VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Aurimas VILKELIS

MODELLING OF THE AUTOMOTIVE DISTRIBUTION NETWORK BY MERGING SUPPLY CHANNELS OF MANUFACTURERS

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
TRANSPORT ENGINEERING (03T)

VGTU
LEIDYKLA
TECHNIKA
Vilnius 2013

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2009–2013.

Scientific Supervisor

Assoc Prof Dr Aidas VASILIS VASILIAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Transport Engineering – 03T).

The dissertation is being defended at the Council of Scientific Field of Transport Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Habil Henrikas SIVILEVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Transport Engineering – 03T).

Members:

Prof Dr Žilvinas BAZARAS (Kaunas University of Technology, Technological Sciences, Transport Engineering – 03T),

Prof Dr Habil Marijonas BOGDEVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Transport Engineering – 03T),

Dr Audrius GARGASAS (Aleksandras Stulginskis University, Social Sciences, Management – 03S),

Prof Dr Ulrich WEIDMANN (Swiss Federal Institute of Technology Zurich, Technological Sciences, Transport Engineering – 03T).

Opponents:

Assoc Prof Dr Artūras KERŠYS (Kaunas University of Technology, Technological Sciences, Transport Engineering – 03T),

Prof Dr Habil Ramūnas PALŠAITIS (Vilnius Gediminas Technical University, Social Sciences, Management – 03S).

The dissertation will be defended at the public meeting of the Council of Scientific Field of Transport Engineering in the Senate Hall of Vilnius Gediminas Technical University at 2 p. m. on 26 September 2013.

Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.

Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;

e-mail: doktor@vgtu.lt

The summary of the doctoral dissertation was distributed on 23 August 2013.

A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Aurimas VILKELIS

AUTOMOBILIŲ SKIRSTYMO TINKLO MODELIAVIMAS JUNGIANT GAMINTOJŲ TIEKIMO KANALUS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
TRANSPORTO INŽINERIJA (03T)

VGTU
LEIDYKLA
TECHNIKA
Vilnius 2013

Disertacija rengta 2009–2013 metais Vilniaus Gedimino technikos universitete.

Mokslinis vadovas

doc. dr. Aidas VASILIS VASILIAUSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, transporto inžinerija – 03T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Transporto inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. habil. dr. Henrikas SIVILEVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, transporto inžinerija – 03T).

Nariai:

prof. dr. Žilvinas BAZARAS (Kauno technologijos universitetas, technologijos mokslai, transporto inžinerija – 03T),

prof. habil. dr. Marijonas BOGDEVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, transporto inžinerija – 03T),

dr. Audrius GARGASAS (Aleksandro Stulginskio universitetas, socialiniai mokslai, vadyba – 03S),

prof. dr. Ulrich WEIDMANN (Ciuricho federalinis technologijų universitetas, technologijos mokslai, transporto inžinerija – 03T).

Oponentai:

doc. dr. Artūras KERŠYS (Kauno technologijos universitetas, technologijos mokslai, transporto inžinerija – 03T),

prof. habil. dr. Ramūnas PALŠAITIS (Vilniaus Gedimino technikos universitetas, socialiniai mokslai, vadyba – 03S).

Disertacija bus ginama viešame Transporto inžinerijos mokslo krypties tarybos posėdyje 2013 m. rugsėjo 26 d. 14 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.

Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;

el. paštas doktor@vgtu.lt

Disertacijos santrauka išsiuntinėta 2013 m. rugpjūčio 23 d.

Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).

VGTU leidyklos „Technika“ 2160-M mokslo literatūros knyga.

Introduction

The Research Problem

Increasing pollution levels, traffic congestion and accident rates are outcomes of irrational logistic solutions and plays increasingly important role in our life. Statistical data published by Eurostat show that the largest share of cargo in Europe is carried by road transport, however, empty run accounts for about 25 per cent, while the loading factor is merely 78 percent. These two indicators show that logistics management is inefficient. This is caused mainly due to extremely high dynamics of freight distribution. Consequently, efforts of individual manufacturers or logistics companies to optimize the use of transport resources and distribute finished output cannot be optimal tool, which would allow reducing negative environmental impact on the macro level. In many cases, companies rendering transport services are the connecting thread in output distribution among different automotive manufacturers. However, inefficient planning of transport routes, features of competition among industrialists, uneven loading and haulage requirements – all this leads to difficulties in finding backhaul and ensuring better loading factors of vehicles.

Logistics-related cooperation is a new challenge for many industries. Nevertheless a successful course of cooperation requires relevant measures to bring the cooperation beyond not just being a strategy to improve results of operations of individual companies. To achieve this goal, the author proposes a concept designed for the European automotive industry where the production supply process is considered as a separate distribution system without a focus on logistic features of individual manufacturers.

The Relevance of the Work

Trends to diminishing free trade and market supply restrictions imposed on the transport sector have provided ideal conditions for evolution of a strongly unbalanced system with means of communication that are heavily overfilled and have negative environmental effects. Therefore, a research for alternative ways involving intermodal transport was seen as an inevitable option in the EU, thus stimulating stronger competition and more efficient management of transport resources. Many scientific publications analyze distribution problems in individual industries ant too often based only on unimodal rather than intermodal or multimodal concept, and the solutions are hypothetical and do not always provide a clear answer whether the proposals correspond to the relevant problems of a specific industry and the object of discussions.

Various solutions that are intended for output flow management, such as, transformation of distribution networks, integration of transport means with

higher loading factor, management of own transport fleet and involvement of greener trucks related to measures with lower environmental impact. In order to validate efficiency of such solutions, many automotive manufacturers highlight the distance of one transported vehicle. Among proposals for more efficient use of transport means the author includes cooperation among individual manufacturers, however, some scientists have analyzed this option theoretically and haven't revealed strategy development guidelines or attractiveness of expected results in terms of parity.

Author states that conceptual integration of individual automobile manufacturers into a common output distribution network may lead to solutions for more efficient use of transport resources and infrastructure, which would consequently enable us to diminish negative indicators of logistic operations.

The Object of the Research

The object of the research is the distribution network connecting the supply channels of production of automotive manufacturers in Europe.

The Aim of the Work

The aim of the work is to develop a distribution network of production of European automotive manufacturers and develop algorithms for establishing supply links and ensuring seamless transportation.

The Tasks of the Work

In order to achieve the aim of the work, the following tasks have been formulated:

1. To analyze the application of distribution methods of finished production in automotive industry and to establish the most important parameters of managing the distribution network.
2. To develop a joint network of factories, land and sea terminals with marginal production capacity and capacity sizes of distribution centers and to develop an algorithm for establishing new vehicle supply links for targeted markets.
3. To develop distribution routes based on distances among all established infrastructural nodes and to create an algorithm connecting transport flows to diminish the negative impact of transport operations.
4. To develop two options of new vehicle distribution for validation of efficiency of the developed algorithms and logistic cooperation concepts, with the first one distributing all production by road transport and the second one- by multimodal (road, railway and sea) transport.

The Methodology of the Research

The analysis of data from various sources involved methods of grouping and processing statistical data. The research was carried out with the help of topology methods based mainly on the concept of Milk Run and algorithm of Nearest Neighbor. For the purposes of experimental and numerical research, restrictions of loading and transporting were prescribed, which are characteristic to solutions of production flow and transport resource management problems. During the research, experts were interviewed to validate some marginal values.

The Scientific Novelty

1. An original algorithm to establish the connection of new vehicles supply to distribution centers was developed to solve route selection problem, it allows establishing supply links of output of individual industries to target markets.
2. Developed and verified in a numerical experiment, the transport flow connection algorithm allows establishing malfunctions of the supply system, search for alternative routes, reduce empty runs of freight transport and ensure route continuity.
3. The concept of logistics cooperation among different automotive manufacturers proposed in the dissertation has shown that it is possible to establish evaluation parameters of a common supply system and make more efficient use of transport resources without highlighting specific supply features of different manufacturers.

The Practical Value

1. Considering the volume of production and realization, as well as their characteristic seasonal factor, the author developed an algorithm for establishing the connection of new vehicles supply to distribution centers (DC), and adaptability of the algorithm was justified in distribution of 9,5 mill. vehicles, therefore, the application of the algorithm in shaping distribution networks, assessing the deviation of stock and advance planning of the necessary resources of transport can be adapted for different industries.
2. Numerical experiments revealed disturbances of the distribution network, and the solution of the optimization task showed an improvement of the transport flow connection ratio by 6 percent and a 42 percent lower transport distance per production unit.
3. Integration of transport means with a higher loading factor (rail and sea) into the new vehicle distribution network allowed reducing the

amount of accumulated stocks in factories by 46 percent and diminishing the number of haulage without continuation by 62 percent through directing road transport means to alternative routes.

Defended Propositions

1. After applying equal production distribution conditions for factories of lower capacity freight flows to target markets is directed to a distribution center with a higher pull coefficient, which allows establishing the catchment areas that may feature a regional deficit of vehicles and need for intermediary supply operations.
2. Adjusting the developed transport flow connection algorithm to different conditions of new vehicle distribution makes it possible to determine the reason behind the malfunction of the supply system and select an alternative solution method.
3. The use alternative means of transport in general makes it possible to diminish malfunctions of the supply system and deficit of freight flows, even if the distance from the factory to the demand locations is a few times higher, as compared with road transport.

The Scope of the Work

The dissertation consists of the introduction, three chapters, general conclusions, references, list of publications and seven annexes.

The volume of work is 98 pages, the text contains 30 numbered formulas, 24 pictures and 5 tables. 91 references were used in the dissertation.

1. Analysis of Automotive Market and Review of Distribution Methods of Finished Production

The number of initiatives launched by European countries to renew the car fleet and various projects intended for establishment of new factories and efficient distribution of finished production indicates the importance of the transport and logistics sector in the European Union context. The extremely high demand for cars in Europe and the rest of the world requires development of technological innovations and new solutions that help ensuring safe and uninterrupted supply market.

Inefficient use of transport resources is one of the major problems the logistics sector faces today. Modes of transport used for simultaneous haulage of extremely large amounts of freight, such as sea or railway transport, are not integrated into the infrastructure of freight flow distribution to a sufficient degree. Consequently, one of the latest objectives of the EU transport policies is to

achieve that 30 percent of freight transported by roads across distances of more than 300 km would be shifted to other types of transport, i.e., railways or water, by 2030, with the percentage exceeding 50 percent in 2050. To ensure more efficient management of transport resources, the dissertation formulates a presumption that consistent functioning of transport systems requires contribution of separate industries.

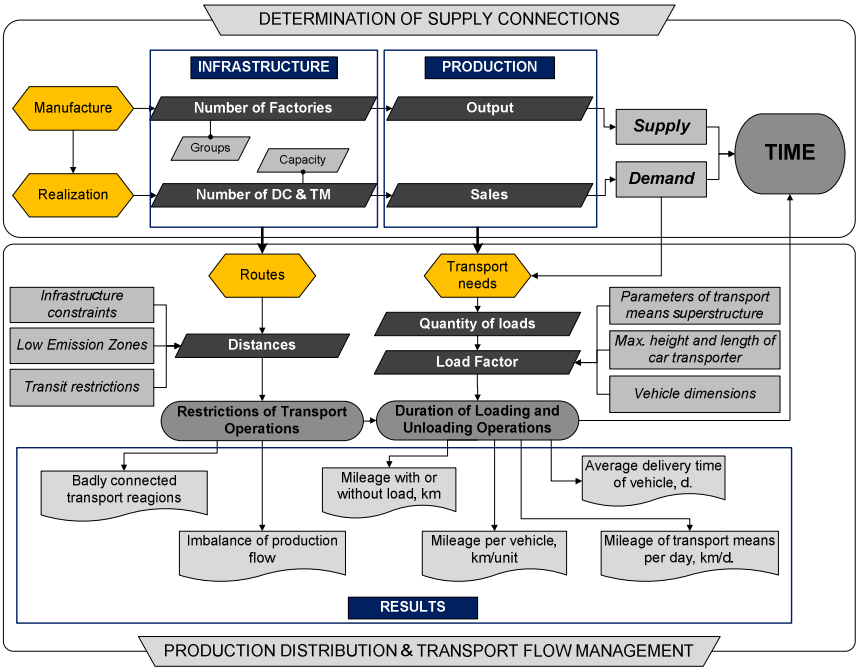

Fig. 1. Hypothetical model of production supply and transport flow

An analysis of methods and best practice examples of output distribution of automotive manufacturers has revealed that automotive industry try to target their strategies of logistics operations towards using types of transport with a higher loading factor (railway and seas), however, road transport remains in the dominant position.

From the scientific point of view, solutions of many production distribution and transport problems tend to establish a fixed number of factories, retailers and transport means, applying random restrictions of distribution operations

for supply functions. Therefore, the hypothetical new vehicle distribution model includes two interconnected structural parts (Fig. 1), with the first one establishing potential supply links between existing factories and target markets DC and Cross Nodes (TM) by existing production supply and demand volumes at a specific moment, and the second one defining management function of production flows and transport operations.

2. Modelling of Supply Networks of Car Manufacturers

An analysis of examples of cooperation among various manufacturers in the automotive industry has shown that standardization of car parts, sharing of know-how of engineering solutions and assembly of a few brands of cars in the same factory is not somewhat to be necessarily avoided or prohibited but more often is a new possibility, therefore, the dissertation makes a presumption that automotive manufacturers may be able to organize a distribution of finished output together, as well. Based on the hypothesis, the author proposes a unified distribution network of realization markets that would cover certain regions in Europe, including 83 factories, 70 DC and 24 ports (TM). New vehicle supply links were established in line with output capacities of individual automotive manufacturers and capacities of the DC infrastructure in every country of output realization.

Based on the statistics provided by ACEA, OICA and INTERO, the volume of production output of every automotive manufacturer over a certain period of time was established. The data allowed ascertaining production push coefficients FS_{kx} of factories of individual brands, which are calculated by dividing F_{ox}, the output of one manufacturer in a separate factory, by the number of all vehicles assembled in all of the manufacturer's factories over the same period:

$$FS_{kx} = \frac{F_{ox}}{\sum_{x=1}^{} \sum_{o=1}^{} F_{ox}}, \tag{1}$$

where x means the number of manufacturer's factories; o – number of assembled vehicles.

A condition is accepted that storage of one vehicle in a DC requires an area of 20 m^2. Imported vehicles are distributed by terminal sizes expressed in vehicle units. A presumption is made that the DC size describes the intensity of vehicle demand in the target region where the DC is present. Considering the infrastructure capacities of selected DC, i.e., its capacity to accommodate a certain number of vehicles at a time, the dissertation established imports vo-

lumes for every DC in the country. Some countries in the model – Switzerland, Slovakia or Bulgaria – each have merely one DC for vehicles. Consequently, if there is one DC in a country, the entire flow of production will be delivered to a single destination. Otherwise, if a country has more than one DC, it is vital to establish certain intensity of DC output pull. Pull coefficients TD_{ky} of a certain center of distribution are calculated by the following formula:

$$TD_{ky} = \frac{T_{iy}}{\sum_{y=1}\sum_{i=1} T_{iy}}, \tag{2}$$

where T_{iy} means the number of vehicles stored in a country's separate DC at a time; y – number of DC; i – number of vehicles in DC. Figure 2 below provides a graphic example of an algorithm establishing the connection of new vehicles supply to distribution centers.

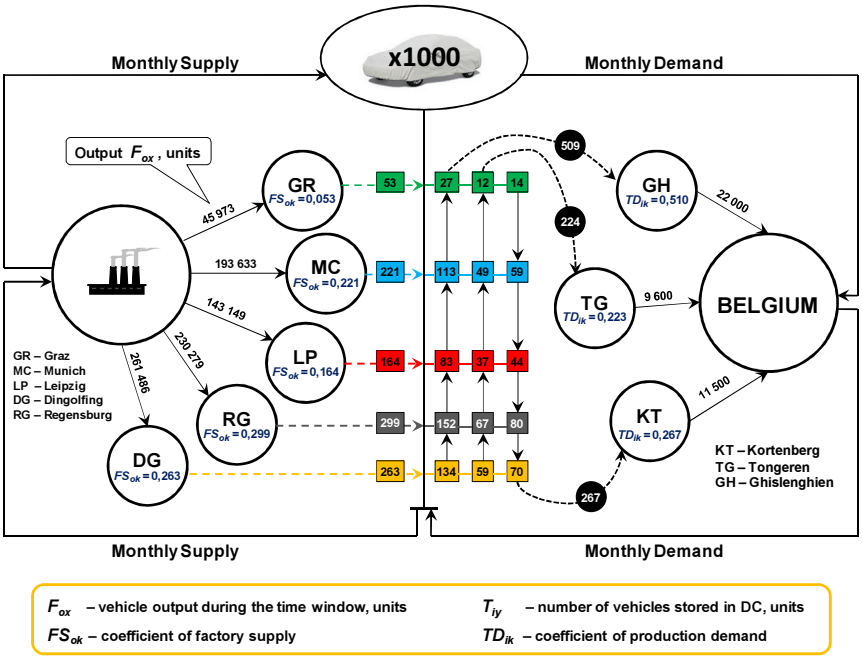

Fig. 2. Graphic view of algorithm establishing the connection of new vehicles supply to DC

Considering the dimensions of Passenger cars (PC) and Light commercial vehicles (LCV) type cars assembled by factory assembly lines and measurements of superstructure of transport means and maximum length and height requirements applied in individual countries, loading factors onto transport means for every factory were established. In the hypothetical model, production residue in factories is treated as vehicles present in dealers for every manufacturer's exposition or fairs, while production carried from factories and distributed into freights is treated as the vehicle demand reflecting client orders. Consequently, haulage of partial loads is not included into the production flow model, therefore the amount of transported products equals the established loading factor.

It makes no difference to the end customer whether products of one manufacturer are delivered together with the production of another brand manufacturer. Consequently, there are no reasons to tie transport means to the product manufacturer, from the end customer's point of view, in an effort to emphasize its exclusivity and cover the additional costs caused by irrational use of transportation resources. As an example, we should think of consumer behaviour in grocery stores when people take a shopping basket or a shopping cart for their purchases. In this case, the shopping basket or cart stands for transport means intended to carry products of different manufacturers. If clients had to go separately to the cash register to pay for products of each manufacturer and then return to the store for items of a different manufacturer, they would probably refuse to come back to the store ever again. Therefore, based on this example, a production distribution network was worked out where different automotive manufacturers are participants of a unified distribution network with no emphasis on their uniqueness, whereas transport resources and infrastructure are not dependent upon an individual supply chain.

As factories of many manufacturers do not assemble the entire variety of offered models and there is no information about factories attributed to a certain region, the belief is that production is supplied to all countries from all factories of a certain manufacturer in line with the established output push and pull coefficients. Due to the lack of data on the network of authorized sales centers, the proposed automotive distribution model only features international product supplies to the regional DC or TM.

3. Problem Solution of Production Flows and Transport Resource Management in a Unified Supply Network

Based on the analysis of examples of management of practical and scientific transport processes and resources, the author formulated the expected re-

sults, which would allow defining the current situation of distribution of finished products. To achieve the objective, the complex solution of the problem was focused on overall and empty run, the distance per unit of carried cars, the number of delivered freights and the demand for resources. In the production distribution model, it is important to highlight badly connected transport regions, where the existing imbalance of freight flows makes it impossible to ensure efficient loading of trucks and find a backhaul. With the above-mentioned critical zones established, it would be possible to apply haulage alternatives that would allow more efficient use of the existing transport resources.

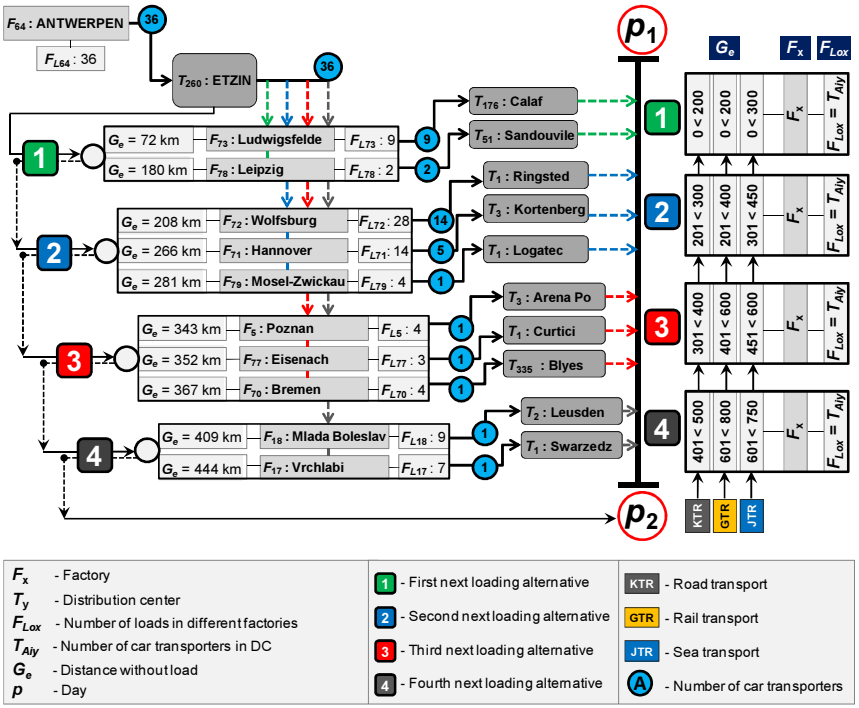

Fig. 3. Graphic view of transport flow connection algorithm

Some researchers, in particular prof. Cordeau in their examination of the practical problem of automotive transshipment terminal identified that optimization of certain processes can be made on the basis of actual data for one month, as the outcome will reflect continuity of the optimization function and

allow observing how results of one-day operations lead to operations for the next day. Considering the recommendation, a decision was made to choose January for calculations due to the large sample of data, as the past period features a rather high demand for transport due to failure to deliver production by the end of the earlier year and annual winter holidays with closed factories, while many vehicles return to their home depots.

To reduce the level of inefficiency in the use of transport resources in the common distribution network of output of European automotive manufacturers, a transport flow connection algorithm was developed to ensure continued use of vehicles. Figure 3 provides an example of how transport means arriving from DC are diverted to the nearest factory for continued circulation of the same vehicles by way of distribution of freights and application of the condition of open route.

Once the production is delivered from the target market DC, transport means in the next phase is directed to the nearest factory. To achieve the goal, possible driving directions are formulated in the unified distribution network, and the choice of the directions is determined by the amount stock in the factory and the transport means in the single DC attributed to the specific region. Considering the condition that unloaded transport means cannot be diverted to factories that would take a working day to reach, additional links between the DC and the production supply points are made in line with specific intervals of driving unloaded. If the distance is shorter than the maximum daily run allowed for the transport means, a few routes can be made within a day. However, the calculations showed that in nearly all cases the return was made to the same factory. Introduction of a condition restricting the transport means perform more than one haulage operation over a certain period of time allowed to limit a possibility to load a backhaul in the earlier point. This allowed ensuring direction of transport means to different factories with the highest pull coefficients.

Results of calculations systematized by certain periods of time shows that every factory had remaining stock, at the same time establishing the number of transport means remaining in DC. If the production is insufficient in the nearest factories over the next few days, a production deficit is recorded and it determines idle time of transport means in DC. Production remaining in factories leads to disproportional balance of imports and exports, which formulates a need for additional resources. These zones are reported as badly connected transport regions, and interruption points in the distribution system are established.

To establish the current situation of the proposed common distribution network of new vehicles and the interruptions of the supply system, the author formulated two options of distributing production, with the first one making the

entire supply flow part of the road transport, and the second one – to the road, railway and sea transport.

In the first option of new vehicle distribution, the applied transport flow connection algorithm, which searched for alternative loading points in four zones of distances, showed that more than half of available connections were performed in the first iteration, 33 percent in the second iteration, 7 percent in the third iteration and 8 percent in the fourth iteration. This leads to a conclusion that, in order to increase the number of connected routes, it is important to provide additional opportunities for transport means to go to more remote points, however, established maximum search distances should not exceed the maximum daily run. The biggest average daily distance covered by a car transporter (426 km) was recorded on routes with the duration of haulage of four days (0+4), while the shortest (312 km) was observed on routes lasting between five (0+5) and eight (0+8) days. This was determined by routes that lasted longer than five days due to weekends when truck traffic is prohibited and distances shorter than 500 km (particularly in cases when the distance of haulage is under 100 km), and the time of covering the distances was listed as one day (0+1). The results received from the first new vehicle distribution option showed that the biggest interruptions in the supply system caused by low production capacities and high vehicle demand were observed in Northern Italy and Central France, while the biggest factory interruptions and inconsistencies of freight imports and exports were reported in Eastern Europe, Spain and Southern Germany.

Identified problematic of production supply points and achieved results received from the first new vehicle distribution option revealed existing disruptions of the supply system and efficient use of resources. Based on the data, the second production distribution version was revised to include railway and sea transport, which is known for a higher loading factor and can serve as an alternative for amortization of the imbalanced freight flow by serving the badly connected transport regions and reducing the need for car transporters. As the number of loading and unloading operations in sea and railway transport was limited over a certain period of time, the time of departure was established randomly to avoid idle time and interruptions of supplies. Preliminary calculations showed that, regardless of the above-mentioned condition, more than two trains or sea ferries arrived at some points of imports at the same time. With the interruptions reported, the links were scratched in the final phase of route selection and they were attributed to road transport. The results of the first and the second new vehicle distribution options are provided in Table 1.

An alternative of using transport means with higher loading factor for optimization of new vehicle distribution network allowed increasing the connected

routes of freight road transport by 6 percent, however, the results revealed that 16 percent of the routes had no continuation.

Table 1. Comparison of results of the first and the second production distribution options

Results	1st option	2nd option			
		Total	Transport means		
			Road	Rail	Sea
Transport demand per day, units	12 798	8 665	7 840	802	23
Number of routes, units	5 810	6 345	5 810	378	157
Mileage with load, km	90 780 408	56 308 578	54 959 187	523 641	825 750
Mileage without load, km	9 677 925	6 543 837	6 205 775	203 638	134 424
Distance for one vehicle, km/veh.	186	107	186	8	6
Average delivery time of vehicles, in days	3	3	3	2	4
Average mileage with load per day, km/d.	367	523	364	635	570
Import of new vehicles to DC, units	539 665	585 625	328 200	89 031	168 394
Export of new vehicles from factories, units	642 676				

Results of experiments showed that the alternative means of distribution applied in the hypothetical model of production supply and transport flows did not solve all interruptions of the new vehicle distribution network, therefore, a proposal was made that solving such types of future problems in further research should examine the possibility of formulating additional functions, with a focus on the possibility of intermediate haulage operations, which lead to overall losses of logistic operations due to inefficient use of transport resources.

General Conclusions

1. The numerical experiment carried out with a classic transport task solution showed that the most expensive or most remote points in the distribution network were eliminated in the search for the cheapest distribution alternative or an alternative with the smallest sum value. The result revealed that such types of solutions scrap points with no econom-

ic benefit, which means that certain regions will not be supplied with the necessary production and suffer a deficit.

2. Margins of attainability and the number of fixed production distribution connections applied in dynamic route solutions burden the establishment of disorders of the supply system and route revision by replacing them with alternative ones. Consequently, in order to increase the volume of connected routes, the proposal is to allow additional opportunities for transport means to drive to more remote points, however, established marginal search distances should not exceed the maximum daily run of a transport means.
3. Under the conditions of the first and the second new vehicle distribution options, the travel of car transporters without load accounted for about 10 percent of the total run. Considering the specific field of haulage, the result confirms that the developed transport flow connection algorithm is an efficient way of reducing the empty running factor.
4. Numerical research showed that production flows from factories with lower production capacities is redirected to a distribution center with a larger infrastructure capacity – this leads to a regional production deficit and the need for intermediary distribution operations.
5. The use of railway transport was found to be inefficient due to regional imbalance of transport flows and insufficient amount of freights in certain factories in distances to the next loading site, as compared to other types of transport, furthermore, the distance covered without a load accounted for 28 percent of run, while the percentage was about 10 percent for car transporters and 19 percent for ferries, therefore, in order to improve the indicator, distribution operations should look into the possibility of using single wagons.
6. Integration of additional types of transport into the common distribution network allowed reducing distances of transportation per unit of production by 42 percent and reducing the volume of production left in factories by 62 percent.

List of Published Works on the Topic of the Dissertation

In the Reviewed Scientific Periodical Publications

Vasilis Vasiliauskas, A.; Vilkelis, A.; Zinkevičiūtė, V.; Batarlienė, N. 2010. Development of automobile distribution networks on the basis of multi-criteria evaluation of distribution channels, *Transport* 25 (4): 361–367. ISSN 1648-4142. (Thomson ISI WOS).

Vilkelis, A.; Jakovlev, S. 2013. Outbound supply chain collaboration modelling based on the automotive industry, *Transport* doi:10.3846-16484142.2013.789980 – Accepted. ISSN 1648-4142. (Thomson ISI WOS).

In the Other Editions

Vilkelis, A.; Kaušylas, M. 2011. Assessment of cargo flow covering transport of automobiles via territory of Lithuania, in *Proceedings of the 8th International Conference "Environmental Engineering"*, *held in Vilnius on May 19–20, 2011,* Vilnius: Technika, 1235–1239. ISBN 978-9955-28-829-9. (ISI Proceedings).

Vilkelis, A. 2011. Utilisation of transport capacities and opportunity to mitigate negative environmental impact of logistics operations, in *Proceedings of the 7th International Scientific Conference "TRANSBALTICA 2011"*, *held in Vilnius on May 5–6, 2011*, Vilnius: Technika, 275–279. ISBN 978-9955-28-840-4.

Vilkelis, A.; Greičiūnė, L. 2012. Europos krovinių srautų geografinio pasiskirstymo ir logistinių procesų priklausomybės analizė [Analysis of dependence between geographical distribution of European freight flows and logistic processes], Transporto inžinerija ir vadyba [Transport engineering and management]: 15-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“, įvykusios Vilniuje 2012 m. gegužės 4 d. straipsnių rinkinys. Vilnius: Technika, 72–76. ISBN 978-6094-57-132-9.

Vilkelis, A. 2012. Automobilių rinkos pokyčių įtaka Lietuvos vežėjams [Impact of changes in the automotive market upon Lithuania carriers],Transporto inžinerija ir vadyba [Transport engineering and management]: 15-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“, įvykusios Vilniuje 2012 m. gegužės 4 d. straipsnių rinkinys. Vilnius: Technika, 77–80. ISBN 978-6094-57-132-9.

About the Author

Aurimas Vilkelis was born in Vilnius on 25 of March, 1984.

In 2007, he graduated from the Faculty of Transport Engineering of the Vilnius Gediminas Technical University with a degree in Management and Business Administration. Later he acquired a Master's degree in MBA at the same Faculty in 2009. In 2009–2013, he was a doctoral student at the Vilnius Gediminas Technical University. Aurimas Vilkelis had an internship in transport and logistics company *Gefco Österreich GmbH* in Austria in 2010 and 2012. In 2012, Aurimas Vilkelis carried out research at the Institute for Transport Planning and Systems of the Swiss Federal Institute of Technology (ETH) in Zurich and had an internship at the Institute for Transport and Spatial Planning of the University of Applied Sciences in Erfurt in 2013. In total, Aurimas Vilkelis spent 7 months in internships abroad. Since 2007, he has held leading positions in several transport and logistics companies in Lithuania. In 2012, Aurimas Vilkelis joined the Lithuanian Society of Automotive Engineers.

Acknowledgment

A number of transport and logistics specialists, researchers and consultants in Lithuania and abroad contributed to the preparation of the dissertation. I would like to convey my sincerest gratitude to:

- Transport and logistics company *GEFCO Österreich GmbH* and CEO Mr. Guillaume Chavanat for an opportunity take a closer look at the automotive industry, logistics and transport processes across the globe;
- Professor Dr. Ulrich Weidmann, director of Transport Planning and Systems Institute of ETH Zurich for inspiration, new ideas, critical attitude and excellent opportunities for research at ETH Zurich;
- Professor Dr. Florian Heinitz of Transport and Spatial Planning Institute of FH Erfurt University for motivation and support in the final phase of the dissertation and organizational assistance in the preparation of the public presentation of research results to the academic community of FH Erfurt University;
- Ralf-Charley Schultze, director of GEFCO Multimodal Logistics Division, and BLG Autorail CEO Gerald Binz for their valuable advice and consultations in the design of railway transport flows;
- Representatives of companies FIAT, FORD, ŠKODA, VOLVO, NISSAN, ARS Altmann and ACEA association for their time to get acquainted with my research, practical insights, remarks and necessary information.

My special thanks goes to my family, colleagues and friends for their understanding and support, supervisor and reviewers for their constructive remarks, Mrs. Jadvyga and Mr. Sigitas Kuršeliai for their care and wonderful moments during my internships in Austria.

AUTOMOBILIŲ SKIRSTYMO TINKLO MODELIAVIMAS JUNGIANT GAMINTOJŲ TIEKIMO KANALUS

Problemos formulavimas

Didėjantis užterštumo ir triukšmo lygis, eismo spūstys bei avaringumas – tai klaidingų logistinių sprendimų rezultatas, neatsiejamas nuo mūsų kasdienybės. Statistiniai Eurostat duomenys byloja, jog didžiausia dalis krovinių Europoje yra vežama kelių transportu, tačiau tuščia jo rida sudaro apie 25 proc., o pakrovimo faktorius siekia vos 78 proc. Šie du rodikliai parodo, jog beveik pusė krovininio transporto parko yra naudojama neefektyviai. Krovinių skirstymas dėl itin didelės dinamikos yra sudėtingas, atsakomybės ir daug pastangų reikalaujantis procesas. Todėl individualaus gamintojo ar logistikos įmonės pastangos užtikrinti efektyvesnį transporto išteklių panaudojimą, skirstant pagamintą

produkciją, šiandien negali būti įrankiu, leidžiančiu sumažinti neigiamą poveikį aplinkai makro lygiu. Daugeliu atvejų jungiamoji produkcijos skirstymo grandis tarp skirtingų automobilių gamintojų yra transporto paslaugų įmonės. Tačiau dėl neefektyvaus transporto srautų planavimo, pramonininkų konkurencijos ypatumų, regioninio krovinių disbalanso, nevienodų krovimo bei transportavimo reikalavimų susiformuoja kliūtys rasti atgalinį krovinį ir užtikrinti geresnį transporto priemonės pakrovimo faktorių.

Logistinis bendradarbiavimas – tai naujas iššūkis daugeliui pramonės šakų. Tačiau sėkmingam jo įgyvendinimui reikia surasti tinkamas priemones tam, kad bendradarbiavimas netaptų vienpusiškai naudinga strategija pagerinti atskirų įmonių veiklos rodiklius. Šiam tikslui pasiekti siūloma koncepcija, skirta Europos automobilių pramonei, kur produkcijos tiekimo procesas būtų traktuojamas kaip atskira skirstymo sistema, neišskirianti skirtingų gamintojų logistinio savitumo.

Darbo aktualumas

Mažėjantys laisvos prekybos bei rinkų aprūpinimo suvaržymai transporto sektoriui sudarė idealias sąlygas vystytis iki smarkiai išsibalansavusios sistemos su perpildytomis ir neigiamu poveikiu aplinkai pasižyminčiomis susisiekimo rūšimis. Todėl alternatyvų paieška siūlant įvairius transporto projektus Europos Sąjungoje tapo neišvengiamu procesu, skatinančiu didesnę konkurenciją ir efektyvesnį transporto išteklių valdymą. Tačiau šios idėjos, įgyvendintos didelių investicijų dėka, gali būti tik geros praktikos pavyzdžiais ir kelti abejones dėl savo tęstinumo. Daugelyje mokslinių publikacijų nagrinėjamos atskirų pramonės šakų produkcijos skirstymo problemos bei sukurti jų sprendimai yra hipotetiniai ir ne visada aišku, ar pateikti siūlymai atitinka aktualias konkrečios pramonės šakos problemas bei diskusijų objektą. Įvairūs sprendimai, skirti produkcijos srautų valdymui, kaip antai: skirstymo tinklo transformacijos, didesniu pakrovimo faktoriumi išsiskiriančių transporto rūšių integravimas, nuosavų transporto išteklių valdymas, ekologiškesnių sunkvežimių naudojimas yra susiję su mažesnę taršą aplinkai darančiomis priemonėmis. Šių sprendimų efektyvumui pagrįsti daugelis automobilių gamintojų išskiria transportavimo atstumą, tenkantį vienam produkcijos vienetui. Efektyvesniam transporto resursų panaudojimui siūlomas atskirų gamintojų bendradarbiavimas, tačiau daugelis mokslininkų šią galimybę analizuoja teoriniu lygmeniu, neatskleidžiant strategijos vystymo gairių bei numatomų rezultatų patrauklumo „pariteto“ prasme. Suformavus atskiros pramonės šakos logistinio bendradarbiavimo koncepciją bei integravus atskirus gamintojus į bendrą produkcijos skirstymo tinklą galima formuoti sprendimus, skirtus efektyvesniam transporto išteklių bei infrastruktūros panaudojimui, kurie leistų mažinti neigiamus logistinės veiklos rodiklius.

Tyrimų objektas

Darbo objektas – skirstymo tinklas, jungiantis skirtingų automobilių gamintojų pagamintos produkcijos tiekimo kanalus Europoje.

Darbo tikslas

Šio darbo tikslas – sudaryti Europos automobilių gamintojų produkcijos skirstymo tinklą bei sukurti algoritmus, kuriais remiantis būtų nustatytos tiekimo jungtys ir užtikrintas krovininių transporto priemonių panaudojimo tęstinumas.

Darbo uždaviniai

Darbo tikslui pasiekti suformuluoti šie uždaviniai:

1. Atlikti pagamintos produkcijos skirstymo metodų taikymo automobilių pramonėje analizę ir nustatyti svarbiausius skirstymo tinklo valdymo parametrus.
2. Sudaryti bendrą gamyklų, sausumos bei jūrų terminalų tinklą, nustatant ribinius gamybinio pajėgumo bei talpos dydžius ir sukurti algoritmą, kuriuo remiantis būtų nustatomos naujų automobilių tiekimo jungtys į tikslines rinkas.
3. Sudaryti skirstymo maršrutus, įvertinant atstumus tarp visų nustatytų infrastruktūrinių mazgų ir parengti transporto srautų jungimo algoritmą, skirtą mažinti neigiamus transporto veiklos rodiklius.
4. Sukurtų algoritmų ir logistinio bendradarbiavimo koncepcijos efektyvumui pagrįsti sudaryti du naujų automobilių skirstymo variantus, iš kurių pirmame visas produkcijos srautas būtų skirstomas kelių transportu, o antrame – kelių, geležinkelių bei jūrų transportu.

Tyrimų metodika

Analizuojant įvairių šaltinių duomenis buvo naudojami statistinių duomenų grupavimo ir apdorojimo metodai. Tyrimuose taikomi topologijos metodai, paremti Pieninino maršruto koncepcija, pritaikant Artimiausio kaimyno algoritmą. Eksperimentiniams ir skaitiniams tyrimams atlikti nustatyti pakrovimo ir transportavimo ribojimai, būdingi krovinių srautų ir transporto išteklių valdymo problemų sprendimams. Tyrimų eigoje kai kurių ribinių reikšmių pagrindimui buvo apklausti ekspertai.

Darbo mokslinis naujumas

1. Sukurtas originalus naujų automobilių tiekimo į skirstymo centrus ryšio nustatymo algoritmas, skirtas maršrutų parinkimo uždavinių spren-

dimams, leidžia nustatyti atskiroje pramonės šakoje pagamintos produkcijos tiekimo jungtis į tikslines rinkas.
2. Sukurtas ir skaitiniu eksperimentu patikrintas transporto srautų jungimo algoritmas leidžia nustatyti tiekimo sistemos sutrikimus, atlikti alternatyvių maršrutų paiešką, sumažinti krovininių transporto priemonių tuščią ridą bei užtikrinti reisų tęstinumą.
3. Disertacijoje pasiūlyta skirtingų automobilių gamintojų logistinio bendradarbiavimo koncepcija parodė, jog neišskiriant skirtingų gamintojų produkcijos tiekimo savitumo galima nustatyti bendros tiekimo sistemos vertinimo parametrus ir efektyviau naudoti transporto išteklius.

Darbo rezultatų praktinė reikšmė

1. Atsižvelgiant į gamybos bei realizavimo apimtis ir joms būdingą sezoniškumo faktorių buvo sukurtas naujų automobilių tiekimo į skirstymo centrus ryšio nustatymo algoritmas, kurio pritaikomumas pagrįstas skirstant 9,5 mln. automobilių, todėl šio algoritmo taikymas formuojant skirstymo tinklus, įvertinant atsargų nuokrypius bei iš anksto planuojant reikalingų transporto išteklių kiekį gali būti naudojamas skirtingose pramonės šakose.
2. Atlikti skaitiniai eksperimentai atskleidė sudaryto skirstymo tinklo sutrikimus, o optimizavimo uždavinio sprendimas parodė 6 proc. geresnį transporto srautų jungimo santykį bei 42 proc. mažesnį vežimo atstumą, tenkantį vienam produkcijos vienetui.
3. Didesniu pakrovimo faktoriumi išsiskiriančių transporto rūšių (geležinkelių ir jūrų) integravimas į naujų automobilių skirstymo tinklą 46 proc. leido sumažinti susikaupusių krovinių kiekį gamyklose ir 62 proc. sumažinti vežimų, kurie neturėjo tęstinumo nukreipiant kelių transporto priemones alternatyviais maršrutais.

Ginamieji teiginiai

1. Mažesnio gamybinio pajėgumo gamykloms pritaikius vienodas produkcijos skirstymo sąlygas krovinių srautas į tikslines rinkas adresuojamas į stipresnį traukimo koeficientą turintį skirstymo centrą, tai leidžia nustatyti kuriose aprėpties zonose gali susiformuoti regioninis automobilių deficitas ir tarpinių operacijų poreikis.
2. Pritaikius sukurtą transporto srautų jungimo algoritmą skirtingomis naujų automobilių skirstymo sąlygomis, galima nustatyti tiekimo sistemos sutrikimų priežastį ir parinkti alternatyvų sprendimo metodą.
3. Panaudojant alternatyvias transporto rūšis galima sumažinti tiekimo sistemos sutrikimus ir krovinių srautų deficitą net jei atstumas nuo ga-

myklos iki produkcijos paklausos vietų, lyginant su kelių transportu, yra kelis kartus didesnis.

Darbo struktūra

Disertaciją sudaro įvadas, trys skyriai, bendrosios išvados, literatūros sąrašas, autoriaus publikacijų disertacijos tema sąrašas ir septyni priedai.

Darbo apimtis yra 98 puslapiai, tekste panaudota 30 numeruotų formulių, 24 paveikslai ir 5 lentelės. Rašant disertaciją buvo panaudotas 91 literatūros šaltinis.

Pirmasis skyrius skirtas mokslinės literatūros, skirtos produkcijos skirstymo problemų sprendimams, analizei. Išanalizuoti pasaulio automobilių gamintojų taikomi produkcijos skirstymo sprendimai.

Antrasis skyrius skirtas statistinių duomenų sisteminimui, naujų automobilių tiekimo į skirstymo centrus ryšio nustatymo algoritmo ir hipotetinio pagamintų automobilių skirstymo modelio sudarymui.

Trečiasis skyrius skirtas transporto srautų jungimo algoritmo sudarymui, kurio pagrindu būtų apskaičiuojamos pakrovimų alternatyvos bei nustatomi sudaryto modelio galimi skirstymo sutrikimai.

Bendrosios išvados

1. Skaitiniam eksperimentui atlikti panaudotas klasikinio transporto uždavinio sprendimas parodė, jog ieškant pigiausios arba kitaip mažiausią suminę reikšmę turinčios skirstymo alternatyvos buvo neįvertinami brangiausi arba didžiausiu atstumu nutolę skirstymo tinkle esantys taškai. Šis rezultatas atskleidė, kad tokio pobūdžio sprendimuose panaikinami ekonomiškai nenaudingi taškai, o tai lemia, jog tam tikri regionai nebus aprūpinami reikiama produkcija ir susiformuos deficitas.
2. Dinaminių maršrutų sprendimuose taikomos pasiekiamumo ribos bei pastovus produkcijos skirstymo jungčių kiekis riboja nustatyti tiekimo sistemos sutrikimus bei sudaryti maršrutų performavimo galimybes juos keičiant alternatyviaisiais. Todėl siekiant padidinti sujungiamų maršrutų apimtis, siūloma sudaryti papildomas galimybes transporto priemonėms vykti į tolimesnius taškus, tačiau nustatyti ribiniai paieškos nuotoliai negali viršyti maksimalios transporto priemonių ridos per vieną dieną.
3. Pirmojo ir antrojo naujų automobilių skirstymo variantų sąlygomis automobilvežių važiavimas be krovinio sudarė apie 10 proc. nuo bendros ridos. Įvertinant, kad tai yra itin specifinė vežimų sritis, gautas rezultatas patvirtina, jog sukurtas transporto srautų jungimo algoritmas yra veiksminga priemonė mažinti tuščios eigos faktorių.

4. Atlikus skaitinius tyrimus nustatyta, kad produkcijos srautas iš mažesnio gamybinio pajėgumo gamyklų yra peradresuojamas į didesnį infrastruktūrinį laidumą, turintį skirstymo centrą – tai daro įtaką regioniniam produkcijos deficito susiformavimui bei tarpinių skirstymo operacijų poreikiui.
5. Nustatyta, kad geležinkelių transporto priemonių panaudojimas dėl transporto srautų regioninio disbalanso ir nepakankamo krovinių kiekio tam tikrose gamyklose, atstumuose iki kito pakrovimo, lyginant su kitomis transporto rūšimis, nebuvo efektyvus, ir nuvažiuotas atstumas be krovinio sudarė iki 28 proc., kai tuo tarpu automobilvežiams šis rodiklis siekė apie 10 proc., o keltams – 19 proc., todėl siekiant pagerinti šį rodiklį, skirstymo operacijose siūloma įvertinti pavienių vagonų naudojimo galimybes.
6. Papildomų transporto rūšių integravimas į bendrą produkcijos skirstymo tinklą leidžia sumažinti transportavimo atstumą, skirtą vienam produkcijos vienetui iki 42 proc., užtikrinti mažesnes susikaupusių neišvežtos produkcijos apimtis gamyklose iki 62 proc.

Trumpos žinios apie autorių

Aurimas Vilkelis gimė 1984 m. kovo 25 d. Vilniuje.

Vilniaus Gedimino technikos universiteto Transporto inžinerijos fakultete 2007 m. įgijo vadybos ir verslo administravimo bakalauro laipsnį, 2009 m. – vadybos ir verslo administravimo magistro laipsnį. 2009–2013 m. – Vilniaus Gedimino technikos universiteto doktorantas. Aurimas Vilkelis 2010 ir 2012 m. stažavosi, transporto ir logistikos įmonėje Gefco Österreich GmbH, Austrijoje. 2012 m. mokslinius tyrimus atliko Ciuricho federalinio technologijų universiteto ETHZ (vok. *Eidgenössische Technische Hochschule Zürich*), Eismo planavimo ir transporto sistemų institute (vok. *Institut für Verkehrsplanung und Transportsysteme*). 2013 m. atlikto stažuotę Erfurto taikomųjų mokslų universiteto (vok. *Fachhochschule Erfurt*), Transporto ir erdvinio planavimo institute (vok. *Institut für Verkehr und Raum*). Nuo 2007 m. iki dabar dirba Lietuvos transporto ir logistikos įmonėse logistikos vadovo pozicijose. Nuo 2012 m. yra Lietuvos automobilių inžinierių sąjungos narys.

Padėka

Prie šios disertacijos rengimo prisidėjo daug transporto ir logistikos srities specialistų, mokslininkų, konsultantų Lietuvoje ir užsienyje. Ypatingą padėką norėčiau pareikšti artimiesiems, kolegoms ir draugams už supratimą ir palaikymą, vadovui bei recenzentams už konstruktyvias pastabas, Jadvygai ir Sigitui Kuršeliams už rūpestį ir nuostabias akimirkas stažuotės metu Austrijoje.