

OPTIMIZATION OF TRANSPORTATION DECISIONS UNDER EXCLUSIONARY SIDE CONSTRAINTS IN FOOD SUPPLY CHAIN

Marcin Anholcer^(a), Arkadiusz Kawa^(b)

^{(a),(b)}Poznań University of Economics,
al. Niepodległości 10, 61-875 Poznań, Poland

^(a)m.anholcer@ue.poznan.pl, ^(b)arkadiusz.kawa@ue.poznan.pl

ABSTRACT

The main objective of this paper is to develop an effective model of planning food supplies, when exclusionary constraints are present. In order to achieve this objective, we performed two stages of research, each of which had its own partial goals. The first part of the research aims for identification of the types of the exclusionary constraints that exist in the real world. The objective of the second stage is to develop mathematical models of transportation problems that include the exclusionary constraints existing in reality.

Keywords: optimization of transportation, exclusionary constraints, food supply chain

1. INTRODUCTION

A supply chain is a network of organizations working together in different processes and activities in order to bring products and services to the market, with the purpose of satisfying customers' demands (Ahumada and Villalobos 2009). In the case of a food supply chain, as any other supply chain, it is an integrated process where raw materials are acquired, converted into products and then delivered to the consumer; speaking colloquially, it flows from the plant to the plate. The chain is linked with the feed forward flow of materials and the feedback flow of information (Jiang 2009). Tijssens et al. (2001) conclude that the main fact that differentiates food supply chains from other supply chains is a continuous change in quality from the time the raw materials leave the grower to the time the food reaches the consumer.

The topic of the food supply chain is very popular among scientists. This is evidenced by a wide range of research and publications. They concern general problems in food supply chains (Vorst 2000), but there are also investigations which tackle specific problems, such as safety and security issues in the fresh good supply chain (Bruzzone, Longo, Massei, Nicoletti and Agresta 2014), optimization of the fresh food supply chain (Rong, Akkerman and Grunow 2011), evaluating the effectiveness of different policies in managing frozen goods supply chain, (Bruzzone, Massei and Poggi 2007), sustainability and efficiency of logistics in the integrated food district (Bottani, Rizzi and Vignali

2014), traceability (De Cindio, Longo, Mirabelli and Pizzuti 2011a) and track & trace system (De Cindio, Longo, Mirabelli and Pizzuti 2011b) for a food supply chain.

According to Mardsen, Banks and Bristow (2000), creation, operation and evolution of food supply chains are key dimension in the new patterns of rural development now emerging.

The food supply chain is also an interesting subject for institutions which create some rules and best practices for business. In 2010 the European Commission (EC) introduced The High Level Forum for a Better Functioning Food Supply Chain, which ensures the follow up of the recommendations of the High Level Group on the Competitiveness of the Agro-Food Industry (ec.europa.eu 2015). According to EC, the food supply chain consists of three important issues – agriculture, the food processing industry and the distribution system. Those three sectors together account for more than 5% of the European added value and 7% of employment. It is worth to emphasize that the food supply chain has direct consequences for all European citizens, because food represents 16% of the European household expenditures (Commission of the European Communities 2009).

A characteristic thing of the food supply chain is a large variety of entities: farmers, food processors, traders, wholesalers, distributors, logistics companies and retailers. Among these, there are also very large companies and small and medium-sized enterprises which are simultaneously competitors, suppliers or customers. In this industry, companies increasingly cooperate in order to optimize the supply chain. This is reflected most often as: joint commercialization agreements, tying and bundling, joint purchasing agreements (buying alliances) and the increasing use of private labels (Commission of the European Communities 2009).

A lot of challenges are related with food supply chains. One of them is price pressure which forces supply chain leaders into constant efforts to decrease product prices, even when the competitive strategy is primarily focused on such characteristics as quality or delivery time. Globalization and internationalization of enterprises have also contributed to the fact that a large number of

European and American companies produce or commission production in the Asian market (Anholcer and Kawa 2012). According to the McKinsey consultancy, by 2020, production of approximately 80% of goods will take place in a country different from the one where it will be consumed. It will cause huge changes in the movement and consumption of goods (Balou 2007).

What is closely connected with the flow of goods among the entities of the food supply network is transport, which is considered to be one of the most important elements of a logistic system and requires careful planning and control. Lack of planning, ineffective decision making, and poor visibility in transportation can cause companies to overpay, miss delivery targets, and loose valuable business. Transportation costs can be a significant part of a company's overall logistics spending (Murray 2014). According to various estimates, transportation constitutes one-third of the logistics costs (Tseng et al. 2005). Moreover, transportation is the largest end-use contributor toward global warming in many developed countries. Transportation has a significant impact on the food sector because it often involves long-distance shipments, most frequently by road (Wakeland, Cholette and Venkat 2012). Pirog et al. (2001) notice that nearly half of all fruit sold in the US is imported, and that produce grown in North America travels an average of 2.000 km from the source to the point of sale. All the costs are transferred to the customer who needs to pay more for the goods. That is why cutting transportation costs is the major target for companies.

There is a number of transportation strategies that can be applied by management to help improve performance (Murray 2014). One of them is logistics outsourcing. Companies commonly use outside resources, particularly in transport. Logistics service providers often handle loads that come from many different customers. These are products having different physical and chemical properties. They also show different susceptibility to transport, which causes some problems. That is why in many cases it is necessary to impose some exclusionary constraints on the transportation process. In particular, it can be the case when some types of goods cannot be transported by the same mean of transport (like alive animals and frozen fruits and vegetables). Another situation where such constraints have to be imposed is when some suppliers do not want their products to be delivered to the same customer (e.g. because of some reasons concerning the marketing strategy of the company). However, as we can see below, it is not easy to find effective methods of dealing with such types of constraints.

For these reasons the main objective of this paper is to develop an effective model of planning food supplies, when the exclusionary constraints are present.

2. EXCLUSIONARY CONSTRAINTS

For the purpose of this paper we have performed two stages of research. In the first stage empirical research

was conducted with the use of secondary and primary sources. On the basis of the secondary sources (scientific papers, industry materials, market reports), we identified exclusionary constraints that were subjected to primary research. Next, we conducted the primary empirical research based on qualitative research in the form of FGI (Focus Group Interview). The main objective of this research was to diagnose the types of exclusions emerging in transport. In July 2015 we conducted FGIs in three cities in Poland using questionnaires with managers from transport and distribution companies. The sample size was three groups, each of which consisted of 5-7 persons.

In order to ensure comparability, the studies in the three cities proceeded along the same scenario. A moderator supervised the procedure, and was also responsible for making all participants contribute to the discussion as equally as possible and, if necessary, for stopping those who excessively tried to impose their views on the other group members. The interviews took place in professional focus rooms, making the experiment comfortable. They took approximately one and a half hours, the procedure was recorded (audio and video). On the basis of those focus group interviews, the following exclusionary constraints that occur in shipment were determined:

- Sensitivity to duration of transport.
- Sensitivity to carriage temperature.
- Sensitivity to air humidity.
- Sensitivity to effects of light.
- Sensitivity to absorption of odors.
- Chemical composition of the product.
- Perishable goods.
- Dangerous goods.
- Animals.
- Competitive products.
- Exclusive transport agreement.

The majority of the above agree with the exclusionary constraints presented in the literature.

In the second stage, based on the determined exclusionary constraints existing in reality, we developed mathematical models of the transportation problems.

3. TRANSPORTATION PROBLEM MODEL

The transportation (and, more generally, network) problems with linear side constraints were considered e.g. in (Glover et al. 1978; Klingman and Russel 1975; Thompson and Setbi 1986). It seems that the transportation problem with exclusionary constraints (TPESC), which are in turn nonlinear, appeared for the first time in (Cao 1992). The author considered an ordinary transportation problem with additional condition that for each supplier there are some pairs of destinations that cannot be served at the same time, i.e.:

$$x_{ij} \cdot x_{ik} = 0 \quad (1)$$

for certain triples (i, j, k) , where i is number of a supplier and $i \neq j$ are numbers of destinations. The author provided a branch and bound method to solve this problem. In (Cao and Uebe 1995) the same problem was solved with tabu search. In (Sun 2002), Sun proposed two branch and bound methods to solve the 0-1 mixed integer formulation of the discussed problem. Goossens and Spieksma in (Goossens and Spieksma 2009) studied the computational complexity of the TPESC, proving that it is NP-hard and becomes solvable in pseudo-polynomial time when the number of supply nodes is fixed. They also studied the TPESC with identical exclusionary sets. Recently, Vancroonenburga et al. (2014) studied the so-called red-blue transportation problem, being a special case of the TPESC, where suppliers are assigned to one of two disjoint sets, and each customer is supposed to obtain the deliveries only from the suppliers from one of these sets.

Of course all the above problems have very specific form, as the transportation network in each case has the form of bipartite graph. This is usually not the case in the real-life problems. Another issue is that the authors rather arbitrarily assumed the type of possible exclusions, at least they did not refer to any real-life data.

Also other types of networks were studied. Darmann et al. in (2011) consider the Minimum Spanning Tree Problem, the Maximum Matching Problem and the Shortest Path Problem with binary disjunctive constraints. Pferschy and Schauer in (2013) studied, among others, the Maximum Flow Problem with additional exclusionary constraints, where the exclusions were not restricted to the arcs starting in one vertex. As one can easily see, the last mentioned problems, although involving various types of possible networks, do not focus on the optimization of the transportation process. In some sense, this was the goal of Zhang et al. (2011), who considered the Minimum Spanning Tree Problem with exclusionary constraints and of Öncan et al. (2013), who considered the Minimum Cost Perfect Matching Problem with exclusionary constraints. In both cases, however, the transportation network has so simple structure, that it is far away of the reality.

To summarize, no one so far has considered the minimization of the transportation costs in the networks (especially in food supply chain), which structure is close to the real-life networks and exclusionary constraints are present. Only some attempts were made in the last years to investigate simple models. In consequence no one has studied the methods of solution of problems similar to the real-life problems. From this point of view, the model presented below has pioneering nature.

Let us start with the structure of a typical logistic food supply chain. If we consider a single product, such a chain has the structure of layered network, as presented on Fig.1. Between the layers all the connections are

possible, however, in practice, only few of them are in use (it follows from the properties of the solutions of network problems and consistent with the common sense).

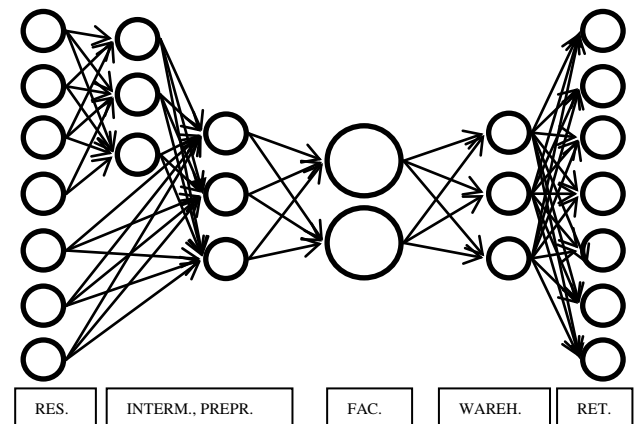


Figure 1: Scheme of food supply chain

What is important, there are many suppliers of the resources, then there are some intermediaries and factories pre-processing the resources and very few (sometimes even one) factories producing the final product. Then the chain starts to be wider again – there are usually more warehouses/logistic centers than factories and much more retailers/ final customers. If we divide the chain into two parts, one can easily see that the part before the main factories can be a little bit complicated (some resources are delivered to the first layer of factories, some of them to the second layer, sometimes the same resource may be necessary in various layers), which sometimes may even cause the network loose the layer structure. What is more important for us – the chains of various products are usually disjoint in this stage. According to the performed research, the problems with exclusions more likely appear in the second part of the chain. Even if the exclusionary constraints rarely touch the products leaving one factory, they start to be important on the level of warehouses/logistic centers, where various products are combined. It is a direct consequence of the fact that the logistic chains of many products intersect at this stage. In the remainder of this section we will thus focus on the second part of the chain.

As we already observed, it can be assumed that the transportation network on this stage consists of the layers and the transportation is possible only between two neighboring ones. We number the layers with consecutive integers and denote the number of a layer with $l, l = 1, 2, \dots, L$ (where L denotes the total number of layers). The number of agents in layer l (factories, centers, warehouses, shops etc.) will be denoted by $n(l)$ and the index of chosen agent by $i(l)$. The total number of goods to be transported is G , and the index of a good will be denoted by g . The amount of good g accessible at any node of the network in the considered period will be denoted by $a(l, i(l), g)$ – this numbers are positive for all the layers except the last one, where the negative

values correspond with the demand (all those numbers are parameters in the presented model, but can be treated as variables if one considers a dynamic version, see the section “Conclusions and future work”). We assume that the links between nodes are not capacitated (e.g., it is always possible to send more trucks in order to transport all goods). The capacities of the nodes are denoted by $u(l, i(l))$ (they are defined only for the inner nodes, i.e. the nodes in all the layers except the first and last ones). The volume of a unit of good g is $v(g)$. The unit costs of transferring good through respective node (e.g. the production costs, storage costs etc.) will be denoted by $d(l, i(l), g)$. The unit cost of transportation of good g between agent $i(l)$ from layer l and agent $i(l+1)$ from layer $l+1$ will be denoted by $c(l, i(l), i(l+1), g)$. The variables will correspond with the flows of goods between the nodes/agents and to the amounts of good transferred through the respective nodes. In particular, the amount of good g transported between agent $i(l)$ from layer l and agent $i(l+1)$ in layer $l+1$ will be denoted by $x(l, i(l), i(l+1), g)$. The total amount of good g transferred through node $i(l)$ in layer l will be denoted by $y(l, i(l), g)$.

Since we are interested in the minimization of the cost, the objective function (to be minimized) has the form:

$$f(x) = \sum_{g=1}^G \sum_{l=1}^{L-1} \sum_{i(l)=1}^{n(l)} \sum_{i(l+1)=1}^{n(l+1)} c(l, i(l), i(l+1), g) x(l, i(l), i(l+1), g) + \sum_{g=1}^G \sum_{l=1}^L \sum_{i(l)=1}^{n(l)} d(l, i(l), g) y(l, i(l), g) \quad (2)$$

The capacity constraints have the form:

$$\sum_{g=1}^G v(g) y(l, i(l), g) \leq u(l, i(l)), \quad (3)$$

$$l = 2, \dots, L-1, i(l) = 1, \dots, n(l)$$

$$x(l, i(l), i(l+1), g) \geq 0, \quad (4)$$

$$l = 1, \dots, L, i(l) = 1, \dots, n(l),$$

$$i(l+1) = 1, \dots, n(l+1), g = 1, \dots, G$$

The mass balance constraints are:

$$\sum_{i(2)=1}^{n(2)} x(1, i(1), i(2), g) \leq a(1, i(1), g), \quad (5)$$

$$i(1) = 1, \dots, n(1), g = 1, \dots, G$$

$$\sum_{i(l-1)=1}^{n(l-1)} x(l-1, i(l-1), i(l), g) + a(l, i(l), g) = y(l, i(l), g), \quad (6)$$

$$l = 2, \dots, L-1, i(l) = 1, \dots, n(l), g = 1, \dots, G$$

$$\sum_{i(l+1)=1}^{n(l+1)} x(l+1, i(l), i(l+1), g) \leq y(l, i(l), g), \quad (7)$$

$$l = 2, \dots, L-1, i(l) = 1, \dots, n(l), g = 1, \dots, G$$

$$\sum_{i(L-1)=1}^{n(L-1)} x(L-1, i(L-1), i(L), g) \geq -a(L, i(L), g), \quad (8)$$

$$i(L) = 1, \dots, n(L), g = 1, \dots, G$$

Finally, we need to include the exclusionary constraints. As mentioned before, sometimes two goods cannot be transported together because of their properties. Assume that good g_1 and g_2 cannot be included in the same transport. Then the constraints could take the form:

$$x(l, i(l), i(l+1), g_1) x(l, i(l), i(l+1), g_2) = 0, \quad (9)$$

$$l = 1, \dots, L-1, i(l) = 1, \dots, n(l), i(l+1) = 1, \dots, n(l+1)$$

This is a nonlinear constraint. However, we can preserve the linearity of the model by introducing sufficiently large number M (for example equal to the maximum capacity of a node in the supply chain) and binary variables $\alpha(g_1, g_2, l, i(l), i(l+1))$ (equal to 1 if the good g_1 can be transported and g_2 cannot, and 0 otherwise). Then for each $l, i(l)$ and $i(l+1)$, the constraint (9) can be written in an equivalent form (note that we need to use two constraints here instead of one):

$$x(l, i(l), i(l+1), g_1) \leq \alpha(g_1, g_2, l, i(l), i(l+1)) M \quad (10)$$

$$x(l, i(l), i(l+1), g_2) \leq (1 - \alpha(g_1, g_2, l, i(l), i(l+1))) M \quad (11)$$

Another kind of exclusion can take place if two goods cannot be transferred simultaneously through chosen nodes. In such case the constraint, for defined l and $i(l)$, would be as follows:

$$y(l, i(l), g_1) y(l, i(l), g_2) = 0 \quad (12)$$

Again we can use a similar transformation as in the case of constraints (9), by using respectively defined variables $\beta(g_1, g_2, l, i(l))$:

$$y(l, l(i), g_1) \leq \beta(g_1, g_2, l, i(l)) M \quad (13)$$

$$y(l, l(i), g_2) \leq (1 - \beta(g_1, g_2, l, i(l))) M \quad (14)$$

4. CONSLUSIONS AND FUTURE WORK

The exclusionary constraints are defined for goods – e.g. if some pair of good cannot be transported together, the constraint looks same for all the combinations of nodes. This together with the possibility of involving the binary variables suggests that the problem can be solved by a branch-and-bound method. It is well-known, however, that such methods work in a polynomial time, which is not acceptable when taking

into account the number of the binary variables even in small instances of the problem. Thus usage of some heuristics or metaheuristics could be useful. The design of various solutions methods for the problem described above will be our main interest in the nearest future.

What is worth mentioning, the above model is quite simple. At least four modifications could be introduced and will be analyzed in the future. The first one is introduction of time to the model, i.e. changing the static model described in this article into a dynamic one. The second modification is the generalization to the supply chains where transportation is possible also between two non-neighboring layers (or, in other words, the network is no more a layered network). Third possible modification is considering the fixed charge costs. The fourth one – considering the model where the costs are nonlinear (in particular piecewise linear). Also in the case of these four modifications the development of effective solution methods will be one of our interests.

ACKNOWLEDGMENTS

The paper was written with financial support from the National Center of Science (Narodowe Centrum Nauki) – the grant of the no. DEC-2014/13/B/HS4/01552.

REFERENCES

- Ahumada O., Villalobos J. R., 2009. Application of planning models in the agri-food supply chain: A review. *European Journal of Operational Research*, 196(1), 1-20.
- Anholcer M., Kawa A., 2012. Optimization of Supply Chain via Reduction of Complaints Ratio". In: Jezic G., Kusek M., Ngoc-Thanh Nguyen N.-T., Robert J., Howlett R.J., Lakhmi C., Jain L.C. (eds.): "Agent and Multi-Agent Systems. Technologies and Applications". Lecture Notes in Computer Science, 2012, Volume 7327/2012.
- Balou R.H., 2007. The evolution and future of logistics and supply chain management, "European Business Review", vol. 19, no. 4.
- Bottani E., Rizzi, A. and Vignali G. 2014. Improving logistics efficiency of industrial districts: a framework and case study in the food sector. *International Journal of Logistics Research and Applications*, (ahead-of-print), 1-22.
- Bruzzone A.G., Massei M. and Poggi S., 2007. Simulation based analysis on different logistics solutions for fresh food supply chain. In *Proceedings of the 2007 spring simulation multiconference-Volume 3* (pp. 84-89). Society for Computer Simulation International.
- Bruzzone A.G., Longo F., Massei M., Nicoletti L. and Agresta M., 2014. Safety and security in fresh good supply chain, "International Journal of Food Engineering", 10 (4), pp. 545-556.
- Cao B., 1992. Transportation problem with nonlinear side constraints a branch andbound approach. *Mathematical Methods of Operations Research (ZOR)* 36, 185–197.
- Cao B., Uebe G., 1995. Solving transportation problems with nonlinear side constraints with tabu search. *Computers and Operations Research* 22, 593–603.
- Commission of the European Communities, 2009. A better functioning food supply chain in Europe, Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions, Brussels, 28.10.2009, COM, 591 final.
- Darmann A., Pferschy U., Schauer J., Woeginger G.J., 2011. Paths, trees and matchings under disjunctive constraints. *Discrete Appl Math* 159 (16):1726–1735.
- De Cindio B., Longo F., Mirabelli G., Pizzuti T., 2011a. Modelling a Traceability System for a Food Supply Chain: Standards, Technologies and Software Tools. In: *Proceedings of the 10th International Conference on Modeling and Applied Simulation*. p. 488-494, ISBN: 978-88-903724-5-2, Rome, SEPTEMBER 12-14 2011.
- De Cindio B., Longo F., Mirabelli G., Pizzuti T., 2011b. Tracking and tracing in the food industry: Opportunity and competitiveness advantage analysis. *Industrie alimentari*, vol. 50, p. 7-19.
- Glover F., Karney D., Klingman D., and Russel R., 1978. Solving singly constrained transshipment problems, *Transportation Science* 12, 277–297.
- Goossens D., and Spieksma F.C.R., 2009. The transportation problem with exclusionary side constraints. *4OR, A Quarterly Journal of Operations Research*, 7, 51–60.
- http://ec.europa.eu/agriculture/markets-and-prices/food-supply-chain/index_en.htm (accessed 14 July 2015).
- Jiang Y., Zhao L. and Sun S.A., 2009. Resilient Strategy for Meat-food Supply Chain Network Design, 2009 IEEE International Conference on Industrial Engineering and Engineering Management.
- Klingman D., Russel R., 1975. Solving constrained transportation problems. *Operations Research* 23:91 – 106.
- Marsden T., Banks, J. and Bristow G., 2000. Food supply chain approaches: exploring their role in rural development. *Sociologia ruralis*, 40(4), 424-438.
- Murray M. (2014), Reducing Transportation Costs, <http://logistics.about.com/od/forsmallbusinesses/a/Reducing-Transportation-Costs.htm> (accessed 14 July 2015).
- Öncan T., Zhang R. and Punnen A.P., 2013. The minimum cost perfect matching problem with conflict pair constraints, *Computers and Operations Research*, Volume 40, Issue 4, April 2013, Pages 920–930.
- Pferschy U., Schauer J., 2013. The maximum flow problem with disjunctive constraints. *Journal of Combinatorial Optimization*, 26, 109–119.

- Pirog R., Pelt T.V., Enshayan K. and Cook E., 2001. Food, fuel, and Freeways: An Iowa perspective on how far food travels, fuel usage, and greenhouse gas emissions. Ames, Iowa: Leopold Center for Sustainable Agriculture.
- Rong A., Akkerman R., Grunow M., 2011. An optimization approach for managing fresh food quality throughout the supply chain. *International Journal of Production Economics*, 131(1), 421-429.
- Sun M., 2002. The transportation problem with exclusionary side constraints and two branch-and-bound algorithms. *European Journal of Operational Research*, 140, 629–647.
- Thompson G.L., Setbi A.P., 1986. Solution of constrained generalized transportation problems using the pivot and probe algorithm. *Computer and Operational Research* 13:1- 9.
- Tijssens L.M.M., Koster A.C., Jonker J.M.E., 2001. Concepts of chain management and chain optimization, *Food Process Modeling*, Woodhead Publishing Ltd., Cambridge, UK.
- Tseng Y., Yue W.L. and Taylor M.A.P., 2005. The role of transportation in logistics chain. *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol. 5, 1657–1672.
- Vancroonenburga W., Della Croce F., Goossens D., Spieksmae F.C.R., 2014. The Red–Blue transportation problem, *European Journal of Operational Research* 237, 814–823.
- Vorst, V. D. J., 2000. Effective food supply chains; generating, modelling and evaluating supply chain scenarios, PhD Thesis.
- Wakeland W., Cholette S., and Venkat K., 2012. Food transportation issues and reducing carbon footprint. In *Green Technologies in Food Production and Processing* (pp. 211-236). Springer US.
- Zhang R., Kabadi S.N. and Punnen A.P., 2011. The minimum spanning tree problem with conflict constraints and its variations. *Discrete Optimization* 8(2):191–205.

AUTHORS BIOGRAPHY

Dr. **Marcin Anholcer** is assistant professor at the Department of Operations Research. He got PhD in economics (2006) and mathematics (2011). His scientific interests are related to graph theory and network optimization.

Dr. **Arkadiusz Kawa** is assistant professor at the Department of Logistics and Transport. He got PhD in economics (2009). His scientific interests are related to logistics, supply chain management and business network.