maneuvers. Specific studies should be conducted for statistical justification of this statement.

Figure 10. A shot from video material of experimental data obtaining process where dangerous overtaking maneuver has been fixed

Overtaking maneuver of long combination vehicles is longer compared to overtaking maneuver of standard/typical combination vehicles. The extra overall length of LCVs is only one of the factors affecting parameters of overtaking maneuver. Drivers' discipline in Latvia, driving culture and technical condition of road infrastructure highly affect road safety and danger of overtaking maneuvers in particular (example on Figure 10).

Subchapter 4.3. Analysis of Parameters Influencing the Occurrence of Road Traffic Accidents of Freight Transport Vehicles

Impact assessment of traffic flow parameters and road geometric parameters on traffic accident risk involving freight transport vehicles has been accomplished in this subchapter. The mathematical prediction model using Zero-Inflated Negative Binomial (ZINB) theoretical distribution has been developed for quantitative analysis of impact parameters. Mathematical modeling was done using several databases including information on the situation in Washington State of the U.S.A. geometric parameters (elevations, longitudinal profile) of all two-lane road sections in the Washington State and accident characteristics (place of occurrence, vehicle data, driver data, road conditions) of a four-year period has been used for development of mathematical prediction model.

Traffic safety theory assumes that number of road accidents that occur during given period on given length of road section corresponding to the normal distribution. Since traffic accidents are discrete events, the Poisson distribution (theoretical distribution for discrete variables) should be used instead of normal distribution (continuous events). In the Poisson regression model, the probability of having m_i accidents in given time interval at given roadway section is given by:

$$P(m_i) = \frac{e^{(-\lambda_i)}\lambda_i^{m_i}}{m_i!} \quad (1)$$

Where $P(m_i)$ is the probability of roadway section i having m_i accidents during the given time interval and λ_i is the Poisson parameter for roadway section *i*.

The relationship between the expected number of road accidents and the Poisson parameter could be expressed in terms of mathematical expectation: $E[m_i] = \lambda_i$. The expected number of road accidents (rate of expected event *i*) is a function of explanatory variables (parameters) of each roadway section (e.g., roadway width, curvature, vehicle-miles traveled, AADT). Usually, function between set of roadway parameters and Poisson parameter is expressed in exponential form:

$$\lambda_i = e^{(\beta X_i)} = EXP(\beta X_i) \quad (2)$$

Where β is a vector of parameters being estimated and X_i is a vector of set of explanatory variables (parameters of roadway section). Poisson distribution opportunities for usage in road transport data analysis is described in literature (Washington, et al., 2003), (Miaou, et al., 1993), (Miaou, 1994), (Lord, et al., 2005). If the Poisson parameter is known, probability of having road traffic accident on the *i*-th section of roadway could be written in this form:

$$P_{0,i} = EXP(-\lambda_i) \quad (3)$$

$$P_{j,i} = \left(\frac{\lambda_i}{j}\right) P_{j-1,i}$$

Where $P_{0,i}$ is probability of having zero (none) road traffic accidents on *i*-th section of roadway in the given time period. The probability $P_{j,i}$ determines that road traffic accidents will occur on *i*-th roadway section during given period. Furthermore, *j* represents the number of road accidents ($j = 1, 2, 3, ...$).

If the variance of accident data is significantly larger than its mean, the Negative Binomial (NB) regression model is usually used. The Negative Binomial regression model is close related to the Poisson distribution model and it is created after formulation of the heterogeneity of data. The expected frequency of occurrence of each *i*-th observation now could be expressed in this way:

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \quad (4)$$

The function $EXP(\varepsilon_i)$ used in the equation (4) is a descriptive term of Gamma distribution error with mean 1 and variance α^2. The Negative Binomial distribution function could be written in several forms, one of them is as follows:

$$P(m_i) = \frac{\Gamma\left((\alpha^{-1}) + m_i\right)}{\Gamma(\alpha^{-1})(m_i!)} \left(\frac{\alpha^{-1}}{(\alpha^{-1}) + \lambda_i}\right)^{\alpha^{-1}} \left(\frac{\lambda_i}{(\alpha^{-1}) + \lambda_i}\right)^{m_i} \quad (5)$$

Term $\Gamma(\dots)$ used in equation (5) is a Gamma function. The likelihood function, based on probability mass function (PMF), could be written in this form:

$$L(\lambda_i) = \prod_{i-1}^{n} LN \left[\frac{\Gamma\left((\alpha^{-1}) + m_i\right)}{\Gamma(\alpha^{-1})(m_i!)} \left(\frac{\alpha^{-1}}{(\alpha^{-1}) + \lambda_i}\right)^{\alpha^{-1}} \left(\frac{\lambda_i}{(\alpha^{-1}) + \lambda_i}\right)^{m_i}\right] \quad (6)$$

Two types of observing zero traffic accidents are determined in prediction models of road traffic accidents. The first type of zero-count state is related to non-occurred accident, which could occur with some probability in other period. The second type of zero-count state of accidents on specific roadway section determines non-occurred accidents, which are true zero accident (could not happened in other period as well). Both types of zero-count state appear as zeros in the data set used for mathematical prediction modeling. Zero-Inflated models are designed to determine if there are any observations that are close to or in zero-count state and are it follows some known count process. It is curtail, how well prediction model distinguishes between these two types of zero-count states.

Specific forms of Poisson distribution and Negative Binomial distribution models: Zero-Inflated Poisson (ZIP) and Zero-Inflated Negative Binomial (ZINB) regression models have been developed to solve counting processes with large amount events in the zero-state (Washington, et al., 2003).

Algebraic forms of ZIP and ZINB regression models provided by Williamson (Williamson, et al., 2007) are adopted in this research. Assume that M_i is non-negative integer number of road traffic accidents occurred on i-th roadway section, where $i = 1,2,3 \dots N$. The probability of having zero accidents occurred on specific roadway section during defined time is π_i, where $0 \le \pi_i \le 1$. According to Y.B. Cheung (Cheung, 2002), if the random variable M_i follows to ZIP distribution, than (Williamson, et al., 2007):

$$P(\mathrm{M_i} = \mathrm{m_i}) = \begin{Bmatrix} \pi_i + (1-\pi_i)e^{-\lambda_i}, \text{ ja } m_i = 0 \\ (1-\pi_i)\frac{e^{-\lambda_i}\lambda_i^{m_i}}{m_i!}, \text{ ja } m_i > 0 \end{Bmatrix} \tag{7}$$

If $i = 1,2,3 \dots N$.

Mathematical expectation of random variable following to ZIP distribution is equal to:$E(M_i) = (1-\pi_i)\lambda_i$, but dispersion is equal to: $VAR(M_i) = (1-\pi_i)\lambda_i(1+\pi_i\lambda_i)$.

If the random variable M_i follows to ZINB regression distribution, than (Williamson, et al., 2007):

$$P(M_i = m_i) = \begin{Bmatrix} \pi_i + (1-\pi_i)\left(\frac{1}{1+\alpha\lambda_i}\right)^{\alpha^{-1}}, & ja\ m_i = 0 \\ (1-\pi_i)\frac{\Gamma\left((\alpha^{-1})+m_i\right)}{\Gamma(\alpha^{-1})(m_i!)}\left(\frac{\alpha\lambda_i}{1+\alpha\lambda_i}\right)^{m_i}\left(\frac{1}{1+\alpha\lambda_i}\right)^{\alpha^{-1}} & , ja\ m_i > 0 \end{Bmatrix} \tag{8}$$

If $i = 1,2,3 \dots N$.

Mathematical expectation of random variable following to ZINB regression distribution is equal to: $E(M_i) = (1-\pi_i)\lambda_i$, but dispersion is equal to: $VAR(M_i) = (1-\pi_i)\lambda_i(1+(\alpha+\pi_i)\lambda_i)$, where α is over-dispersion parameter. If $\alpha \to 0$, ZINB regression model is equal to ZIP model and equation (8) takes the same form as equation (7).

Appropriate prediction model guidelines provided by Shankar (Shankar, et al., 1997) are used in this research. Method is based on possible values of Vuong test and on t-statistics of over-dispersion parameter α. The Vuong statistics (Vuong, 1989) is used to determine which of the theoretical distributions is more appropriate for given data sample.

Since for 96.5% of observations (roadway sections) in used data sample there have not been fixed event (road traffic accident involving one transport unit – single truck or road vehicle combination) during the analyzed time period, the impact of zero-count events is important for accuracy of prediction model.

Value of statistical parameter of Vuong Non-Nested Hypothesis Test is: V =- 10.175; it is recommended to use Zero-Inflated prediction model. According to test findings, the Zero-Inflated Negative Binomial (ZINB) prediction model is chosen in order to determine the frequency of expected occurrence of traffic accidents.

For each roadway section i, a function of expected occurrence of road traffic accidents involving one transport unit – single truck or truck-trailer combination could be written in this form:

$$\lambda_i = (L_i)EXP(\beta X_i + \varepsilon_i) \quad (9)$$

Parameter (L_i) used in the equation (9) is length of each i-th roadway section in miles, β is coefficient of each parameter, which should be calculated, and ε_i parameter characterizing NB regression.

If a risk of road traffic accident has been defined as number of road accidents versus total vehicle mileage on definite roadway section in specific period, than function $EXP(\beta X_i + \varepsilon_i)$ expresses risk of occurrence of these traffic accidents.

Data analysis and probability density function is calculated using the software R 2.7.1 and statistical module “pscl” developed by Political Science Computational Laboratory, Stanford University (Jackman, 2008).

The obtained mathematical model provides satisfactory compliance with the statistical data. The modeling result is quantitatively comparable indicators of road geometry and traffic flow influencing the number of road traffic accidents involving one transport unit: truck or road combination vehicle. Results are summarized in Table 2. By analyzing the results of mathematical regression model, it could be concluded that:

1. The most influencing parameter of analyzed types of road traffic accidents (RTA) is percentage of trucks in road transport flow on particular roadway section. Effect of parameter is positive: as more trucks moving along the road section as higher risk of road traffic accidents involving trucks and combination vehicles.

2. The total mileage on each roadway section is the only parameter that significantly affects both potential number of RTA and likelihood that traffic accident will not happen on this roadway section during definite time. Parameter has positive influence on RTA risk (as the value of parameter is increasing the potential risk of road traffic accident is growing). On the other hand, the parameter is only relevant parameter that determines completely safe roadway segments at true-zero state of prediction model. It could be seen in results of modeling that the probability of not having any accident decreasing rapidly by increase of total mileage on each road section.

3. Road shoulder width significantly affects the likelihood of analyzed type of RTA. The minus sign for the estimated value of this variable indicates that wider shoulders decrease number of accidents. Width of right and left shoulder has been used separately in model developing stage; however, using them as two separate parameters, they are not significantly affecting risk of RTA.

4. Both curves with degree more than 6 degrees and more than 10 degrees have been found significant. The increasing influence of both these variables indicates that roadway segments with higher percentage of length with sharp curvature have higher likelihood of large truck RTA. Variables indicating percentage of segment length with curvature less than 6 degrees are found insignificant.

Table 2. Parameters significantly influencing the risk of road traffic accidents taking place on two-lane road rural segments involving one road transport unit – truck or road combination vehicle; Zero-Inflated Negative Binomial estimation of accident expected number

Count Model Coefficients (Negative Binomial with Log Link)				
Variable	Description of Variable	Estimate Value	Standard Error	z value
Constant	Estimated constant	-3.694	0.193	-19.136
TruckPrct	Truck percentage in traffic flow	0.071	0.005	13.058
MVMT	The total mileage of road vehicles	0.515	0.051	10.004
aadt	The anual average daily traffic flow	-0.113	0.017	-6.568
PrincipArterial	The rural principal arterial (main road)	0.594	0.099	5.981
AveShldWid	The average width of both shoulders	-0.067	0.020	-3.273
PrcCurveC	The percentage of roadway segment length with degree of curvature 6 <= ά < 10 degrees	0.022	0.003	7.587
PrcCurveD	The percentage of roadway segment length with degree of curvature ά => 10 degrees	0.023	0.003	7.444
Zero-Inflation Model Coefficients (Binomial with Logit Link)				
Variable	Description of Variable	Estimate Value	Standard Error	z value
Constant	Estimated constant	2.541	0.186	13.678
MVMT	The total mileage of road vehicles	-10.308	1.970	-5.233
Log-likelihood with constant only (G)				-2467
Log-likelihood at convergence (G)				-1979

5. It is found that grade of roadway has not significant influence on single-vehicle large truck accidents; none of the grade characters have been found significant. This finding is similar to results of other truck accident models created earlier.
6. The highest potential risk of occurrence of road traffic accidents involving large trucks is on road sections with large AADT and high percentage of freight trucks in traffic flow. All the parameters characterizing the traffic flow have increasing influence on risk of traffic accident occurrence.
7. According to descriptive statistical analysis, the most frequently occurred type of road traffic accident involving one transport unit – truck or road combination vehicle is striking appurtenance or striking other stationary object (summary 37%) followed by vehicle overturning (35%). Strikes the end of other vehicle is the most happening

type of road accidents involved more than one transport units, one of which is truck, truck-trailer or other road combination vehicle.

Annexes of the Thesis work

Annex 1. Example of Long Combination Vehicles Usage in the European Union. Information about implementation process of long combination vehicles and technical requirements of European Modular System (EMS) defined by national legislation of Sweden.

Annex 2. Used Data and Results of Freight Transport Analysis. Findings from freight transportation analysis and information about the data sample (processed results are shown in graphical and tabular form).

Annex 3. Previous Research Results Analyzed Costs of Road Transportation Operations. Comprehensive review of previous studies and cost distribution by cost items of road haulage companies.

Annex 4. The Efficiency Indicators Characterizing Business Projects of Road Haulage. Efficiency indicators and their forecasted changes over the time for one business project of road haulage company.

Annex 5. The Graphical Model Schemes for Analysis of Maneuverability of Combination Vehicles Developed in program PC-Crash 8.0. Graphical model schemes of six configurations of typical combination vehicles and long combination vehicles developed for analysis of road combination vehicles maneuverability parameters (combination vehicles are making a turn to the right for ninety degrees with the internal rim rounding of 8 and 12 meters).

Annex 6. The Highway Safety Information System (HSIS) Data Base Fields Used for the Development of Mathematical Prediction Model. Information of parameters and their characteristics required for development of the mathematical prediction model.

Annex 7. Code in Computer Software „R 2.7.1." for Development of Mathematical Prediction Model. Code in text form of computer program for modeling mathematical prediction model.

Annex 8. The overall review on the Thesis work and the review on practical importance of the Thesis work from Latvian Road Carriers Association "Latvijas auto ".

Annex 9. The review on the Thesis work from the Latvian National Association of Freight Forwarders "LAFF".

8. CONCLUSION

Commercial road freight transport is an important part of the Latvian economy. An evolution and development of long distance freight could provide better situation for Latvia in the international freight transit and transportation market. The possible implementation effects of new and innovative technical solution of road transport vehicles have been analyzed in the Doctoral Thesis.

The Thesis work is practical and significant to road transport industry. The practical importance of the study is confirmed by reviews from Latvian Road Carriers Association "Latvijas auto" and the Latvian National Association of Freight Forwarders "LAFF". The initiation and the need of research have been prompted by managers of commercial transport companies looking for solutions and possible improvements for the transport efficiency.

All the research parts included in the Thesis have been carried out systematically, according to the chosen methodology and scientific research principles. The Doctoral Thesis consists of several research parts constituting one completed study and giving answers to all research objectives and tasks. The goal of Dissertation is fully achieved.

The research has been conducted in four areas: possibilities of legal use of long combination vehicles for divisible cargo transportation operations, efficiency of the usage of LCVs and opportunities for improving transport efficiency, possible impact of LCVs on the existing road infrastructure and analysis of associated road safety problems.

The defended theses of the Promotional work are:

1. By quantitative analysis of transport documents accompanying information on quantity of transported cargoes, it is determined that LCVs are effective for only certain categories of goods for long-distance transport.
2. The results of experimental measurements done according to developed measuring method points out the relatively poorer maneuverability of LCVs at low speed, which may result in additional road safety risk.
3. The results of experimental measurements of overtaking maneuvers on roads of Latvia show that the increased overtaking maneuver length of longer combination vehicles should not be considered as the primary factor affecting level of road safety.
4. The evaluation of effectiveness of commercial haulage project by using developed computer simulation model has given positive results, what sould be assessed when consedering the possibilities to use LCVs for comercial haulage operations.

Number of issues related to possible introduction of long combination vehicles has been analyzed in the Doctoral Thesis. The engineering research has been made, advantages and disadvantages of LCVs have been ranged, several computer simulations and mathematical prediction model have been developed. It makes possible to express the following statements:

1. According to research results, 24% of all freight transport to/from third party countries provided by Latvia haulers could be transported using long combination vehicles (switched from typical combination vehicles). This is a way to increase the transported cargo volume per freight unit (one vehicle) without violating the restrictive rules of total mass. The length of cargo space of combination vehicles is primary limiting factor of transported cargo volume.
2. None of the configurations of long combination vehicles can take U-turn (turn to opposite driving direction) in borders of concentric circle set defined in the Directive 96/53/EC. Maneuverability characteristics of the all configuration long combination

vehicles turning within 90 degrees (at corner with rounding 8 meters and 12 meters) are 10% to 23% worse (longer and wider turning trajectory) as for standard/typical combination vehicles (results of computer modeling). It is not possible to drive in and to park long combination vehicles in the service areas designed for servicing standard/typical vehicle combinations.

3. By comparing the overtaking maneuvers made at legal speed regime on rural roads, calculated length of the overtaking maneuver, where car is overtaking 25.25 meters long combination vehicle, will be up to 13% longer compared to overtaking maneuver, where typical combination vehicle (18.75 meters length) has been overtaken. The length of overtaking maneuver is significantly affected by traffic flow speed and speed difference between overtaken and overtaking vehicle. It could not be said that the increased length of the long combination vehicle is the primary road safety-influencing factor.
4. The most influencing parameter of road traffic accidents involving one transport unit – truck or combination vehicle is percentage of trucks in road transport flow on particular roadway section. The total mileage of each road section is the only parameter that significantly affects both the potential number of road accidents occurred and the likelihood that there will occur none traffic accident in specific time.
5. There are several discrepancies and inconsistencies in legislation of the European Union, Republic of Latvia and other Member States' national legislation in the field of usage of road combination vehicles; there is no consensus on several technical and legal issues; the usage of LCVs is possible only after making several amendments to the normative documents.
6. It is possible to increase the effectiveness of haulage projects by using LCVs. In the equal conditions of economic activity, the total costs per unit of cargo turnover (ton-km) would be reduced by 23% in commercial road transport projects where standard/typical combination vehicles will be substituted with LCVs.

Conducted transport research on long combination vehicles provides additional theoretical knowledge and practical skills and it improves the researching experience for the author. Study developer has gained experience in engineering research organization and in conducting experiments. Knowledge and expertise will be extensively used in future professional activities.

The research results, encouraging discussion and conclusion are important for Latvian transport sector professionals, representatives of state institutions and the transport industry researchers. The study used a systemic approach and the methodology used to ensure adequate accuracy of research results and the impartiality of finding.

The chosen research topic is topical compounded by the various expert opinions and discussions of transport professionals and among researchers. Currently, the possible consequences related to usage of long combination vehicles are not fully evaluated in the European Union. The scientific work and research might be continued, specifying and completing conclusions but this will require additional specific studies.

Aivis GRISLIS

ANALYSIS OF POSSIBLE USE OF LONG COMBINATION VEHICLES FOR DIVISIBLE CARGO TRANSPORT

Summary of Doctoral Thesis