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PORTABLE TELEMATIC SYSTEM AS AN EFFECTIVE TRAFFIC FLOW MANAGEMENT IN WORKZONES

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Traffic infrastructure localities with temporal restrictions for example due to reconstructions, or modernization, are important aspects influencing the traffic safety and traffic flow. On the basis of our research, we can identify main factors, which generate travel time loses, and which often cause traffic accidents in bottlenecks. First of all, it is improper late merge, speeding, tailgating, lower tolerance and consideration to other road users. Nervousness and ignorance of drivers also play an important role in generation of traffic congestions, lower level of service and resulting external economic loses. One of the tools eliminating the traffic restriction negative impacts is usage of portable telematics systems. In 2011 to 2013,project ViaZONE was in progress, which was to design an intelligent system with the aim to eliminate the mentioned risks and reduce economic losses generated by traffic congestions. Using available data and information, we have proved profitability and cost-effectiveness of dynamic systems for traffic control of work zones. Regarding traffic management, the system showed some problems due to indisciplined drivers and the system proved that speeding in these hazardous road segments is a common practice which caused accidents and congestions

Keywords: Workzones, Traffic management, accident, congestion, detectors, portable variable message signs

1. Introduction

The reconstruction and modernization of highways is a complicated process in all countries while developing road infrastructure. Unlike smaller roads, highways and major roads do not usually have a comparable alternative, which could be used by the drivers in the course of reconstruction. As a consequence, work is usually done during normal traffic, which inevitably leads to formation of bottlenecks. In such case it is necessary to try finding an effective, but also affordable way of managing the traffic flow in the working zone and the surrounding areas in order to minimize the negative effects on road capacity, and safety of not just the drivers, but also the workers themselves. In 2011 to 2013, project ViaZONE was in progress "Traffic Flow Harmonisation and Increase of Road Capacity at Road Works with the Use of Co-operating ITS Systems – Portable Traffic management", which was to design an intelligent system with the aim to eliminate the mentioned risks and reduce economic losses generated by traffic congestions.

The research team consisted of Centrum dopravního výzkumu, v.v.i. as the coordinator and cooperating organizations HIT HOFMAN, s.r.o. and Brno University of Technology, Faculty of Civil Engineering. The project was funded by Technological Agency of the Czech Republic within Alfa programme. The project aimed to develop, produce, test and verify a pilot operation of "Portable System of Traffic Management", particularly on sites in front of and in traffic closures. The aim of the project was reached in December 2013, when the pilot operation of the system was finished on a motorway D1 segment between Brno and Vyškov.

This paper presents the result of the impact assessment of the pilot testing VIAZONE system.

Some political issues of research which were done in frame of POLITE project funded under INTERREG IVC programme of European Union have been introduced in this paper as well.

1.1. The portable telematics system - ViaZONE

The system in question consists of interoperable components, which are tailor-made to the requirements for portable systems [6]. The main feature of these components is their modularity, portability, minimum requirements for installation, calibration and maintenance, economic operation, and independence of mains. The complex system is a set of HW and SW tools which allow for an effect on drivers through portable, mobile, variable road signs. Unique algorithms for the displayed pictograms and messages on variable road signs are displayed in real time on the basis of evaluated input data from various traffic detectors which are installed in several predefined profiles of an area in question. Reliability of all used components of the system was verified during testing. Evaluating and control software allowed for remote controlling and automated operation of the system without any problems. Subsequently, the data from the measuring and system operation were evaluated and methodology "Methods to Improve Road Safety and Traffic Flow at Traffic Closures Using ITS" was produced.

Figure 1. Illustrative photo made during system pilot testing

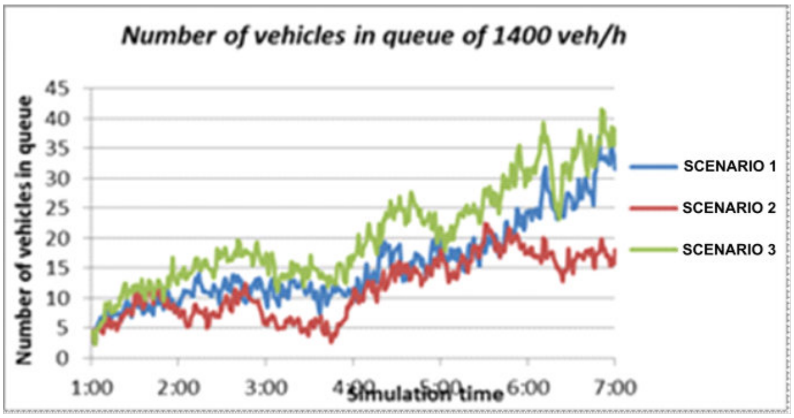
2. Theoretical background for system effectiveness

In-depth analysis of traffic flow behaviour at road closures was performed in the first stages of the project. Traffic detectors were installed at several reference traffic closures for the period of 6 weeks. The obtained data were used for creation of micro-simulation models. Input values of the model were obtained from measurements performed on highway closures and also using the values for estimating the capacity of highway closures in [1] and [2]. Traffic flow model was calibrated and validated in comparison with the source data from floating vehicles [8]. Control scenarios, which were verified on the models, were created in the other stage. After performing more than 300 simulation tests, the most suitable scenario was selected (Graph 1 shows Scenario 2), which was a combination of adaptable speed reduction and warning system with the function of informing of queues, possibly other hazards. The system design and algorithms used in model has been suggested in relationship between capacity and driver behaviour [3].

The performed analyses show that the use of dynamic controlling according to Scenario 2 is able improve the capacity of a bottleneck by approximately 10 - 15%.

Regarding the late merge, the critical value for the Czech Republic is approximately 1400 v/h. Higher traffic volume is beyond the capacity of late merge and queues are likely to occur. Model cases show that the use of the dynamic system may lead to the harmonization of traffic flow and the rule of late merge could be respected more (with the current vehicles classes). Regarding traffic closures which uses two narrowed traffic lanes, there is not such frequent occurrence of queues, but queues and significant time losses are likely in crisis situations and peak hours.

The conclusion of analytical studies show that dynamic controlling in work zones may lead to significant road safety improvement and improvement of travel times by 10%-15% and reduction of the number of vehicles standing in the queue by 15% - 20%.



Graph 1. Number of vehicles in queue of 1400 veh/h

3. Pilot testing of an innovative system

3.1. Basic information on road closure

Reconstruction of motorway D1 near Brno started in the middle of 2013. This concrete road pavement reconstruction was the largest reconstruction of D1 with the exception of the modernized segments between Brno and Prague which are under the progress. The traffic was guided in both directions in two auxiliary traffic lanes using the hard shoulder.

In the time period from 20 September 2013 to 3 December 2013, a system of Portable traffic management, which is the main outcome of the project of Portable Traffic Management, was installed on motorway segment Olomouc – Brno on kilometres 213 to 229.

3.2. System architecture within pilot testing

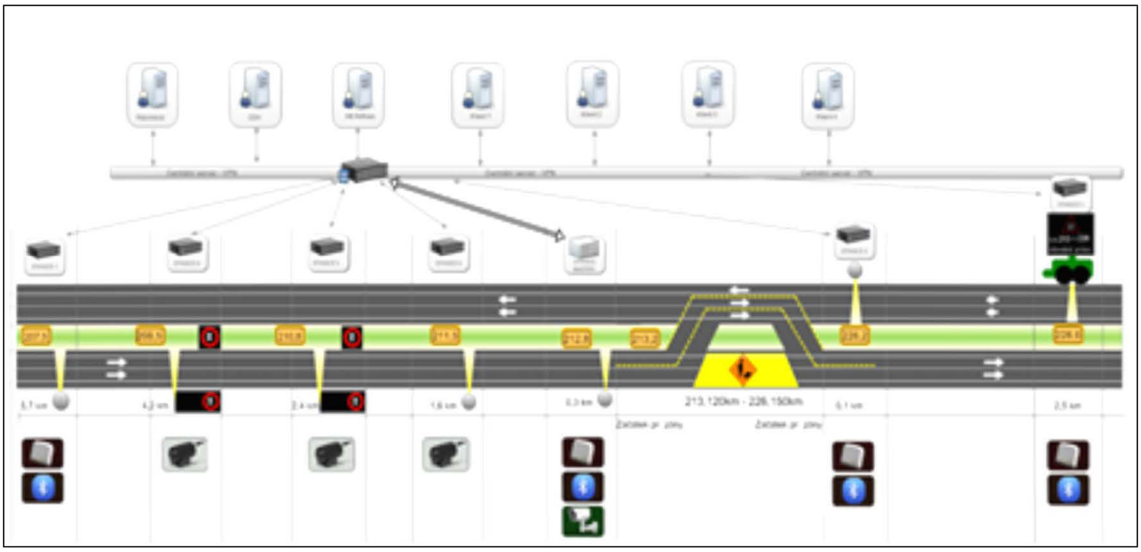


Figure 2. Complete architecture within pilot testing on D1 motorway segment between kilometers of 207.5 – 229.5

During the pilot testing has been installed these system components with respect of requirements in [4]:

- Portable VMS installed in the middle of the road (2x)
- Information trailer LED (3x)
- Nonintrusive traffic detector Wavetronix (4x)
- The queue radar detectors (3x)
- Travel time detectors (4x bluetooth detectors)
- Camera

- Industrial PC with minimum power consumption, compatible with all detection and display components with GPS, GPRS (9x)
- Evaluation software
- Alternative source of energy

The evaluation software has been installed in the station MASTER (212.650 km) as well as in the central server. It concerns redundancy evaluation, while the basic evaluation is performed in the central server. The supervisory and controlling software ViaZONE was installed on the motorway Police department and Highway directorate of Czech Republic and on the organization which provided the servicing and maintenance of the system. Regarding alarm situations (technology failures, critical power supply status of batteries, etc.), the system informed operators and send text messages to selected phone numbers with such message content which specifies he identified problem. This function aims to speed up a reaction to the occurred problem. All system functions respected the requirements in [5].

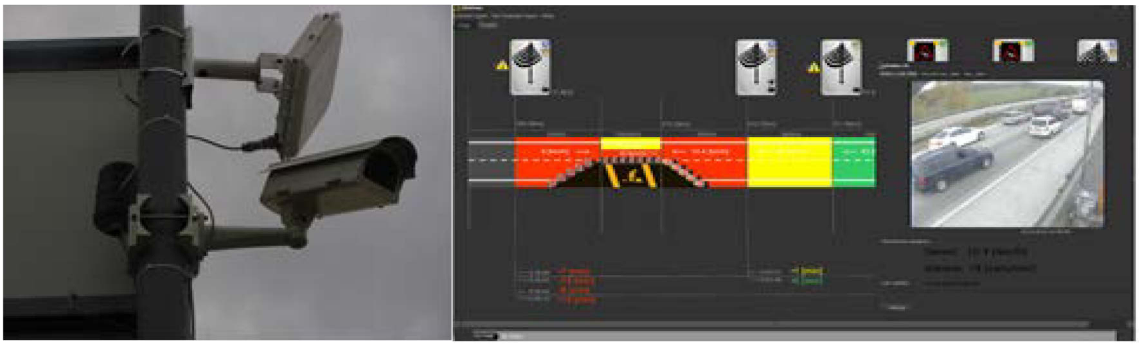


Figure 3. Portable detectors on the left and printscreen from the on-line visual control SW on the right

4. Evaluation of the pilot testing

Testing of the system can be divided into four separate chapters.

- Analysis of accidents
- Analysis of economic indicators
- Technical matters
- Traffic management

4.1. Analysis of accidents

During the period of traffic closures in 2013 (71 days), 48% (25 accidents) of all accidents in that year were reported on the monitored segment. We are talking about incidents where the Police of the CR had to intervene. In 2012, traffic closures on the same segment lasted only 53 days, however, during that period occurred 17 accidents, which is 33% of all accidents in that particular road segment in 2012.
For example during the 71 days immediately prior to installation of traffic closures only one traffic accident occurred on this segment of the motorway. In the period from January to June 2013 there were 26 accidents in the monitored segment. So in the test segment, during the two years of monitoring there was 3.84 times higher probability of an accident in the segment with transport limitations compared to the period with no traffic limitations on the monitored segment. From these data it is evident that road closures are significant risky places, which should be provided with a system to harmonize traffic, in combination with repressive systems that will enhance respect for road signing and marking.

4.2. Analysis of economic losses due to the work zone on D1 and congestions at the site of pilot installation

After completion of the testing it was attempted to determine the total economic losses incurred due to delays in the work zone near Vyškov and show the importance of measures that lead to elimination of delays and traffic accidents. For these calculations, we used data from the system RODOS (from the system of floating car data) [8], where we compared the five-minute aggregated outputs from ASIM detectors located at road mileage 207 and 226 (traffic volume, classification) with the values of delay in individual segments of the affected site. As input values for idle time of cars, trucks and buses we used the HDM-4 methodology [7]. All 71 days of the existence of this work zone were covered and all delays in the segments exceeding 3 minutes were included.

Table 1. Total time losses due to the traffic closure, quantified in Czech crowns

Total losses	Cars	Trucks	Total losses
Direction Vyškov - Brno	CZK 53,378,380	CZK 26,687,742	CZK 80,066,132
Direction Brno - Vyškov	CZK 9,147,871	CZK 4,768,595	CZK 13,916,466

4.3. Technical matters

The testing of the system was technically successful. The assumption of system reliability proved true and testing also revealed weaknesses of the system that were tuned in the process of testing. Of course, even after testing the system continues to be enhanced. From this perspective, testing of the system under practical conditions is irreplaceable. Laboratory conditions and theoretical assumptions can never discover specific cases that arise only in real-world conditions. On the technical side we note in particular the following results of the pilot testing:

- We have verified the reliability of bluetooth detection and benefits for control algorithms of the system. The hypothesis proved true that 10% penetration rate of equipped vehicles is sufficient as an input for dynamic traffic management and at the same time, such a penetration rate occurs on the roads in the Czech Republic at any time of the day.
- We have attested the accuracy of detectors, which can be used as an alternative to stationary detection devices with the accuracy more than 95% in intensity and more than 85% in classification
- Configuration and control SW was significantly changed during the testing and after. We have attested the feasibility of traffic management on the basis of matrix algorithms that allow easy adjustment of algorithms by a normal system user. In this context it should be noted that during the testing, control algorithms have evolved considerably, especially with regard to crisis management, such as when the required data from any of the detection profiles are not available.
- We have verified the reliability of evaluation HW system elements that can be without any problems powered by batteries or solar cells.
- It was verified (5) that the system cannot operate on only one communication technology. GPRS technology is not sufficiently permeable to allow (at least in 99% of cases) sending the data every minute to the evaluation server. This interval was defined as the minimum necessary for traffic management.
- Control SW Viazone, or more precisely the control algorithms of the system allowed commanding the Information trailer LED from different supplier, which demonstrated the possibility of independence of the system on LED technology vendors.
- The possibility of trouble-free maintenance of interim ITS systems was demonstrated what is suggested in (4). Regular replacement of batteries in the central reserve may be routine and very fast operation that does not disturb traffic flow.

4.4. Traffic management matters

If we wanted to fulfil the theoretical assumptions drawn from the prepared calibrated models and shorten travel times and the length of queues in the place of work zones with the use of dynamic management (theoretical models indicate the potential for improved traffic-carrying capacity by more than 10%) based on the speed limit, it would be necessary to propose additional measures. The degree of acceptance of variable road signs by drivers is insufficient and disobedience and arrogance of most drivers occurs. The data showed that traffic flow is faster on average by about 20 km/h than is the permitted speed limit, even at places of work zones where workers are moving and the width of lanes is significantly reduced.

An average traffic volume was 27 vehicles/ min (minimum of 10 vehicles/min, maximum 45 vehicles/min). The speed was evaluated for 5 minutes. From the performed tests we can conclude that by displaying the road sign 80, slowing the speed of traffic flow by about 25% down to the speed of around 100 km/h (at best) is achieved. Better results is obtained by displaying a warning sign “Queue“

(results are better than with maximum 80). The average speed was reduced to the speed around 95 km/h. Before displaying the symbol, the speed of traffic flow was 112 km/h (max. 115 km/h and min. 108 km/h). In the first minute, traffic flow moved without limitation, in minute 2-3 there was also no significant decrease in the speed (average 107 km/h) but in the 4th minute the average was 92.4 km/h and in the 5th minute 98.2 km/h.

From the above it can be deduced that drivers react more to warning road signs that symbolize certain approaching danger than to speed limit signs.

These results, however, are insufficient for traffic management, as they do not match the model assumptions by far and therefore it is not possible to make a reliable statement on the effectiveness of the tested pilot system to improve traffic flow and increase throughput at bottlenecks. It is also not possible to make a credible statement with regard to the length of pilot installation, since the effectiveness and efficiency of the system should be evaluated at least after 1-2 years of its routine operation.

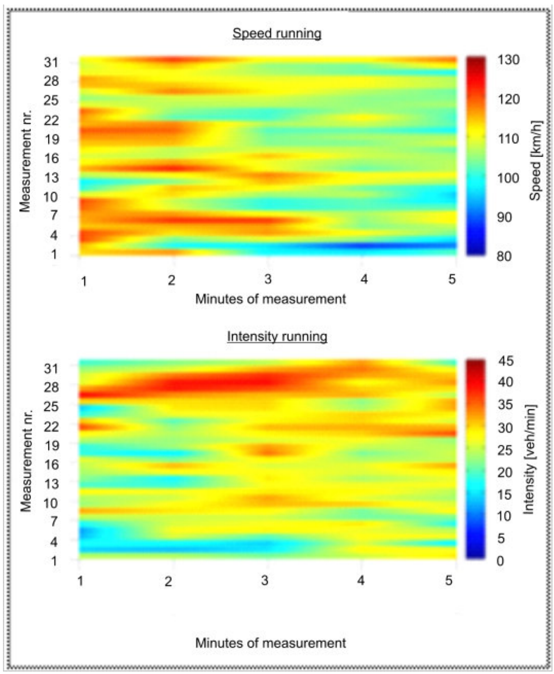


Diagram 1: Comparison of speeds and traffic volumes during the long-term measurement.
There is no apparent relationship between speed limit compliance and traffic volume.
Upper diagram show the slowing traffic flow, if the max 80 km/h has been displayed

5. Telematics system´s economic indicators

In order to estimate the benefits of active management of work zones it is not possible to make a simple statement that traffic flow improved and travel times shortened. The initial investments in the system and its subsequent operation generate substantial costs that need to be taken into account. When calculating the economic indicators of the system a model case was established, which was simulated based on real data. The simulation was carried out on a calibrated traffic model that was created in earlier stages of the project and related to one traffic closure in each direction. Consideration was given to the data that emerged from real testing the system, so the already calibrated models were set according to specific values coming from drivers' reaction to the system (these results are presented later in this document). Therefore, the input values are more realistic compared to initial simulations. Therefore, the creation of an economic model counted with savings in travel times between 7-9%. In the model, the system was used in configuration of an adaptable speed decreasing system of 3 VMS profiles (on both right and left side) and one information trailer. On the other side of the working zone a warning and information system was used in configuration with 2 VMS profiles (both on the right and left side) and an information trailer.

These inputs to the economic model were used:

- Values of time spent in congestions specified by HDM-4 (National methodology) [7]

- The value of time spent in congestions related to classification of vehicles on the motorway D1 according to data from a fixedly mounted profile detector
- The value of travel time savings during a simulation experiment
- The investment costs of the system.
- Maintenance and operation of the system, including depreciation
- Comparison of benefits and costs of the system

The findings of this economic model show that for the given test configuration and time, the system efficiency index calculated as the ratio of benefits and costs of its operation was CIES = 6.6. Thus, the system during the monitored time within the simulation period proved to theoretically generate savings of more than six times the operating costs. Index like this is quite crucial for evaluating the economic efficiency of the system.

However, it is important to emphasize that it is not possible to search for a fixed number for the system, but always a combination of the system, installation location and operating time.
The resulting system efficiency index is determined inter alia, by the following factors:

- Traffic volume in the site of installation influences the efficiency index the most. As it turned out, shortening of travel times is in the case of active traffic management more pronounced for low traffic flow, i.e. more vehicles in a queue.
  On the contrary, the management may be counterproductive in case of a lower number of vehicles.
- Operating time of the system includes phases during the day with higher and lower volumes, which reflects in its effectiveness. If the system is in operation 24 hours a day, its effectiveness will be lower than in the case where it is active only during the weekdays and only during the daytime.
- Seasons influence drivers' behaviour in work zones. In the winter months, drivers tend to drive more slowly and the dynamics of traffic flow is therefore different from the summer months.

Generally it can be stated that although the system under study was tested on data especially during the time of the day that involves afternoon rush hours, its index is so high that it would fall to the zone of unprofitability only in case of very unfavourable combination of several of these factors acting simultaneously

6. Conclusions

All the above facts have one clear and easily verifiable result. In areas of road closures, the probability of traffic accidents is approximately 4 times higher than on the segments of motorways and expressways with no limitations. It is the result of exceeding speed limits, not maintaining safe distances and not adjusting the driving to road surface conditions. However, drivers themselves do not perceive this fact.

From the perspective of research, we can therefore consider the results of this testing as very valuable. In order to achieve the theoretical assumptions of the possibility to reduce economic losses from increased travel times and accidents through telematics tools, it is necessary to seek other appropriate measures. It could be effective to use restrictive measures in the form of heavy fines and point penalties for violations of traffic rules in work zones. It is necessary to take into account the safety of workers in work zones, which is considerably endangered by fast driving. The above mentioned large number of traffic accidents is a sad evidence of the critical situation in complying with traffic rules in work zones.

According to discussions with members of the police force is not easy to penalize drivers in road closures. There is a problem with a place to stop vehicles. For this reason, possibilities should be considered of dedicating a place in road closures to measure the speed of vehicles with the possibility of their stopping. In the long run, it is necessary to increase respect of drivers from these places similarly as in tunnels where exceeding the speed limits is much less frequent.

Another result of the performed tests and analyses shows that the design and management of traffic closures has a significant impact on the overall losses in travel times of drivers and related economic losses. For this reason, it is necessary to provide sufficient space for the planning process of system deployment. At least the following sequence should always be observed:

- Familiarity with the plan of a closure, traffic routing, the number of lanes and their width, familiarity with traffic volumes at the time of planned closure
- Preparation of a model of traffic closure
- Determining a predicted delay with and without management
- Calculation of CIES
- Decisions about the form of the system, its functions (managing, warning, surveillance, etc.) and the number of components depending on information gained in previous steps

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AIR CARGO DEVELOPMENT IN THE REGIONAL AIRPORTS OF THE BALTIC SEA REGION THROUGH ROAD FEEDER SERVICES

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As issued in the Competition Policy Brief on the new state aid rules for a competitive aviation industry by the Competition Directorate–General of the European Commission in February 2014[1], it will be more difficult for unprofitable airports, to obtain financial public subsidies on EU, national or regional level. Although the positive impact of small airports on the regional development and general accessibility was mentioned, still the operating aid to the airports shall be cut out over a maximum of 10 years. It has been further stated that the vast majority of small and regional airports experience problems to cover their running operative costs, as a result from an intensive market competition and overlapping of airports' catchment areas preventing even some promising airports from growth. Public subsidies are mostly used by the airport management for infrastructural investments, to cover operating losses or to attract price-sensitive airlines. Herewith, among other things, the EU Commission is pointing out at the lack of cooperation structures and network strategies among the regional airports and at rather isolated and individual approach during elaboration of the airport development scenarios. However, the Competition Policy Brief permits public aid to regional airports, among other things if there is sufficient transports need to establish transition periods for small airports; the need for more flexibility of the regional airports in the remote areas has been underlined. The EU Commission is expecting herewith not to close the regional airports, but to stimulate them to operate on cost efficient and profitable basis, and that only the most inefficient airports will be closed.

To cope with the upcoming challenges the regional airports are demanded now to revaluate and reconsider their future development plans. While focusing on the passenger traffic many regional airports ignore or underestimate the benefits of the airfreight market. Although the air cargo has rather a low volume, but very high revenue yield part. Business internationalization is one of the important driving forces for the airfreight nowadays as well as decreasing air transport costs due to improving efficiency and growing competition among the air carriers. Most regional airports in the Baltic Sea region that act totally isolated, do not have a clear picture of the current situation on the international air cargo market, its future perspectives and sustainable development plans. Trying to meet the market demand, the regional airports are making huge and unjustified investments, e.g. improving airport infrastructure. It is not clear till now which elements of the Pan-Baltic cargo market could be managed as an alternative revenue yielding services for consolidated operation by air or what infrastructure is needed to provide the opportunity for an optimal economic mix of road-rail-air-sea transport? Nowadays, to a large degree air cargo traffic relies on scheduled, frequent passenger services in hub-and-spoke as well as in point-to-point traffic. Regional airports are presently suffering from a lack of scheduled uplift capacity. The volume currently transported by air in the regional airports is almost entirely based on the occasional charter flights. However, the growth of the air cargo business is likely to be based not only on cargo charters, but to a larger extend on truck-based services for transit shipments. Onward transportation by truck may occur on road feeder service, so called "flying trucks", where a real truck substitutes a flight. "Flying trucks" are having flight numbers etc., therefore they must be prioritized in many ways in the BSR transport policy.

This paper investigates the role of Road Feeder Services concept (thereafter named here as "Flying Truck") as an optional freight value proposition for the development of the regional airports and their possible participation in the air cargo market as a supplement instrument to generate additional revenue, thus making the airports more profitable and attractive.

Keywords: Air cargo, Road Feeder Services (RFS), regional airports, multimodality, air-road concept

1. Introduction and Problem Definition

Aviation plays an essential role in the European economic development for both citizens and industry. With a network of more than 440 airports, and more than 60 air navigation service providers, the European aviation industry carries about 40% of Europe's exports and imports value, and transports over 822 million passengers annually to and from Europe. Although the major part of these activities belongs rather to bigger aviation hubs, the availability of the current regional airports' infrastructure has also a wide range impact on economic activities, enhancing business internationalization, improving regional accessibility, attracting investments and boosting job growth. Playing a role of an economic gravity in a region, the regional airports stimulate business economic competitiveness of the region.

[1] Cf. Competition Policy Brief on the New State aid rules for a competitive aviation industry, Competition Directorate–General of the European Commission, February 2014, ISBN 978-92-79-35541-7

With regard to the specific air cargo market in the Baltic Sea Region (hereafter: BSR) the current results presented in this paper to a large extend are based on the reports and official outputs produced in the framework of the EU funded research project "Baltic.AirCargo.Net" (http://www.balticaircargo.net/)[2].

In order to define the region in the following study, the dimensions of the BSR has been set by the coordinates of the airports Cologne (CGN) for the western and Hahn (HHN) for the Southern boundary in Germany; Mehamn airport (MEH) in Norway sets the Northern and airport Ivanovo (IWA) I Russia defines the Eastern boundary of the BSR (Table 1).

Table 1. Defining BSR airports (FlightStats 2013)[3]

City	Airport Name	IATA Code	ICAO Code	Longitude	Latitude	Country
Mehamn	Mehamn	MEH	ENMR	71.03333	27.833332	Norway
Hahn	Frankfurt - Hahn	HHN	EDFH	49.948334	7.264167	Germany
Cologne	Cologne Bonn	CGN	EDDK	50.878365	7.122224	Germany
Ivanovo	Ivanovo	IWA		56.942955	40.944546	Russia

According to these set frames, there are 290 civil airports in the BSR (i.e. having a 3-letter IATA code) of which 176 airports (61%) have regular scheduled traffic (Table 2).[4]

Table 2. BSR Airports (OAG, Flightstats)

Countries	Number of Airports in the Region[1]	Number of Airports with scheduled Traffic[2]
Belarus	7	1
Denmark	18	9
Estonia	6	4
Finland	31	22
Germany	66	23
Latvia	3	1
Lithuania	6	4
Norway	46	41
Poland	18	12
Russia	33	18
Sweden	56	41
Sum	**290**	**176**

(1) Airports with IATA Code located within the region defined above (cf. Table 1)
(2) Recorded Traffic in 2013

The Baltic states, i.e. Estonia, Latvia, Lithuania and Belarus have 22 airports in total of which ten (four, one, four and one respectively) have regular scheduled traffic. Despite strong competition from Germany, Sweden and Norway the main hub of Denmark - Copenhagen airport (CPH) has a large share of cargo traffic and ranks seventh in terms of number of cargo flights, behind German airports Frankfurt international (FRA; 1.), Frankfurt-Hahn (HHN; 3.), Halle/Leipzig (LEJ; 4.) and Köln/Bonn (CGN; 6.) and the Russian airports SVO (2.) and DME (5.).

It may be also sated that the airports in the BSR are located close to each other with the overlapping catchment areas and close distances to the bigger hubs. Thus the regional airports need to seek a comparative advantage over other airports and countries.

[2] Baltic Sea Region Programme 2007 - 2013, ERDF Funds
[3] Cf. Bubalo, Branko, Economic Outlook for an Air Cargo market in the Baltic Sea region, Baltic.AirCargo.Net Project, 2013
[4] Regular scheduled traffic here - minimum one flight observation per week in 2013, FlightStats.

Figure 1 demonstrates the distribution of the air cargo flights in the BSR of the observations in the 2013. About half of all cargo flights (47%) go through Frankfurt am Main International airport (FRA), ca. 22% of the flights pass Moscow-Sheremetyevo (SVO) airport. The main air cargo market players in the BSR are Germany with a total market share of 59% (Frankfurt [FRA], Frankfurt-Hahn [HHN], Halle/Leipzig [LEJ] and Köln/Bonn [CGN]), Russia with 26,4% share (Moscow-Sheremetyevo [SVO], Moscow-Domodedovo [DME], Saint Petersburg-Pulkovo [LED] and Vnukovo [VKO] airports), Denmark with a 3,4% share (Copenhagen [CPH] airport), Finland with 3,3% market share (Helsinki [HEL] airport), Norway with 1,6% market share (Oslo [OSL] airport) and Sweden with 1,5% share (Stockholm-Arlanda [ARN] and Gothenburg-Landvetter [GOT] airport).

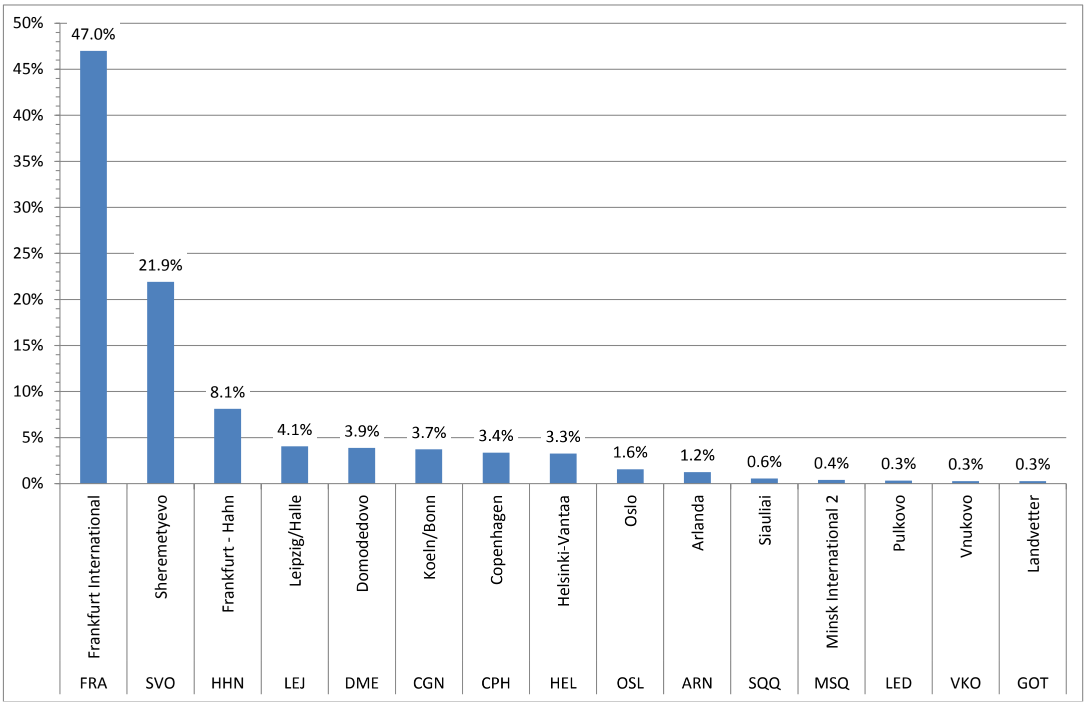

Figure 1. Distribution of Cargo-flights in the BSR[5]

According to breakdown to the average daily movement numbers there might be observed 127 average daily cargo flights at the defined sample of the BSR airports. This could be in indicator for a small and limited market, but with a very strong growth potential. If an average growth rate of 5% per annum can be maintained in the long-term in the BSR, then we may expect a doubling of the daily movements after 15 years and an increase by 164 daily movements (129%) to a level of 291 daily movements by 2030.[6] However, it might be stated that only big airports are taking advantages of the current air cargo business opportunities.

According to the “Baltic.AirCargo.Net” project data, the most regional airports in the Baltic Sea Region unfortunately act isolated and do not have a clear understanding of the current situation on the international air cargo market, they lack future perspectives and in some cases sustainable development plans. Trying to meet the market demand, the regional airports sometimes make huge and very often unjustified and unnecessary investments, e.g. improving airport infrastructure. However, the air cargo transport takes place not isolated but within a global net of value-added supply chains. Furthermore, it is not clear till now which elements of the Pan-Baltic cargo market could be managed as an alternative revenue yielding services for consolidated operation by air or what infrastructure is needed to provide the opportunity for an optimal economic mix of road-rail-air-sea transport?

Furthermore, to a large degree, air cargo traffic relies heavily on scheduled, frequent passenger services in hub-and-spoke system as well as in point-to-point traffic. Regional airports are presently suffering from a lack of scheduled uplift capacity. The volume currently transported by air in the Baltic Sea Region is almost entirely based on the occasional charter flights. However, the growth of the air

[5] Source: Economic Outlook for an Air Cargo market in the Baltic Sea Region, Baltic.AirCargo.Net Project, 2013
[6] cf. Economic Outlook for an Air Cargo market in the Baltic Sea Region, Baltic.AirCargo.Net Project, 2013

cargo business is likely to be based not only on cargo charters, but to a larger extend on truck-based services for transit shipments.

Onward transportation by truck may occur on road feeder service, so called "flying trucks", where a real truck substitutes a flight. "Flying trucks" are having flight numbers etc., therefore they must be prioritized in many ways in the BSR transport policy.

2. Interconnection between Accessibility of the Baltic Sea Region and the Air Cargo

The role of the regional airports for the general accessibility as well multimodality is indispensable regional and national economies in the EU.[7]

The accessibility of the Baltic Sea Region depends heavily on so called hub and spoke transport system. Most of the remote areas of the BSR could not reach the same accessibility (e.g. number of transport routes, destinations or frequencies; transport cost level, etc.) without hub and spoke model:

- Maritime: Container hubs like Hamburg offer overseas (intercontinental) connections and feeder traffic (e.g. Short Sea Shipping) is the spoke between the hub and the hinterland;
- Aviation: Aviation hubs like Copenhagen) offer intercontinental flight connections and feeder traffic (e.g. flying truck, Road Feeder Service) is the spoke between the hub and the hinterland.

Therefore, it can be stated that the Road Feeder Services along with the strong impact on the air cargo market also does heavily support the intercontinental passenger flights and the major aviation hubs of the Baltic Sea Region. Consequently it is very important to consider the fact that major aviation hubs of the BSR influence the accessibility of the BSR significantly and the economic viability of several intercontinental passenger flights strongly depends on the air cargo business, its efficiency and profitability.

The Finnair data might be a good example here: the Majority of Finnair's revenues generated by Europe – Asia traffic; whereas to be noted that the revenues coming from air cargo business represent ca. 20% of Asian revenues. As intercontinental passenger and cargo flights are strongly linked together, the so called "widebody" aircrafts performing the intercontinental flights carry significant part of the air cargo.

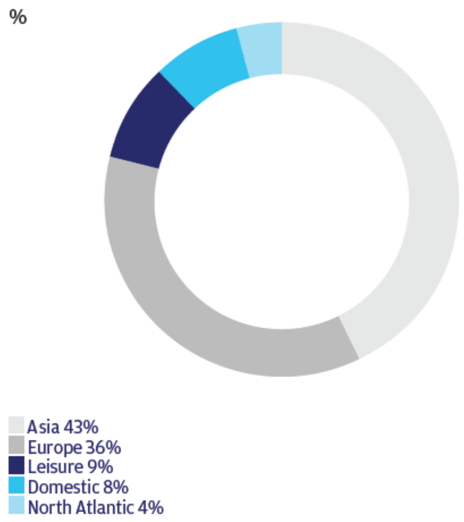

Figure 2. Distribution of revenues in scheduled traffic in Helsinki Airport (source: Finnair 2013)

According to Finnair data, the air cargo transported on scheduled flights (belly cargo) constitutes a significant proportion of the revenue from long-haul traffic; in 2013, belly cargo accounted for approximately 17% of total long-haul revenue. The overall load factor in Finnair's cargo traffic improved to 66%, while the available tonne kilometres rose by 1,3%. The new operating model strengthens air cargo demand in Finnair's Asian passenger flight network, as it also allows Finnair Cargo to offer faster cargo connections between Central Europe and Asia.[8]

[7] cf. European Parliament resolution of 10 May 2012 on the future of regional airports and air services in the EU (2011/2196(INI))

[8] cf. Finnair Annual Report 2013, http://www.finnairgroup.com/linked/en/konserni/23162-Finnair_2013_EN_withlinks_v2.pdf

Thus, it can be stated that the air cargo generates a significant part of revenues for the airlines that operate intercontinental flights. Therefore the economic viability of several intercontinental passenger flights is strongly dependent and directly relates to the air cargo business. The price level for the passengers directly depend on the utilization grade of the air cargo capacities of the "widebody" carriers. The results from the Baltic.AirCrago.Net project also confirm the statement that the major aviation hubs in the Baltic Sea Region generate significant part of their income from the air cargo business.

3. Role of the Road Feeder Services in the Air Cargo

There are different means of transportation that are being currently used to move goods within a fixed framework of a supply chain, business or legal regulations or under consideration of given characteristics and requirements. The air cargo transport may be generally regarded as external or internal transport.[9]

Under external transport it is meant the transfer of goods between single locations, e.g. between the shipper and the carrier. According to the given soft or hard infrastructural constrains, various modes of transportation are available: e.g. rail, road, see/ocean vessels, inland water carriers or aircraft. In the air cargo industry the traditionally assumed mode is considered to be aircraft. However, in practice the major part of supply and distribution of the officially declared air cargo are operated by special road vehicles.

Internal transportation defines the movement of the goods within a certain define infrastructure, i.e. airport. The transport from e.g. a terminal to a warehouse in an airport, whereas both locations belong to a single infrastructure unit.

A very good developed road-network infrastructure in Europe makes the development of alternative services to air transport possible via so called road feeder services. Due to the fact that majority of the pick up and delivery locations in Europe are rather at short or middle range distances, the delivery by truck, i.e. Road Feeder Service (RFS) often is the fastest, reliable and most cost efficient mode of transportation of the air cargo. Therefore the feeder service fulfilled by a truck provides many advantages, such as higher accessibility e.g. by pick up or delivery services, availability / simplicity in regard to executive units (trucks vs. aircrafts), certain flexibility in regard to an official time-schedule applied for the real air crafts e.g. in form of the given time slots and route. A traditional "flying truck" concept can be defined as a truck operating between two airports on so called Air Waybill (AWB) or air consignment note, which refers to a receipt that is issued by an international airline. It is very important to note that one truck might have several route numbers or flight numbers if it is carrying goods from more than one airline.

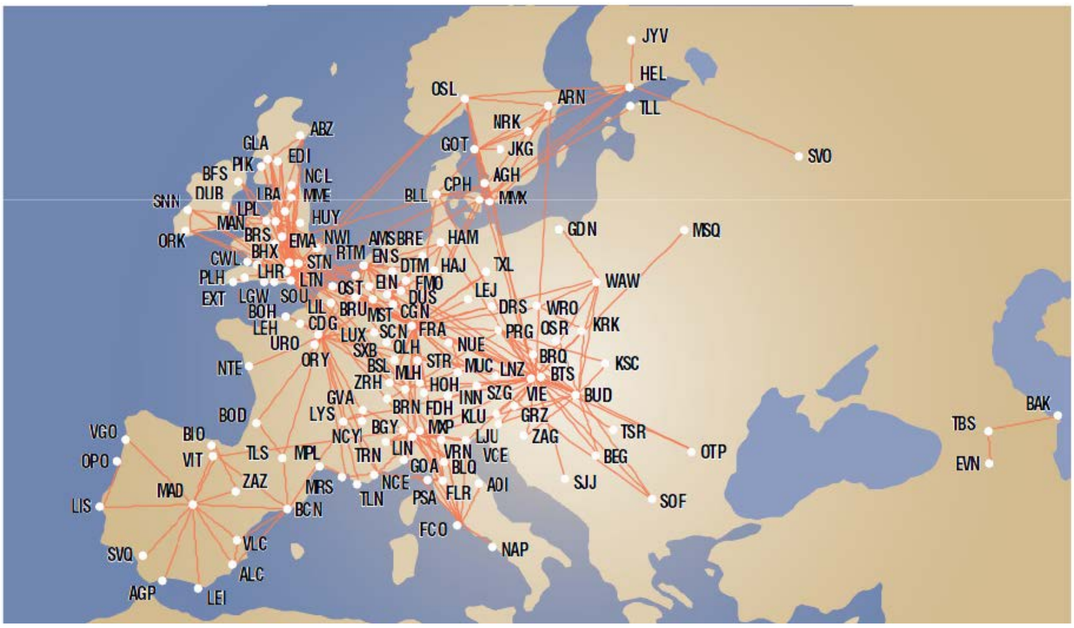

Figure 3. Scheduled truck-flight cargo service routes as of May 2007 (source: Boeing 2008)

[9] cf. Grandjot, Roessler, Roland, Air Cargo Guideline, 2007, 86-88

Roughly summarized, the RFS or “flying trucks” from the point of view of documentation and security requirements processing are treated and handled exactly in the same way like real aircrafts, i.e. the “flying trucks” possess herewith exactly the same insurance as if the goods were transported by aircraft and on route number, they are fulfilling all custom and security regulations set by the relevant authorities as if the goods were really flying by air.[10] The road feeder services mostly belong to the main executive leg in the transport chain and therefore provided and operated by the traditional airlines. Therefore the airlines possess an efficient alternative to deploy RFS for the shipments e.g. from a small or regional airport to a bigger (e.g. international) airport hub. RFS are also used for the air cargo consolidation in the hub/home airport of a given airline. The RFS same as a real aircraft do have a fixed time schedule, i.e. in comparison to traditional trucking services, the “flying trucks” dare not wait e.g. till the load capacity of a given truck is used to full extend, but it must leave the point of departure (e.g. Airport A) to a designated destination (e.g. Airport B) at exact time regardless its current load capacity.

The network of the operational Road Feeder Services in Europe has been considerably extended within last years and the road feeder concept has become to an essential part not only of the airfreight, but the whole logistics structural network. Although the concept is well known to air cargo professionals, it might be a bit unknown to representatives of other transport modes, regional actors and EU policy makers. Moreover the role of Road Feeder Services or “flying truck” concept and relationship to other transport modes as well as to other air cargo concepts is still underestimated and lacks behind its possibilities.

One flying truck can have several route numbers if it is carrying goods from more than one airline. The route numbers are set by local airline cargo manager, so there is no database to see the flying truck routes; and they are changing all the times. The Road Feeder Services also can happen while using the truck along with entire transport chain. The distances might vary from 100 up to 1000 kilometres and even more. Thus, while talking about air cargo transport services within Europe, normally professional mean delivery via RFS.[11]

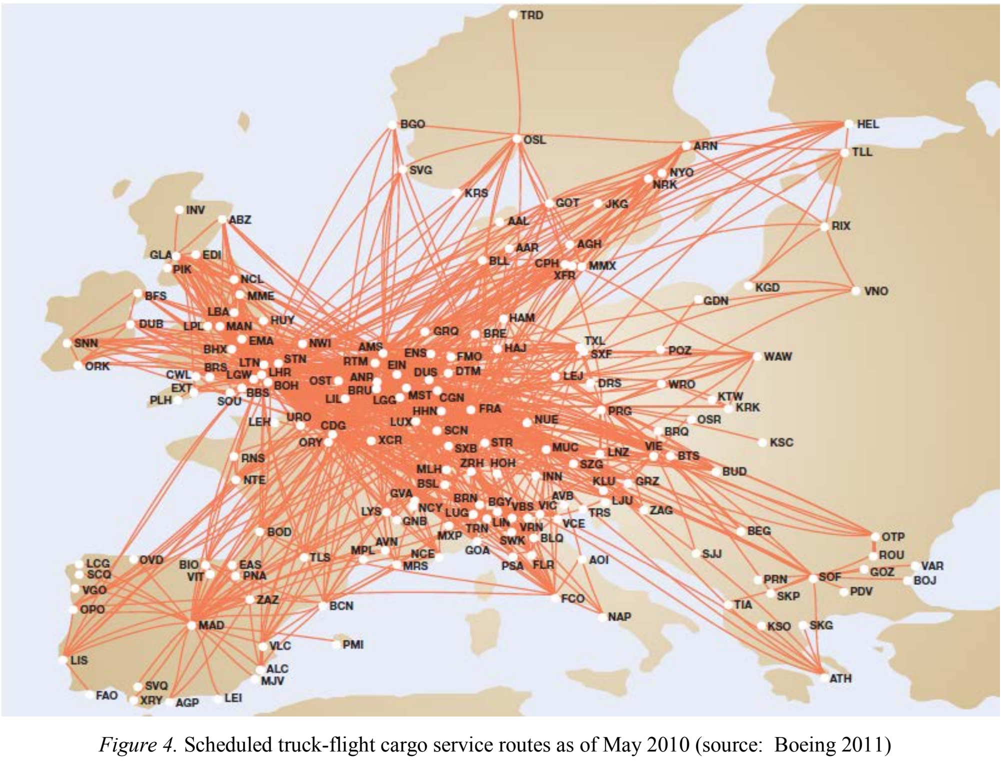

Figure 4. Scheduled truck-flight cargo service routes as of May 2010 (source: Boeing 2011)

The figures 3 and 4 demonstrate the rapid development of the RFS network in the air cargo business. However, according to the results of the Baltic.AirCargo.Net project the current EU transport strategies clearly underestimate its big role. Thus, it is of a vital importance to make “flying trucks” concept and its role in the international logistics network more known and understandable to a broader

[10] cf. Grandjot, Roessler, Roland, Air Cargo Guideline, 2007, 86-88
[11] Grandjot, Roessler, Roland, Air Cargo Guideline, 2007, 86-88

community, for it shall be more efficiently adapted to the EU and BSR transport policies and regional development strategies.

Especially for small and regional airports that do not have international regular air flights and pure freight carriers, the recognition and implementation of the flying trucks concept might be of a special importance. Nowadays very few regional airports in the Baltic Sea Region utilize the Road Feeder Service. In many cases the flying trucks are operated only in the capital cities like Helsinki, Copenhagen, Stockholm (Arlanda) or major hub-airports like Hamburg. The project Baltic.Aircargo.Net is studying possibilities to utilize the concept also by the small and regional airports and thus support the economic viability of the regional airports in the BSR.

The Baltic.AirCargo.Net project has been focusing on remote airports and not on capital / major airports. The project has been trying to promote air cargo operations of remote airports through alternative concepts like “flying trucks”, since might be almost impossible to utilize belly cargo concepts in the remote / regional airports. Also pure freighter concept is rather difficult even, if there is few success stories, for example Billund in Denmark and current plans of Parchim Airport to implement regular pure freighter line with China. Thus, the flying truck concept might be a very interesting and also realistic concept for remote airports when they are trying to access to the air cargo market. Preliminary interview results that have been carried out in the participating regions of the Baltic.AirCargo.Net project showed the regional airports have normally a sub-hub system to forwarders and integrators. Some airports are used as an interim-terminal where goods are collected for further transport to bigger hubs by road feeder services. The local SMEs are completely not involved in the air cargo mostly due to lack of knowledge and insight view of air cargo opportunities.

In the framework of the Baltic.AirCargo.Net Project three regional airports have been chosen as pilot sites for testing and demonstration, aiming also at promoting and implementation of the flying truck concept in their regions., i.e.:

- Tampere Airport in Finland;
- Linköping Airport in Sweden;
- Parchim Airport in Germany.

It has been recommended that the pilot sites interested in flying trucks concept implementation shall define their own detailed demonstration actions related to flying truck concept in the following frame:

- The sites shall familiarize themselves with the air cargo concepts, air cargo markets and roles of air cargo stakeholders. The planning of the demonstrations should be based on these facts of the air cargo.
- The roles of current air cargo concepts, cooperation and connections to other transport modes shall be identified. Each of these concepts has their advantages/disadvantages and thus the concepts are strong in different markets. What is the role of flying trucks, why, when and how it should be used?
- Identification of regional air cargo stakeholders – for example airport, airline (freighters, long-haul wide bodies, others) forwarders, ground handling, integrators, consignor, consignee – and their role in the logistics chain.

Although the concept of flying trucks is not so widely implemented and utilized by regional and small airports, e.g. in Finland only Helsinki is utilizing flying trucks concept and no one of regional airports is taking advantages of this. On the other hand, in Sweden quite many remote and regional airports have been already successfully implementing the flying truck concept:

- NYO, Skavsta
- NRK, Norrköping Kungsangen
- JKG, Jonköping
- AGH, Ängelholm-Helsingborg Airport
- MMX, Malmö Sturup

4. Integration Opportunities of SMEs in the Road Feeder Services

The finding of the Baltic.AirCargo.Net project, among other things showed that one of the most promising opportunities in terms of air transportation services that might be suitable for small and medium sized enterprises (thereafter: SMEs) or entrepreneurship is “Flying Truck” concept, which would enable providing differentiated, specialised qualitative services. The pure air cargo-forwarding sector implies big infrastructural investments, e.g. for the buying, leasing, maintaining of the machinery park, i.e. aircrafts. It is rather a naive assumption to believe that SMEs may possess the needed financial resources to start pure airfreight operations. On the other hand in regard to RFS, and according to the "Baltic.AirCargo.Net" project's results, among ca. 18 companies that offer airfreight transport services in Germany only few possess real aircrafts, i.e. the whole "fleet" of airfreight forwarders consists of normal trucks only and the majority of these transport companies that have been successfully operating on the air cargo transport market may be regarded as middle sized companies. And that were not the huge investments in the "hard-ware" infrastructure, i.e. aircrafts that allowed them to enter airfreight forwarding business, but rather strategically conceptual and "soft" changes.

Rather small and medium transport companies with a "fleet" ranging from 10 to 30 ordinary trucks qualified themselves for air cargo transport business. According to the results of the "Baltic.AirCargo.Net", the importance of the RFS is constantly growing nowadays, e.g. in 2012 the relative volume of air cargo transported by "flying trucks" in the biggest air cargo hub in the Baltic Sea Region - Copenhagen Airport is ca. 35% from the total cargo volume.

By providing such road feeder services, the SMEs may benefit and gain an essential competitive advantage in the air cargo supply chain, due to their traditional flexibility in comparison to big companies. The provision of the air cargo by means of "flying trucks" may allow SMEs to take advantages of for integration with large air cargo forwarders in bigger logistic hubs, e.g. from Hamburg, Berlin. The road feeder services do not require intensive capital investments, fulfilment of the strict legal and security regulation framework and physical resources what would be a premise in case of providing air cargo services by means of an aircraft (airlines). By offering RFS from the air cargo hubs in bigger airport hubs, SMEs may be better involved into the air cargo market and the air cargo supplier network; as elaborated by Thomas and Barton, low technical capabilities of suppliers and limited physical resources (facilities, physical capital etc.) are likely to keep large air cargo forwarders and carriers from using in their supply networks and as part of their supply chains.[12]

5. Summary and Outlooks

It may be observed that during last decade, the regional airports in the Baltic Sea Region have improved point-to-point carriers operations due to general growth of low cost carriers in Europe and in offering their capacity to low cost carriers airlines. Therefore, the supply side of the air transport services within the EU has risen considerably; the competition among both airports and airlines has increased. The "good" consequences like lower fares, increased frequencies and more destinations for passengers and airfreight results also in lower revenues for the airports and airlines. Facing also the upcoming challenges in form of the cuts of the public aid, the regional airports must adopt their development strategies to able to operate on cost efficient and profitable basis. The air cargo business may offer to the regional airports a supplementary opportunity to the passenger traffic, thus making an airport more profitable and attractive for regional business structures.

Air cargo of the Baltic Sea Region is heavily concentrated on the airports, which have intercontinental passenger flights: significant part of the Baltic Sea Region air cargo is utilizing belly cargo concept and intercontinental passenger flights operated by wide body aircrafts. These airports are typically capital airports like Copenhagen (CPH), Stockholm (ARN) and Helsinki (HEL). Also the major part of the Baltic Sea Region freighter flights is operating to the same capital airports, which have the belly cargo flows.

The current results of Baltic.AirCargo.Net Project are pointing out that the Baltic Sea region transport policy should recognize and accept the importance of the Road Feeder Service or "Flying Truck" concept much stronger than it does today.

Aviation, i.e. both airports and airlines, are facing strong competition and the Baltic Sea Region should utilize possibilities that are being offered by Road Feeder Service in order to strengthen the economic viability of the aviation industry.

It can be generally noticed that within the Europe or the BSR the passengers are flying but the goods are being transported by flying trucks. It might be a disputable or provocative notice that the general and basic approach of the Short Sea Shipping corresponds with the concept of the Flying Trucks. The concept of the "Short Sea Shipping" has been introduced, discussed and promoted by relevant

[12] cf. Beifert, A.; Maknyte, L.; Prause, G. SUSTAINABLE SUPPLY CHAIN MANAGEMENT ISSUES: CASE OF REGIONAL SMEs' INVOLVEMENT IN THE AIR CARGO. Journal of Security and Sustainability Issues, 2013, 3(2), 41 - 52.

regional, national and international stakeholders. Should it be now recommendable to mention, promote, develop and implement efficient structures of the concept of Road Feeder Service?

Generally belly cargo concept might be impossible to implement by regional and remote airports since it is based on the intercontinental passenger flights. Furthermore, the freighter concept would be basically possible; however its implementation requires strong and consistent air cargo volume (e.g. 200 tons/week in and out) between the remote airport and some other region.

Thus, the Flying trucks concept might be at this time the only one realistic concept for remote and / or regional airports when they are trying to access to the air cargo market. In case of the acceptance of this hypothesis, the next questions for the regional airports that shall be analysed might be:

1. Role of the airport in the region;
2. What are the possible air cargo volumes, destinations in the catchment area of a given airport?
3. What are the possible “flying truck routes” for a given airport?
4. What are the goods-flows (annual volumes, frequencies) that might be potentially transported as air cargo within BSR? (described per segment: carried by freighters, carried by courier/express planes,” carried by flying trucks”)
5. What are the typical goods carried per route and direction, what is the balance of the flows?

Having fulfilled this analysis the regional airports might have a rough evaluation whether they can be an interesting feeder for some other major air cargo hub of the BSR region like Copenhagen, Helsinki or Stockholm (Arlanda) Airports. Furthermore, in the reference to the passenger traffic (network carriers, low cost, charter) and air cargo (RFS / flying trucks, freighters, mail / express) the following analysis shall be fulfilled:

1. transport forecast, objectives concerning volumes;
2. current capacities that are available in airport and its facilities;
3. future needs and possibilities of airport and its facilities, expansion plans.

Only after fulfilling above-mentioned evaluation it might be possible for regional airports to conduct a development strategy and a sustainable action plan involving among other things air cargo business opportunities.

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SATELLITE MONITORING SYSTEMS FOR SHIPPING AND OFFSHORE OIL AND GAS INDUSTRY IN THE BALTIC SEA

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Shipping activities, oil production and transport in the sea, oil handled in harbors, construction and exploitation of offshore oil and gas pipelines have a number of negative impacts on the marine environment and coastal zone of the seas. In 2004-2014 we elaborated several operational satellite monitoring systems for oil and gas companies in Russia and performed integrated satellite monitoring of the ecological state of coastal waters in the Baltic, Black, Caspian, and Kara seas, which included observation of oil pollution, suspended matter, and algae bloom at a fully operational mode. These monitoring systems differ from the existing ones by the analysis of a wide spectrum of satellite, meteorological and oceanographic data, as well as by a numerical modeling of oil spill transformation and transport in real weather conditions. Our experience in the Baltic Sea includes: (1) integrated satellite monitoring of oil production at the LUKOIL-KMN Ltd. D-6 oil rig in the Southeastern Baltic Sea (Kravtsovskoe oil field) in 2004-2014; (2) integrated satellite monitoring of the “Nord Stream” underwater gas pipeline construction and exploitation in the Gulf of Finland (2010-2013); (3) numerical modeling of risks of oil pollution caused by shipping along the main maritime shipping routes in the Gulf of Finland, the Baltic Proper, and in the Southeastern Baltic Sea; (4) numerical modeling of risks of oil pollution caused by oil production at D-6 oil rig and oil transportation on shore via the connecting underwater oil pipeline.

Keywords: the Baltic Sea, oil pollution, satellite monitoring, shipping, oil and gas pipelines, environmental risk assessment, numerical modeling

1. Introduction

Oil and oily residue discharges from ships, offshore platforms, and oil terminals represent a significant threat to marine ecosystems. These discharges may occur during normal activities or may be accidental or illegal. Oil spills cause the contamination of seawater, bottom sediments, shores, and beaches, which may persist for several months and even years (Kostianoy and Lavrova, 2014c). The world average release of petroleum from all sources to the World Ocean is estimated at 1.3 million tons per year, however, the range is wide from 0.47 million tons to a possible 8.4 million tons per year (Global Marine…, 2015). According to different national and international reports, the main categories of sources contribute to the total oil input as follows: discharges from ships and land-based sources – 24-47%, natural seeps – 7-46%, and offshore extraction - only 2-3% (Global Marine…, 2015).

Public interest in the problem of oil pollution arises mainly during dramatic tanker and oil platform catastrophes such as *"Amoco Cadiz"* (France, 1978), *"Ixtoc I"* (Gulf of Mexico, 1979-1980), *"Exxon Valdez"* (Alaska, 1989), *"The Sea Empress"* (Wales, 1996), *"Erica"* (France, 1999), *"Prestige"* (Spain, 2002), *"Fu Shan Hai"* (the Baltic Sea, 2003), and *"Deepwater Horizon"* (Gulf of Mexico, 2010). According to the International Tanker Owners Pollution Federation (ITOPF, 2015), over the period of 1974-2014, spillages resulting from allisions/collisions, groundings, hull and equipment failures and fires/explosions amounted to 47% of total leakages during tanker loading/unloading and bunkering operations. In the last 45 years (1970-2014) we have observed a significant decrease in the number of the medium (7-700 tons) and large (>700 tons) sized oil spills – from 54.3 and 24.5 in average in 1970's to 5.2 and 1.8 in 2010's. The decade total quantity of oil spilt has also decreased from 3.2 million tons in 1970's to 208,000 tons in 2000's, and to 26,000 tons in 2010-2014 (ITOPF, 2015).

However, tanker and oil platform catastrophes are only a few among many causes of oil pollution. Oil and oil product spillages at sea take place all the time, and it would be a delusion to consider tanker accidents the main environmental danger. Discharge of wastewater containing oil products is another important source, by pollutant volume comparable to offshore oil extraction and damaged underwater pipelines. The greatest, but hardest-to-estimate oil inputs come from domestic and industrial discharges, direct or via rivers, from the atmosphere and from the natural hydrocarbon seeps. The long-term effects of this chronic pollution are arguably more harmful to the coastal environment than a single, large-scale accident (Lavrova et al., 2011; Kostianoy and Lavrova, 2014a,b).

The Baltic Sea is one of the busiest waterways in the World Ocean. It has about 40 ports and oil terminals. The last one was officially open on 23 March 2012 in Ust-Luga (Russia) in the Gulf of Finland. According to the HELCOM AIS, there are about 2,000 ships in the Baltic Sea every day, and each month about 3,500–5,000 ships ply the waters of the Baltic Sea. It is estimated that 15% of the world's trade and 11% of the world's oil transportation pass through the Baltic Sea waters. These values may increase by 64% between 2003 and 2020. For example, the oil transportation increased by 133% between 1997 and 2008 and is now over 250 million tons per year (Pålsson, 2012).

In the last 15 years a number of new oil terminals have been built in the Baltic Sea area, resulting in increased transport of oil by tankers and, consequently, an increased risk of accidents (Kostianoy and Lavrova, 2014a). Thus, shipping activities, including oil transport and oil handled in harbours, may have a major negative impact on the marine environment, marine protected areas, and coastal zone in the Baltic Sea (Kostianoy et al., 2008, 2014a; Kostianoy and Lavrova, 2014a).

As concerns oil exploitation at sea and on the coast, offshore operations have been taking place for some years in Polish waters (two jack-up rigs); Germany operated two platforms very close to the coast; in March 2004 Russia started the oil production at continental shelf in the waters between the Kaliningrad area (Russian Federation) and Lithuania, as well as there are Latvian plans to drill for oil in the waters between Latvia and Lithuania (Global Marine…, 2015). So far as the Baltic Sea ecosystem undergoes growing human-induced impacts, especially associated with an increasing oil transport and production, one of the main tasks in the ecological monitoring of the Baltic Sea is an operational satellite and aerial detection of oil spillages, determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport.

Despite the fact that the Baltic Sea has only 0.1% of the World Ocean surface, at the beginning of 2000s, the oil pollution volume was estimated from about 1,000 to 35,000-60,000 tons a year (Patin, 2008; Kostianoy, 2013; Kostianoy and Lavrova, 2014b).

Oil pollution monitoring in the Mediterranean, North and Baltic seas is normally carried out by aircrafts or ships (Kostianoy, 2008). This is expensive and is constrained by the limited availability of these resources. Aerial surveys over large areas of the seas to check for the presence of oil are generally limited to the daylight hours in good weather conditions. Satellite radar imagery can help greatly identifying probable spills over very large areas (up to 400 x 400 km^2) and then guiding aerial or ship surveys for precise observation of specific locations. The Synthetic Aperture Radar (SAR) instrument, which can collect data almost independently of weather and daylight conditions, is an excellent tool to monitor and detect oil on water surface. This instrument offers the most effective means of monitoring oil pollution: oil slicks appear as dark patches on SAR images because of the damping effect of the oil on the backscattered signals from the radar instrument. This type of instrument was/is currently on board the European Space Agency's ENVISAT (till 8 April 2012) and ERS-2 (till 5 September 2011) satellites, the Canadian Space Agency's RADARSAT-1 (till 29 March 2013) and RADARSAT-2 satellites, the German Earth observation satellite TerraSAR-X, Italian COSMO-SkyMed satellites, and others.

The "Nord Stream" offshore gas pipeline construction was the biggest offshore project performed in 2010-2012 in the Baltic Sea. This is a transport system designed for natural gas export from Russia to Germany and then to the European Union via the Baltic Sea. The pipeline offshore route 1220 km long transects the Exclusive Economic Zones (EEZ) of five states – Russia, Finland, Sweden, Denmark and Germany, as well as waters of the territorial seas of Russia, Germany and Denmark. Its construction and exploitation requested satellite monitoring of all four types of potential contaminants and impacts: oil pollution, suspended matter, algal bloom, and thermal effects which are well tracked from satellites (Grishin and Kostianoy, 2012a,b, 2013; Kostianoy et al., 2014c).

Since 2003, in cooperation among P.P. Shirshov Institute of Oceanology (Moscow) and its Atlantic Branch in Kaliningrad, Russian Space Research Institute (Moscow), Geophysical Center (Moscow), and Marine Hydrophysical Institute (Sevastopol) we elaborated several operational satellite monitoring systems for oil and gas companies in Russia and performed complex satellite monitoring of the ecological state of coastal waters in the Baltic, Black, Caspian, and Kara seas in a fully operational mode (24/24 and 7/7) (Kostianoy et al., 2009; Lavrova et al., 2011). Our experience includes:

(1) Elaboration of the integrated satellite monitoring system (2004) and monitoring of the LUKOIL-KMN Ltd. D-6 oil rig in the Southeastern Baltic Sea in 2004-2014;

(2) Elaboration of the integrated satellite monitoring system (2007) and monitoring (2010) of the underwater gas pipeline "Dzhubga-Lazarevskoe-Sochi" construction in the Eastern Black Sea;

(3) Elaboration of the integrated satellite monitoring system (2006) and monitoring (2010-2013) of the "Nord Stream" underwater gas pipeline construction and exploitation in the Gulf of Finland, the Baltic Sea;

(4) Elaboration of the integrated satellite monitoring system for the underwater gas pipeline "Bovanenkovo-Ukhta" construction in the Baydaratskaya Guba, the Kara Sea (2007);

(5) Elaboration of the integrated satellite monitoring system for the Caspian Sea (2008);

(6) Elaboration of the structure and principles of the integrated satellite monitoring system organization for all coastal seas of Russia (2009-2010);

(7) Numerical modeling of risks of oil pollution caused by shipping along the main maritime shipping routes in the Gulf of Finland, the Baltic Proper, and in the Southeastern Baltic Sea;

(8) Numerical modeling of risks of oil pollution caused by oil production at D-6 oil rig and oil transportation on shore via the connecting underwater oil pipeline.

The above mentioned satellite monitoring systems differ from the existing ones by the analysis of a wide spectrum of satellite, meteorological and oceanographic data, as well as by a numerical modeling of oil spill transformation and transport in real weather conditions. The known accidents with tankers in the sea or that on the BP oil platform "Deepwater Horizon" on 20 April 2010 in the Gulf of Mexico showed that absence of such a permanent integrated satellite monitoring system makes low effective all efforts related to cleaning operations at sea and on the shore during the first days after the accident (Lavrova and Kostianoy, 2010).

In this paper we will focus on a brief review of our experience in the Baltic Sea.

2. Satellite monitoring of oil production at the «LUKOIL-Kaliningradmorneft» D-6 oil rig in the Southeastern Baltic Sea

Since 1993 there has been no regular aerial surveillance of the oil spills in the Russian sector of the Southeastern Baltic Sea and in the Gulf of Finland. In June 2003 LUKOIL-KMN Ltd. initiated a pilot project, aimed to the integrated monitoring of the Southeastern Baltic Sea, in connection with a beginning of oil production at oil rig D-6 at continental shelf of Russia in March 2004 (cut-in (1) in Fig. 1). From 2004 to present (2015), in the framework of the industrial environmental monitoring of the oil field "Kravtsovskoe" (D-6) and a number of Russian and international research projects satellite monitoring of oil pollution of the sea surface in the Southeastern Baltic Sea is carried out (Kostianoy et al., 2006, 2014b; Bulycheva and Kostianoy, 2011, 2014; Lavrova et al., 2011, 2014; Bulycheva et al., 2014). The main directions of this research are: (i) daily radar control of the appearance and drift of oil slicks on the sea surface by the near real time data from different satellites; (ii) detection and identification of possible sources of oil pollution through the AIS system (Automatic Identification System for identifying and locating of vessels); (iii) forecast of the direction and speed of the oil spill drift with the Seatrack Web numerical model of the Swedish Meteorological and Hydrological Institute; (iv) collection and analysis of the auxiliary satellite, meteorological and oceanographic information; (v) systematization and storage of the information. As a result, integrated information on oil pollution of the sea, spatial distribution of the sea surface temperature, suspended matter, chlorophyll concentration, algal bloom, currents and meteorological parameters have been received on a regular base.

Since 2004, to detect oil pollution on the sea surface we have been using radar (SAR/ASAR) images from ENVISAT satellite of the European Space Agency (ESA) (before its failure in April 2012), RADARSAT-1 of the Canadian Space Agency (CSA) (before its failure in March 2013) and RADARSAT-2 of the MacDonald, Dettwiler and Associates Ltd. (MDA, Canada). Acquisition and delivery of these radar images are carried out by the Norwegian satellite operator Kongsberg Satellite Services (KSAT) in Tromsø.

During the analysis of 1844 radar images of the sea surface in the Southeastern Baltic Sea received from 12 June 2004 till 31 December 2014 (cut-in (2) in Fig. 1) we identified in total 1193 oil spills. Fig. 1 shows a cumulative map of all oil spills (with a real shape and size) detected in the monitoring area for the period 2004-2014. We have to note that the density of the satellite image coverage is not uniform over the shown area of the Baltic Sea, because the monitoring was focused on the D-6 oil rig in coastal waters of Russia. This partially reflects on the number of oil spills detected in different parts of the investigated area with their higher density eastward of 18°E and southward of 57°N (Fig. 1).

The oil spills are mainly localized and concentrated along the main shipping routes in the Baltic Sea: southwestward, southward and eastward of Gotland Island (four lines); lines leading to the ports of Riga, Ventspils, Liepaja, Klaipeda, Baltiysk/Kaliningrad, Gdansk and Gdynia (see Fig. 1). In the vicinity of the D-6 oil rig for 11-year period, not a single case of oil pollution has been fixed. There is a relatively clean sea surface along the coast of the Curonian Spit. This is obviously due to the low activity of shipping, as well as due to currents typical for this area, which transport surface contamination mainly to the north-west, north, north-east (Bulycheva et al, 2014; Bulycheva and Kostianoy, 2014).

In the Russian sector of the Southeastern Baltic Sea the most polluted area is waters to the west of the Sambia Peninsula and on the approach to the Kaliningrad Canal (near Baltiysk), where several shipping routes from the north and west converge (see Fig. 1) (Bulycheva et al, 2014; Bulycheva and Kostianoy, 2014). Anchorage area at the entrance to the Kaliningrad Canal, in different years and by different statistics based on satellite observations is regarded as the most polluted area of the Southeastern Baltic Sea, and, perhaps, the whole Baltic Sea (Kostianoy et al., 2006, 2014b; Bulycheva and Kostianoy, 2011, 2014; Lavrova et al., 2011, 2014; Bulycheva et al., 2014). The accumulation of oil spills northward of the Sambia Peninsula near the port of Pionersky, outside of the main shipping routes (see Fig. 1), could be explained by discharges from small fishing vessels not equipped with AIS (Bulycheva et al, 2014).

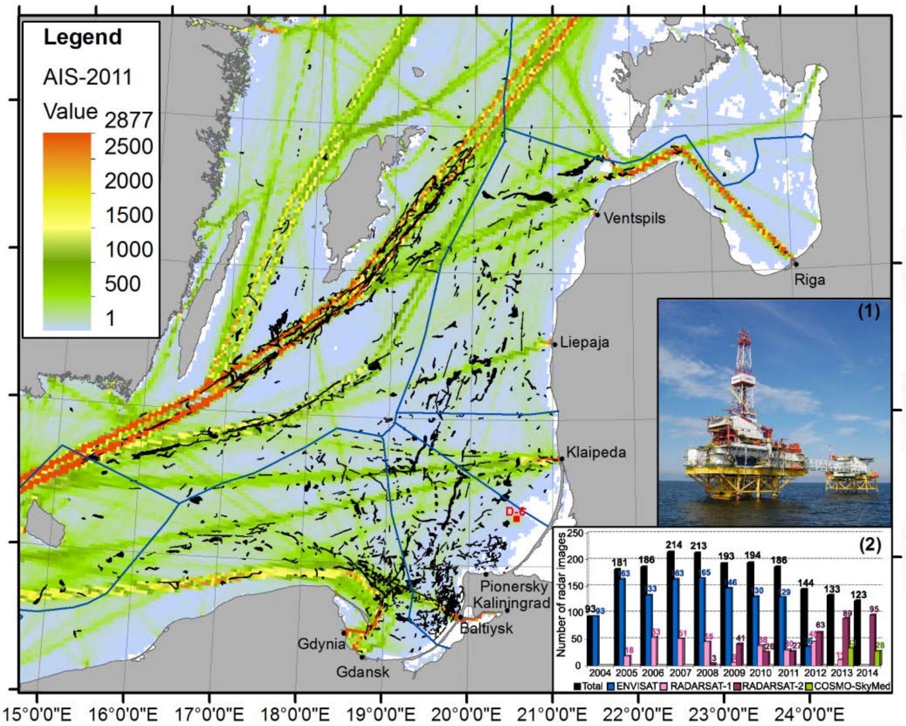

Figure 1. A cumulative map of all oil spills detected in this part of the Baltic Sea for the period 2004-2014 on the color background of AIS density for 2011. *Cut-in (1)* - The LUKOIL-KMN Ltd. oil rig D-6 in the Southeastern Baltic Sea; cut-in (2) - The number of SAR/ASAR images received and analyzed in 2004-2014

Thus, the main reason for oil pollution in the Baltic Sea is shipping, which includes oil and chemical tankers, cargo, container, military ships, ferries, fishery boats, and even passenger ships.

From 2006 to 2011 there was a steady decline in the total number of oil spills (from 212 to 44), detected on radar images, as well as in the total area of oil pollution (from about 833 to 147 km^2) (Fig. 2). These figures correspond to the lower level of the real oil pollution of the sea surface because of the limitations of the method used (satellite radiolocation) and the time gaps between satellite passes, which sometimes reach two days. Nevertheless, there is a clear decreasing trend in the interannual variability of oil pollution in this part of the Baltic Sea. It should be noted that, according to the HELCOM data for the 1988-2011, a similar trend is observed for the whole area of the Baltic Sea (Kostianoy and Lavrova, 2014). In 2012, there was a jump in the number of detected oil spills and, as a consequence, in the total area of oil pollution (see Fig. 2). In 2013, when a small amount of oil slicks was observed, a large total area of oil pollution was fixed due to three huge oil spills detected on 13 September 2013 in Russian EEZ (72 km^2), 20 September 2013 in Swedish EEZ (92 km^2), and 23 May 2013 in Latvian EEZ (34 km^2). All these oil spills were leakages from the moving ships. In 2014, the level of oil pollution returns to the level of 2011 in terms of total spills number and pollution area. Figs. 3-6 show several examples of oil pollution detected on radar imagery in 2005-2014.

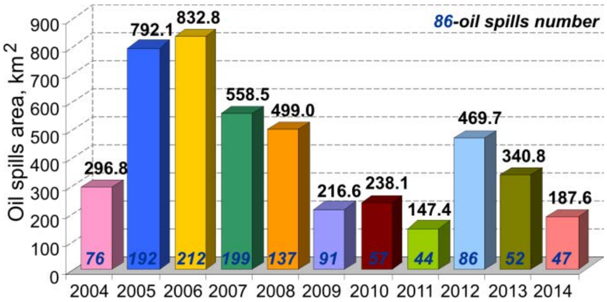

Figure 2. Interannual variability (2004-2014) of the total number of oil spills and polluted area in the part of the Baltic Sea shown in Fig. 1

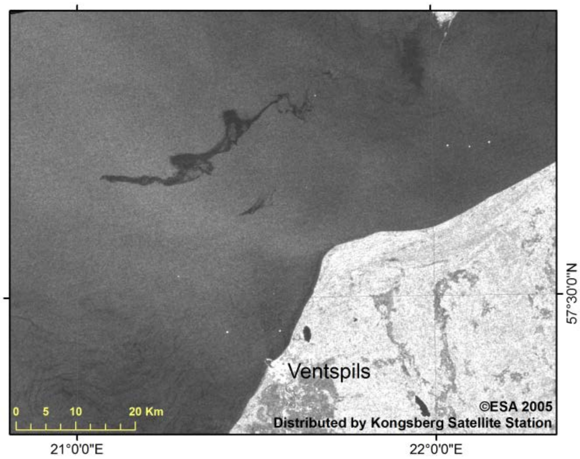

Figure 3. ASAR Envisat, 28.05.2005, 20:19 UTC. Oil pollution northward of Ventspils. Total length - 42 km, total area – 79.2 km^2

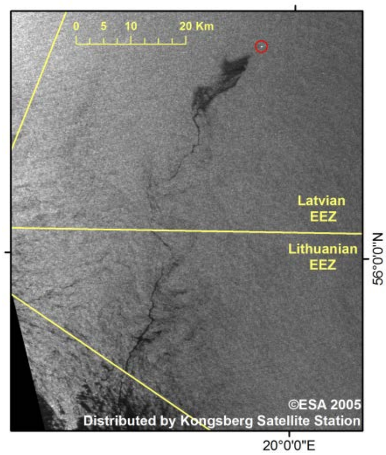

Figure 4. ASAR Envisat, 04.09.2005, 20:05 UTC. Fresh oil spill from a moving vessel (in red circle). Length – 72 km

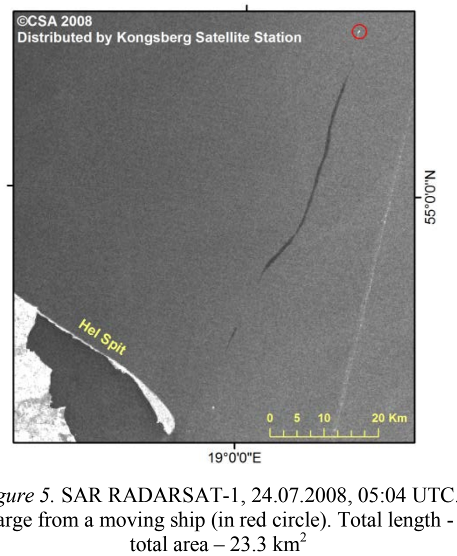

Figure 5. SAR RADARSAT-1, 24.07.2008, 05:04 UTC. Oil discharge from a moving ship (in red circle). Total length - 46 km, total area – 23.3 km^2

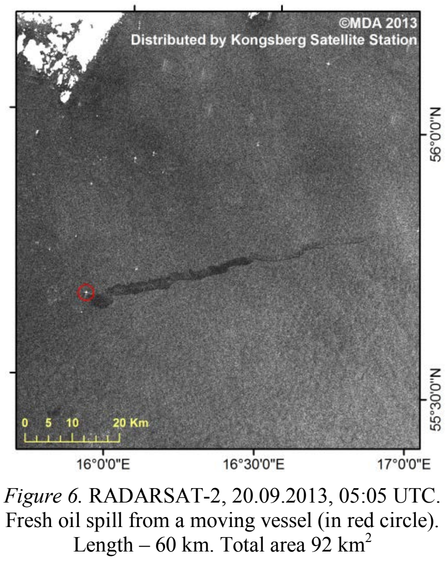

Figure 6. RADARSAT-2, 20.09.2013, 05:05 UTC. Fresh oil spill from a moving vessel (in red circle). Length – 60 km. Total area 92 km^2

3. Numerical modeling of oil spill drift and risks of oil pollution caused by oil production at D-6 oil rig

We used the interactive numerical model Seatrack Web of Swedish Meteorological and Hydrological Institute (SMHI) for a forecast of the drift of: (1) all large oil spills detected by SAR/ASAR imagery in the Baltic Sea (Figs. 7, 8) and (2) virtual (simulated) oil spills from the D-6 oil rig (Figs. 9- 12). The latter was done daily for operational correction of the action plan for elimination of a potential accident at the D-6 oil rig and Environmental Risk Assessment (oil pollution of the sea and the Curonian Spit) (Kostianoy et al., 2008, 2014a; Kostianoy and Bulycheva, 2014).

This version of a numerical model on the Internet platform has been developed at SMHI in close co-operation with Danish authorities. The system uses two different operational weather models ECMWF and HIRLAM (HIgh Resolution Limited Area Model, 22 km grid) and circulation model HIROMB (HIgh Resolution Operational Model for the Baltic sea, 24 layers, driven by the two weather models respectively), which calculates the current field at 1 nm grid with 15 min time step. The model allows to forecast the oil drift for five days ahead or to make a hindcast (backward calculation) for 30 days in the whole Baltic Sea. When calculating the oil drift, wind and current forecasts are taken from the operational models. An oil spreading calculation is added to the currents, as well as oil evaporation, emulsification, sinking, stranding and dispersion. This powerful system today is in operational use in Sweden, Denmark, Finland, Poland, Estonia, Latvia, Lithuania and Russia (Kostianoy et al., 2008, 2014a; Kostianoy and Bulycheva, 2014).

Fig. 7 shows the results of numerical modeling of the drift of an oil spill detected northward of Ventspils on 28 May 2005 (see Fig. 5) during 48 hours from 28 to 30 May 2005. Fortunately, during these two days there was no strong wind and currents that could drift this huge oil spill (42 km long and 79.2 km^2 large) to the coasts of Latvia or Estonia (Saaremaa Island). The next satellite image acquired 12 hours later has proved this forecast and showed that the weathered oil spill remained almost at the same place.

Another interesting case study was done on 9 April 2013 when an oil spill was detected by RADARSAT-2 on 16:15 UTC at a distance of about 10 km from the D-6 oil rig (Fig. 8). The shape of the slick and specific contrast at its boundaries showed that it drifted from north-east to south-west till the time of satellite image acquisition. Between the D-6 oil rig and oil spill two ships were located. Backward model calculation of the spill drift has showed that the detected oil spill was located at a distance of 3 km from the oil rig on 01:00 UTC on 9 April where it arrived from north-west (see Fig. 8). Thus, we can exclude the D-6 oil rig from a list of potential polluters, and on the other hand point out on the right ship as a source of oil pollution, because the spill trajectory has passed exactly via its location (see Fig. 8).

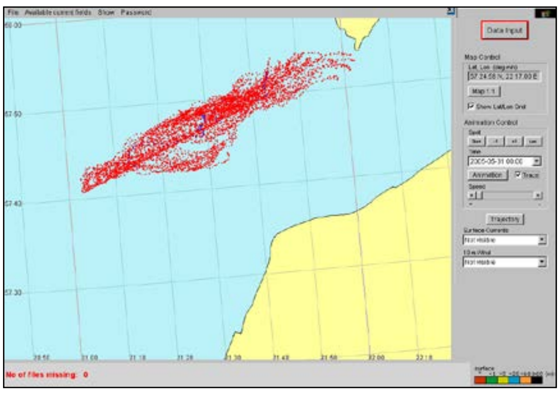

Figure 7. Numerical modeling of the drift (28-30 May 2005) of an oil spill detected northward of Ventspils on 28 May 2005 (see Fig. 5)

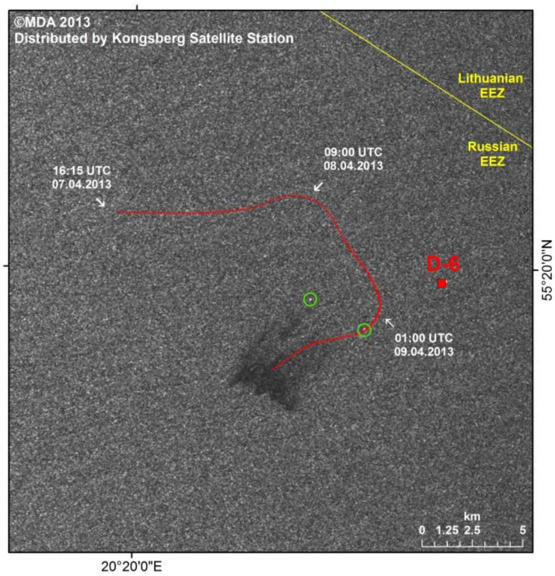

Figure 8. Backward trajectory (red line) of a drift of an oil spill detected by RADARSAT-2 on 9 April 2013 (16:15 UTC). Green circles show two ships located close to the polluted area. Red dot is the D-6 oil rig

In 2004-2005 we daily modeled the drift of an oil spill of 10 m^3 released from the D-6 oil rig during 48 h (Kostianoy et al., 2006, 2008, 2014a). Fig. 9 shows just one example of such a drift on 25 October 2005. This shallow area of the Southeastern Baltic Sea is characterized by strong variability of wind and currents speed and direction which result in a strong variability of daily individual trajectories of oil spill drift. This justifies the use of operation metocean data in the numerical modeling, as it is performed in the Seatrack Web model, instead of averaged climatic meteorological and hydrodynamic characteristics normally used in the Environmental Risk Assessment. Statistics, based on daily forecast of the oil spills drift from the D-6 oil rig in July-December 2004, shows potential probability (%) of the appearance of an oil spill in any point of the area during 48 h after an accidental release of oil (Fig. 10).

The same type of numerical modeling was done from 1 January 2013 to 31 December 2014 (Kostianoy and Bulycheva, 2014). Cumulative drift trajectories of the modeled oil spills released at D-6 oil rig in January 2013 are shown in Fig. 11. The obtained results demonstrate that at the prevailing eastward winds (for example, in October and November 2013) the modeled oil spills will never reach the coast of the Curonian Spit, because they will be advected by the alongshore currents to the north-east direction. The cumulative forecast of an oil spill drift based on daily modeling during January-December 2013 showed that during the first 48 h after a potential accident at the D-6 oil rig the oil spill will never reach the coastline. Potential probability (%) of an oil spill observation on the water area around the D-6 oil rig during 48 h after an accident in 2013 is shown in Fig. 12 (Kostianoy and Bulycheva, 2014).

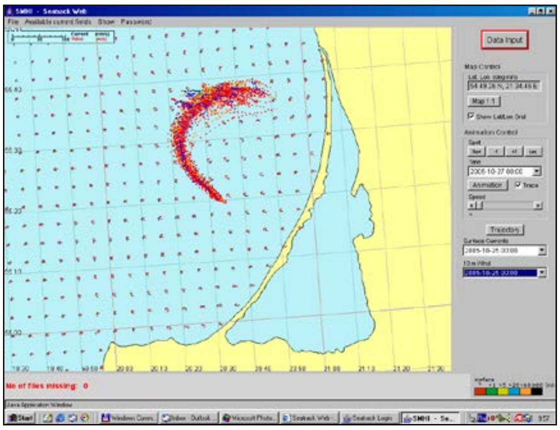

Figure 9. An example of daily forecast of the virtual (simulated) oil spill drift from the D-6 oil rig on 25 October 2005

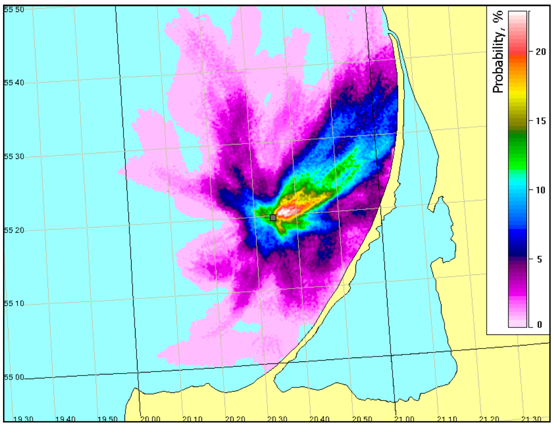

Figure 10. Probability of observation of potential oil pollution from D-6 oil rig during the first 48 hours after an accidental release of 10 m^3 of oil

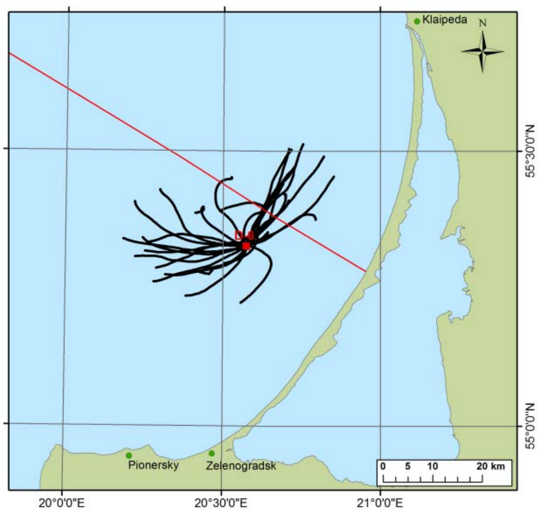

Figure 11. Cumulative drift trajectories of the center of potential oil spills released at D-6 oil rig in January 2013

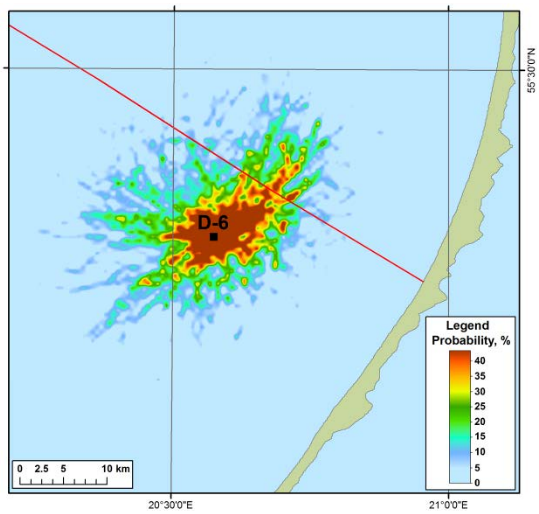

Figure 12. Probability of an oil pollution (%) during 48 h after a potential accident at D-6 oil rig for January-December 2013

4. Satellite monitoring of the “Nord Stream” underwater gas pipeline construction in the Gulf of Finland

The “Nord Stream” is a more than 1200-km long offshore gas pipeline that link Russia to Europe via the Baltic Sea from Vyborg in Russia to Greifswald in Germany. The construction in the sea has started in April 2010. The first line of the Nord Stream was completed in June 2011 and put into operation on 8 November 2011. The second, parallel pipeline has started in May 2011 and it was put into operation in October 2012. The construction process of the pipeline may cause, in particular, the following impact on the marine environment: (i) oil pollution due to the operation of ships, pipe lay ships, dredge ships and mechanisms in the sea; (ii) increase of suspended matter concentration due to dumping of sand and gravel, and dredging operations; (iii) provoking of local algal bloom events in summertime due to vertical mixing resulted from dumping and dredging works (Grishin, Kostianoy, 2012a,b, 2013; Kostianoy et al., 2014c). In many parts of the Baltic Sea the “Nord Stream” pipeline coincides with the main shipping route crossing the sea from the Gulf of Finland to the southwestern part of the Baltic Sea. Along this ship route we have already been yearly observing the maximum of oil spills discharged from ships well before the “Nord Stream” construction (Kostianoy et al., 2006). Besides, we observe very large areas of water with a high concentration of total suspended matter (TSM) and areas of very intense algal bloom. Both are observed yearly and have natural reasons. Thus, there are two very important and interrelated tasks: (i) to monitor in the operational regime the ecological state of the sea at the site of the pipeline construction, and (ii) to discriminate between natural effects and anthropogenic impacts, related to the construction itself. Moreover, oil spills must be distinguished between “own” pollution and “alien” pollution originated from the passing ships.

Since May 2010 till December 2013 in the framework of the contract with the “Nord Stream” Company we performed daily satellite monitoring of TSM distribution on the sea surface in the Gulf of Finland. The main factors for increasing the concentration of TSM during the construction of offshore gas pipelines are preparation of the seabed for the laying the pipeline by constructing pillars of gravel at the bottom grooves to avoid sagging of the tube (pre-lay rock dumping) and follow-up with gravel filling (post-lay rock dumping) in order to achieve a stability of the pipe at the bottom during gas transport, as well as pipe-laying of the tube itself. Dredging in Portovaya Bay for burial of the pipeline in the bottom can also lead to an increase in water turbidity. Analysis of daily satellite imagery during four years of monitoring showed that plumes of turbid waters occasionally appeared along the coasts of Finland, Estonia, southern coast of Russia and in the Gulf of Vyborg (Fig. 13). They were produced by a wind-wave mixing of coastal waters and a runoff of small rivers after the rains. The area of water with high concentration of TSM (due to natural causes) in some places ranged from 100 to 1,000 km^2 (Fig. 13). Most clearly the formation of suspended matter fields related to the construction of the pipeline was seen only in Portovaya Bay during the construction of dams and dredging (Fig. 14).

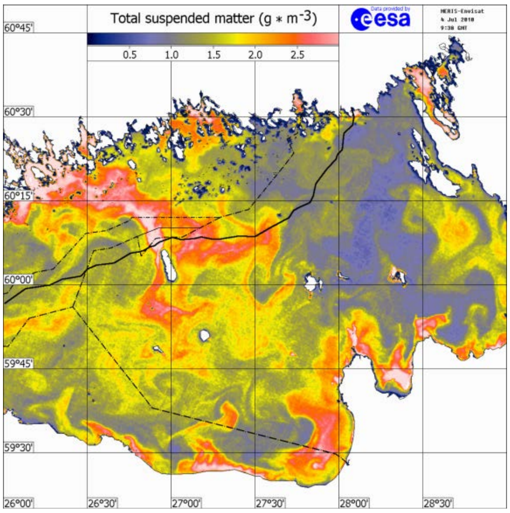

Figure 13. Spatial distribution of TSM in the surface layer of the eastern part of the Gulf of Finland on 4 July 2010 (09:38 GMT) basing on the MERIS Envisat data (©2010, ESA) (black line – Nord Stream gas pipeline route, dashed lines are marine borders between countries, white areas are coasts and islands)

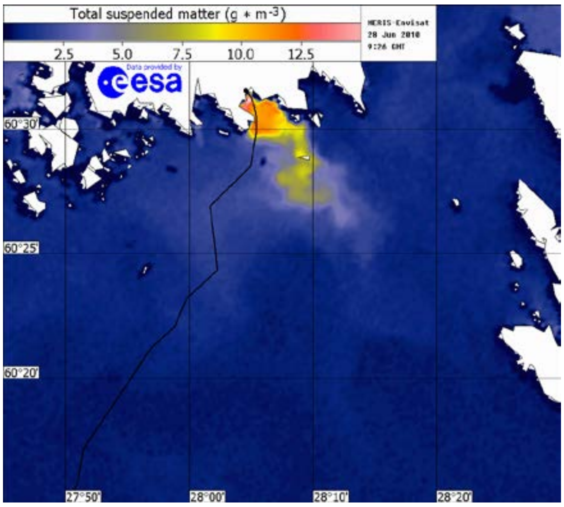

Figure 14. Spatial distribution of TSM in Portovaya Bay and surrounding waters of the northeastern part of the Gulf of Finland on 28 June 2010 (09:26 GMT) basing on the MERIS ENVISAT data (©2010, ESA). Turbid area is of 8 km^2

5. Numerical modeling of risks of oil pollution caused by shipping along the main maritime shipping routes in the Baltic Sea

In the framework of several projects related to organization of the integrated satellite monitoring of the D-6 oil platform in the Southeastern Baltic Sea and a construction of the “Nord Stream” gas pipeline in the whole Baltic Sea we elaborated a new, very effective technology for the quantitative Environmental Risk Assessment, based on the Seatrack Web model (Kostianoy et al., 2008, 2014a; Kostianoy and Bulycheva, 2014). For every kilometer of the coastline, the Baltic Sea Protected Area, Important Bird Area, as well as for any part of the sea surface it allows to calculate in the probability to be polluted by oil, resulted from operations in ports, oil terminals, oil platforms, oil pipelines, and shipping activities in the Baltic Sea. This technology was applied to different points of the shipping route crossing the Baltic Sea from St.-Petersburg to Germany (Kostianoy et al., 2008, 2014a).

From 19 September to 18 November 2014 we carried out numerical simulation of a drift of potential oil pollution along the shipping route in the Gulf of Finland. The total length of the selected line from the St.-Petersburg Dam to the exit from the Gulf of Finland is about 400 km. In the model, along the route, 40 m^3 of lubricating oil was daily evenly poured to the sea and the forecast of the oil pollution drift was calculated for the next 48 h. Sixty one experiments revealed five areas of probable contamination: (i) Hogland Island; (ii) other islands in the waters of the Russia; (iii) small islands off the coast of Finland west of Helsinki; (iv) the northern and (v) southern coast of Russia in the extreme eastern part of the Gulf of Finland. No cases of contamination of islands and the coast of Estonia were recorded. Fig. 15 shows a typical situation when oil pollution drifts from the shipping line to the north, which is observed in most cases because of the prevailing winds in the Gulf of Finland which are directed to the northeast.

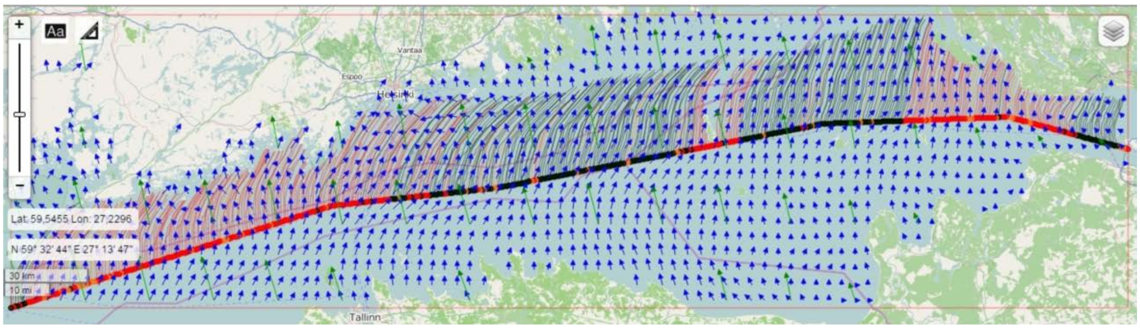

Figure 15. Oil pollution drift in the Gulf of Finland on 24 October 2014

6. Conclusions

In 2004-2014 we elaborated and performed an integrated approach to operational monitoring of the Southeastern Baltic Sea in connection with the beginning of oil production on the D-6 oil rig at continental shelf of Russia in March 2004. In 2010-2013 we used the same system for a monitoring of the “Nord Stream” gas pipeline construction and exploitation in the Gulf of Finland. As a part of this system we also elaborated a new, very effective technology for the quantitative Environmental Risk Assessment, based on the Seatrack Web model. This technology has been applied to different installations of oil and gas industry, as well as to shipping activities in the Baltic Sea.

Acknowledgements

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BRAKING DECELERATION MEASUREMENT USING THE VIDEO ANALYSIS OF MOTIONS BY SW TRACKER

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This contribution deals with the issue of car braking, particularly with the one of M1 category. Braking deceleration measurement of the vehicle Mazda 3 MPS was carried out by the declerograph XL Meter™ Pro. The main aim of the contribution is to perform comparison of the process of braking deceleration between the decelograph and the new alternative method of video analysis and to subsequently examine these processes. The test took place at the Rosina airfield, the airstrip in a small village nearby the town of Žilina. The last part of this paper presents the results, evlauation and comparison of the measurements carried out.

Keywords: braking deceleration, braking time, braking distance, analysis, decelograph XL Meter™ Pro, SW Tracker

1. Introduction

Intensive vehicle braking is usually an essential and defensive drivers´ reaction in order to avoid an accident. Indeed, the detection of the real value reached during intense vehicle braking is one of the key factors in the process of accident investigation. Current statutory requirements for approving technical roadworthiness of the vehicles, define the basic requirements for braking system construction for individual vehicle categories. (Hockicko, P., Ondruš, J., 2012)

2. Test vehicle

Mazda 3 MPS 2,3 MZR DISI model year 03/2011 was used as the test vehicle (Fig. 1). It was loaded with one person (a driver) at the moment of the tests. The vehicles´ technical data is shown in Table 1; the tires of Pirelli brand were of 205/50/R17 93 dimension with the 5.1 mm tread depth of the front tires and 5.7 mm of the rear ones.

Figure 1. Mazda 3 MPS 2,3 MZR DISI

Table 1. Technical data

Identification data:	
Country of origin:	Japan
Make:	Mazda
Model:	3 (2nd-gen. phase-I MPS MazdaSpeed)
Body style:	Hatchback
Doors:	5
Traction:	FWD (front-wheel drive)

Weights:	
Curb weight (without a driver):	1 385 kg
Gross vehicle weight:	1 925 kg
Payload:	540 kg
Towing weight:	
Unbraked:	550 kg
Braked:	1 300 kg

Powertrain:	
Engine:	MZR DISI 2,3L Turbo
Engine type:	Inline, 4-cylinder, DOHC Turbo petrol
Displacement:	2 261 cm3
Bore x Stroke:	87,5 x 94,0
Compression ratio:	9,5 : 1
Valves:	4 per cylinder
Max power:	260 HP (190 kW) at 5 500 rpm
Max torque:	380 Nm (280 lb-ft) at 3 000 rpm
Top speed:	250 km/h
Fuel consumption:	9,6 l/100 km
Fuel type:	Unleaded 98 RON
Emission control system:	3-way catalytic converter
Emission ranking:	Euro Stage V
Transmission:	6-speed manual
Powertrain:	Front engine, front-wheel drive

Weights:	
Curb weight (without a driver):	1 385 kg
Gross vehicle weight:	1 925 kg
Payload:	540 kg
Towing weight:	
Unbraked:	550 kg
Braked:	1 300 kg

Suspension:	
Front suspension:	MacPherson independent struts
Rear suspension:	Independent multi-link

Brakes:	
Front:	Ventilated discs
Rear:	Solid discs
Diameter front:	320 mm
Diameter rear:	280 mm

Acceleration:	
0-100 km/h:	6,1 s
50-100 km/h in 3-rd gear:	4,2 s
80-120 km/h in 5-th gear:	5,4 s

Source: (http://www.automobile-catalog.com/auta_details1.php, 2014)

The safety systems effecting the braking force installed in the vehicle include: ABS (Anti-lock Braking System), EBD (Electronic Brakeforce Distribution), EBA (Electronic Brake Assist), DSC (Dynamic Stability Control), TCS (Traction Control System), LSD (Limited Slip Differencial), active seat belt tensioners, EBS (Emergency Brake-light System).

3. Measurement devices

3.1. Decelograpf – Inventure XL Meter^{TM} Pro

Measurement device XL Meter^{TM} Pro of the 3rd generation was used for measuring (Fig. 2). It is a universal accelero/decelerometer with the alphanumercid LCD display. It serves to measure and evaluate vehicle acceleration and the state of its service brakes; it´s easy to operate as it uses only 3 buttons placed at the top of the device box, each of them being of a different colour (black, green, red) and therefore of a different function.

The device is powered by a battery but it can also be connected via an external source. From the technical point of view, it consists of three main parts: electronics, a vacuum suction cupule and an articulated arm which allows customizable mounting. XL Meter^{TM} Pro is easy to attach to the desired location on the surface of the vehicle windshield or any other smooth surface and it can be fixed to the surface by turning the lever of the vacuum suction cupule. The device is built-in into an aluminium box which is purpose-designed to provide easy controlability and installation. The articulated arm allows zero point calibration while being installed on the vehicle windshield by means of the vacuum suction cupule. (http://www.inventure.hu/xl_meter_en, 2014)

There are two slots at the back panel; nine-pin D-SUB connector RS-232 allows connection with the computer and it may also be used to connect the brake pedal sensor as well as output signal control and the round slot is used to power the device from the external source (CC-in adapter), (Handbook of XL Meter™ Pro, 2011).

Figure 2. XL Meter™ Pro (http://www.inventure.hu/upload/downloads/XLMPLFEN22.pdf, 2014)

The 14-bit measuring technology has been improved in the process of new HL Meter™ Pro development. Thanks to its increased storage capacity it is now possible to realise 8 measurements without the necessity to transfer data directly into a computer. The new functions of synchronisation and remote control enable easier and more comfortable usage. The modular architecture makes XL Meter™ Pro the ultimate device either for speed-up or brake performance tests. (http://www.inventure.hu/upload/downloads/XLMPLFEN22.pdf, 2014). Table 2 shows its basic specifications.

Table 2. Basic specifications

Technical Data	Features
• Number of measurements: **3, 6 or 8**	• Measures Longitudinal- and Lateral acceleration
• Storage capacity*: **3x80s + 5x40 s**	• Extra fast, strong installation, easy handling
• Acquisition Frequency: **200 Hz ... 25 Hz**	• Brake pedal input and trigger output
• Acceleration Measurement (a_x, a_y) - Longitudinal- and Lateral acceleration	• On the spot service brake performance evaluation
- Range: **±5.0 ... ±20.0 m/s²**	• On the spot acceleration performance evaluation
- Resolution: **0.005 m/s²**	• Modular system architecture
• Display: **16x2 PLED**	• Selectable acceleration direction
• PC interface: **RS-232, USB****	• Remote Control
• Dimensions (HxWxL): **50x97x110 mm**	• Optional display language
* for 200 Hz, ** only with additional accessory	• **80 hours** continuous operation with one battery-set
Applications	
• **Service brake performance evaluation**	• **Substitute for Roll Brake Test Bench**
• **Retarder brake performance evaluation**	• **Technical condition survey**
• **Tram brake performance evaluation**	• **Drag racing, tuning**
• **Accident reconstruction**	• **Vehicle dynamics measurement**
• **Vehicle diagnostics measurement**	• **0-100 km/h, 0-1/4 mile etc. speed-up tests**

Source: (http://www.inventure.hu/upload/downloads/XLMPLFEN22.pdf, 2014)

The electronic system of the device continuously records values of output signal voltage during the measurement, with the sampling rate of 200 Hz, i.e. the values are measured and recorded every 5 ms. There is an automatic off position recognition built-in in the device, so the precise zero point setting is not that necessary. The device records the course of acceleration within a span of 40 seconds from the moment of being turned on. After the measurement is over, the screen displays the value of mean fully developed deceleration (MFDD), the braking distance (s_0), the initial velocity (v_0), and the intensive braking time (t_{br}), (Rievaj et al., 2013).

Mean fully developed deceleration (MFDD) is on the basis of norm EHK 13 calculated as the mean deceleration regarding the distances travelled in the interval from v_b to v_e in accordance with the formula (Hockicko, P., Ondruš, J., 2012). Individual parameters appearing in the formula can be also represented graphically (Fig. 3), (Kolla et al., 2014).

$$MFDD = \frac{{v_b}^2 - {v_e}^2}{25{,}92 \cdot (s_e - s_b)}, \tag{1}$$

where:

MFDD –mean fully development deceleration [m.s^{-2}],

$\mathbf{v_o}$ – initial vehicle speed [km/h],

$\mathbf{v_b}$ – vehicle speed at 0,8 v_o [km/h],

$\mathbf{v_e}$ – vehicle speed at 0,1 v_o [km/h],

$\mathbf{s_b}$ – distance travelled between v_o a v_b [m],

$\mathbf{s_e}$ –distance travelled between v_o a v_e [m]

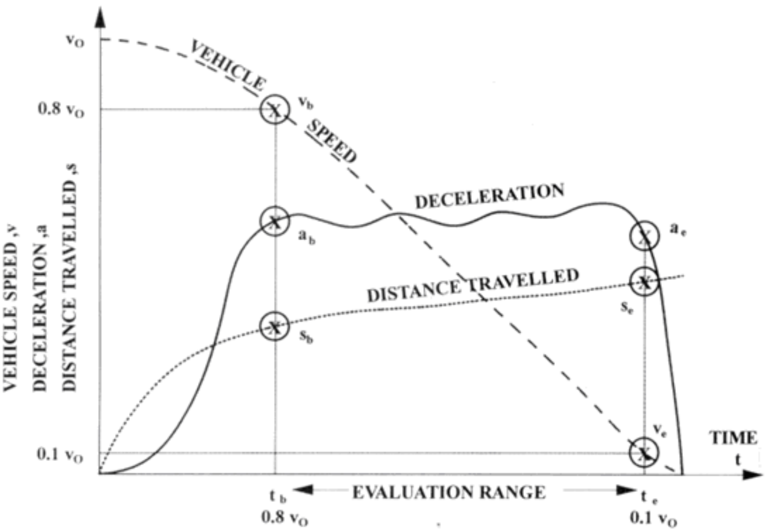

Figure 3. Dependence of vehicle speed, distance travelled and braking deceleration for the calculation of MFDD (Šarkan, B., 2013)

3.2. Digital camera Casio Exilim EX-FH25

Casio Exilim EX-FH25 digital high-speed camera was used for the measurement for videoanalysis purposes (Fig. 4). The camera combines a set of quick functions, such as high-speed serial picture recording that can take up to 30 9-pixel-pictures per seconds, three inch LCD, high-speed film recording that can take up to 1000 images per second, the innovative highly sensitive CMOS sensor for pictures with optimal exposure at 10.1 megapixels, powerful 26 mm wide-angle lens with 20x optical zoom. It also features slow motion view option that enables users to monitor the motion of an object in slow mode before picture capturing, (http://www.exilim.eu/euro/exilimhighspeed/exfh25/, 2014).

Figure 4. High-speed digital camera Casio Exilim EX-FH25 (http://www.exilim.eu/euro/exilimhighspeed/exfh25/, 2014)

Measurement quality depends on the image width and the camera distribution. The acquisition frequency of camera was 30 Hz. In order to have sufficiently distinctive contour and movement of the car, we could not place the camera too far. We decided to install it in such a manner that we had the space of 2.5 m in front of point B (Fig. 6). The braking started when the vehicle passed point B by its left side mirror. The program Tracker measured that the camera shooting width was of 50m which was sufficient for the speed of 100km/h. (Fig. 5). The problem arose at speed over 100km/h as the braking distance overshot the camera coverage. It is also necessary to take into account a certain error when applying the brakes at higher speeds. This error is brought about by a driver's inaccurate estimation of when point B is passed and so the brakes are to be applied.

Figure 5. Camera coverage

4. Measurement and measurement methods

The experiment was carried out on 30 November 2013 at the Rosina airfield. The surface conditions were: dry asphalt runway with the estimated adhesion factor of range 0.80-0.90 and the runway temperature was of 6 °C. The temperature of ambient air was 3 ºC with low speed wind so we could ignore its impact on the measurement. The length of the experimental track was approximately of 250m (Fig. 6). Certain measurement inaccuracy was caused by the surface gratient estimated at 2%.

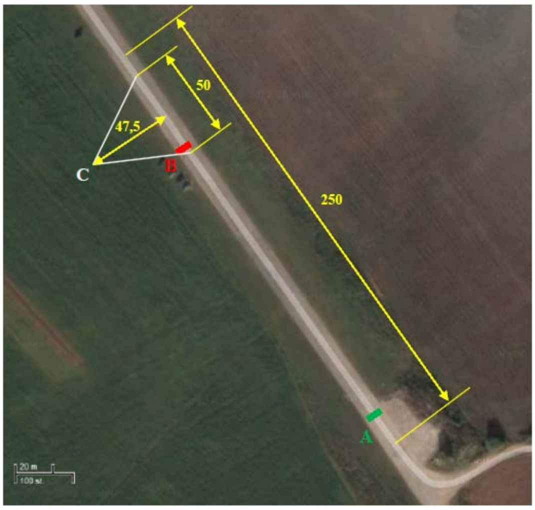

Figure 6. The experimental track

Measurement device XL Meter^{TM} PRO was installed on the inside Mazda 3 MPS 2,3 MZR DISI windshield by means of the vacuum suction cupule (Fig. 7).

The decelerograph was fixed by means of the vacuum suction cupule on the inside windshield during the measurement. The device was positioned in a way so that its measuring axis was parallel to the drive direction and so its controls were within reach of operation.

The device switches into calibration mode after being switched on and successful completion of the automatic system control. The mode then displays current value of measured acceleration. If a vehicle stands still on the horizontal surface, the displayed value is to be of 0 $m.s^{-2}$. Any deviation can be rectified by manipulating the devices´ butt hinge so its measuring axis is in the closest possible horizontal position.

Figure 7. Location of XL Meter™ Pro in the vehicle

System sampling rate was set to 200 Hz, i.e. we had 200 data per second available. Just before the start, it was necessary to launch XL Meter™ Pro measurment process and to signal the person operating the camera to start recording. The camera was placed at point C at the distance of 47.5m and perpendicular to the braking distance. The test was recorded at the frequency of 30 frames per second. The target process to be observed was braking with the fully applied service brake while the vehicle was equipped with ABS. The driver set the vehicle in motion to the desired speed from point A. By activating speed limiter function we achieved the desired speed not to be exceeded. Then at the moment of the desired steady speed the driver violently pushed the service brake pedal when being at point B. Braking was being conducted until the vehicle reached zero speed.

All data were being recorded and were available in a complete file at the end of the experiment. It was necessary to stop data recording when the vehicle reached the zero speed by pushing the off button. The experiment measurement was repeated after a short break.

5. Processing of measured data

Obtained data were processed by the programes SW XL Vision™ Pro and SW Tracker.

5.1. XL Vision™ Pro

All data measured by XL Meter™ Pro can be saved and evaluated later offline. Individual data are stored in the permanent memory so they are accessible even after the device is off but unly until being rewritten. The device enables 8 different measurements to be stored in its memory. It is also possible to transfer all the recorded data into PC by means of serial RS-232 cable or by standard USB cable. Communication and transfer of the measured data between a PC and the XL Meter™ Pro device and its sequential evaluation is provided by the freeware XL Vision™ Pro (Fig. 8). Data transfer is available only in the calibration mode and in the display mode at the end of the display cycle.

XL Vision™ Pro includes ever-increasing number of functions. The aim of the ever-increasing program facilities is to offer the professionals a full computer evaluation of accelerations and decelerations of different vehicles such as passenger cars, commercial vehicles, trucks, coaches, etc. The program also enables very easy documenation and archiving of measured data. Measurement results are possible to be printed in the form of measurement protocol which contains all the important data and information, (Handbook of XL Meter™ Pro, 2011).

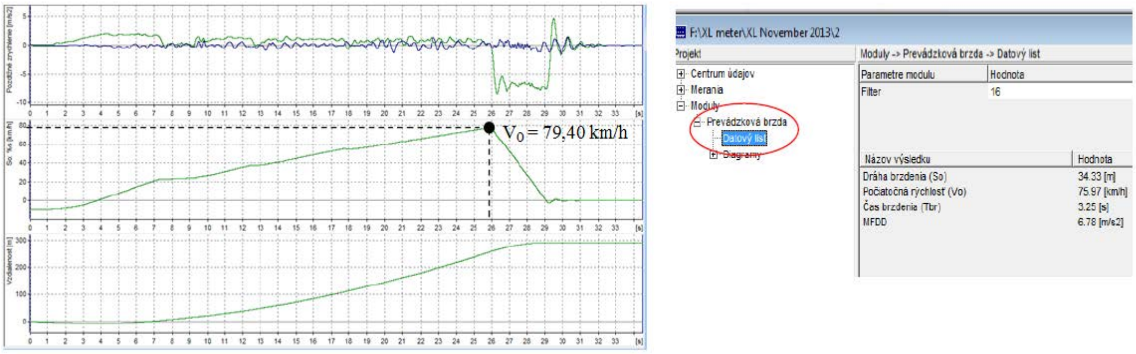

Figure 8. SW XL Vision™ Pro

5.2. SW Tracker (version 4.8)

The program Tracker is a free video analysis and modelling tool built on the Open Source Physics (OSP) Java framework. It is designed to be used in physics education. Tracker video modelling is a powerful new way to combine videos with computer modelling (Fig. 9).

Tracker Features

Tracking:

- Manual and automated object tracking with position, velocity and acceleration overlays and data.
- Center of mass tracks.

Modelling:

- Model Builder creates kinematic and dynamic models of point mass particles and two-body systems.
- Model overlays are automatically synchronized and scaled to the video for direct visual comparison with the real world.

Video:

- Free Xuggle video engine plays and records most formats (mov/avi/flv/mp4/wmv etc) on Windows/OSX/Linux.
- Video filters, including brightness/contrast, ghost trails, and deinterlace filters.
- Perspective filter corrects distortion when objects are photographed at an angle rather than straight-on.
- Radial distortion filter corrects distortion associated with fisheye lenses.
- Export Video wizard enables editing and transcoding videos, with or without overlay graphics, using Tracker itself.
- Video Properties dialog shows video dimensions, path, frame rate, frame count, more.

Data generation and analysis:

- Fixed or time-varying coordinate system scale, origin and tilt.
- Multiple calibration options: tape, stick, calibration points and/or offset origin.
- Switch easily to center of mass and other reference frames.
- Protractors and tape measures provide easy distance and angle measurements.
- Add editable text columns for comments or manually entered data.
- Data analysis tool includes powerful automatic and manual curve fitting.

Other:

- Full undo/redo with multiple steps.
- Page view displays html instructions or student notes.
- User preferences: GUI configuration, video engine, default language, font size, more, (http://www.cabrillo.edu/~dbrown/tracker, 2014).

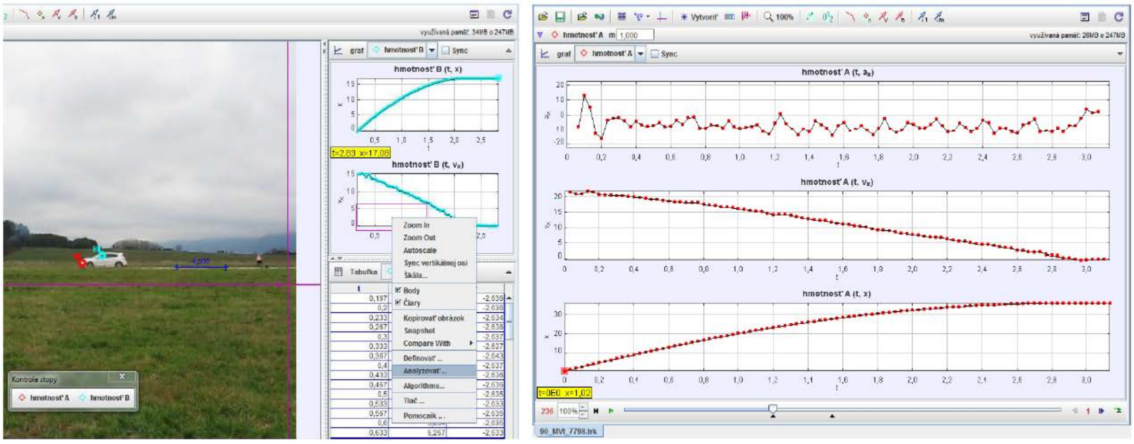

Figure 9. SW Tracker (ver. 4.8.)

6. Evaluation and comparison of the obtained data

The following chart 3 shows the speeds at the beginning of fully braking deceleration, calculated average values for fully braking deceleration time and the data about time and distance the vehicle passed during this section, having various speeds.

Table 3. All experiment results were obtained by XL Meter™ Pro device and processed by XL Vision™ Pro freeware

Measurement no.	Obtained data				
	V [km.h^{-1}]	v [m.s^{-1}]	s [m]	B [m.s^{-2}]	t [s]
7	96.80	26.89	50.10	7.93	3.53
6	84.96	23.60	39.29	8.03	3.13
5	79.51	22.09	33.07	7.89	2.91
4	59.01	16.39	18.43	7.92	2.13
3	56.41	15.67	16.75	8.22	2.02
2	41.66	11.57	9.35	7.71	1.56
1	20.89	5.80	2.52	8.08	0.84

Summary of mean fully developed deceleration by XL Meter™ Pro:

Obtained values

- maximum braking deceleration XL Meter™ Pro: 8.22 m.s^{-2} (trial 3),
- minimum braking deceleration XL Meter™ Pro: 7.71 m.s^{-2} (trial 2),
- average magnitude braking deceleration XL Meter™ Pro: 7.97 m.s^{-2},
- standard deviation of braking deceleration XL Meter™ Pro: 0.149 m.s^{-2}.

Table 4. Experiments resuls processed by the program Tracker, fixed point at the end of the front bumper

Measurement no.	Obtained data				
	V [km.h^{-1}]	v [m.s^{-1}]	s [m]	b [m.s^{-2}]	t [s]
7	83.88	23.30	40.40	7.88	3.53
6	78.12	21.70	34.40	8.02	3.07
5	73.80	20.50	30.40	7.80	2.87
4	58.68	16.30	18.10	7.56	2.16
3	55.80	15.50	15.01	7.73	2.01
2	39.78	11.05	8.39	7.37	1.53
1	18.11	5.03	2.56	7.36	0.86

Summary of mean fully developed deceleration by SW Tracker:

Obtained values

- maximum braking deceleration by SW Tracker: 8.02 m.s^{-2} (trial 6),
- minimum braking deceleration by SW Tracker: 7.36 m.s^{-2} (trial 1),

- average magnitude braking deceleration by SW Tracker: 7.67 $m.s^{-2}$,
- standard deviation of braking deceleration by SW Tracker: 0.236 $m.s^{-2}$.

Figure 10, taken from the program Tracker, plots the evaluation of the course of dependence $v_x(t)$ in the real experiment no. 6. The braking time regarding the fixed point at the end of the rear bumper was of 3.07s. So the deceleration regarding this fixed point was of 8.02m/s^2. The braking distance as well as the initial speed show higher deviation compared to XL Vision™ Pro freeware due to recording problems at a high speed. The braking distance was of 34.4m and the initial speed for the given fixed point was of 78.12km/h.

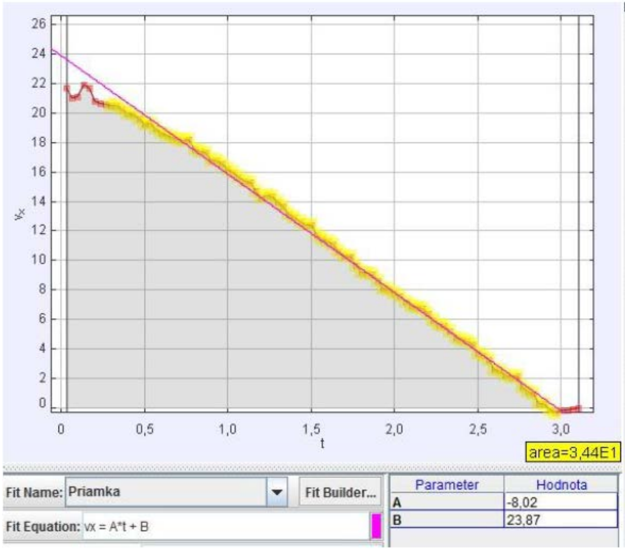

Figure 10. Calculation of deceleration and braking distance in the program Tracker (experiment no. 6)

Comparison of v_x – s dependence

We decided to use the „braking distance – initial speed“ dependence for the final comparison of the obtained data (Fig. 11). The red curve represents the course of the results obtained by XL Meter™ Pro. The green one represents those results obtained by the video analysis processed by the program Tracker.

Each curve is described by the regression equation. Variable y equals to the 2nd order polynomial regression. Variable R^2 shows the equation of the regression reliability. The value is in both cases extremely high what verifies correctness of the chosen regression type. Both curves are almost of the same course which proves both methods are suitable to be used.

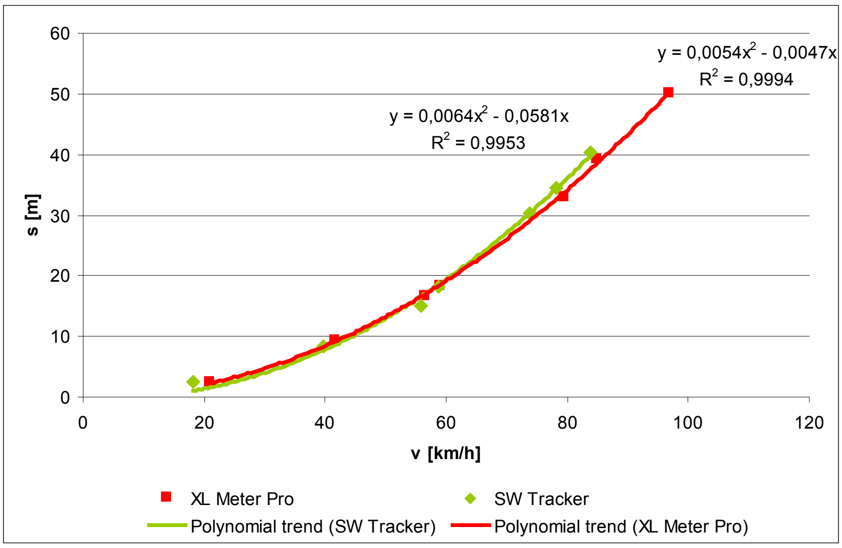

Figure 11. Comparison of the data obtained by SW XL Vision™ Pro and SW Tracker

The factor of sliding friction between the asphalt and the car tires was calculated from the graph parameters on the basis of the previous relationship and the relationship of $b = g\mu$; its value was of 0.61 for the Tracker and 0.73 for the XL Meter™ Pro.

7. Conclusion

Our experiment consisted of 7 deceleration measurements with the sampling rate of 200 data per second. The obtained data comparison shows us that the results processed by the program Tracker correspond with the results processed by XL Vision™ Pro freeware, the accompanying decelerometer software.

The method of video analysis is not to be a substitute for decelerograph; it is, however, an alternative that brings certain pros and cons.

First of all, the use of decelerometer is user-friendlier. It is sufficient to install the measurement device in the vehicle, to calibrate it and to activate it (switch on mode) just before the drive. The device starts automatic data recording within 40 seconds. After measurements are over, it is only necessary to connect it to the PC and to obtain all the numerical and graphical data by means of XL Vision™ Pro freeware.

The method of video analysis requires study of instruction on how to use the evaluation software, in particular the program Tracker. The principle is not very difficult. Another disadvantage of this method is that the accuracy of the results directly depends on more factors such as: camera quality, a vehicles´ contrast with the surroundings, or good weather conditions. The huge advantage of this method is its economic efficiency: measurement can be carried out by any camera, e.g. by todays wide-spread smartphone technology, so a user does not have to buy expensive specialized equipment in case he/she needs to carry out a single measurement, or if he/she owns a high-quality camera, that may be used for the measuremet purposes. (Hockicko, P., Trpišová, B., 2013).

When assessing which device should be preferred, professionals recommend the XL Meter™ Pro due to its size and installation requirements; however, the program Tracker is a freeware and it provides us with the results comparable with those by XL Meter™ Pro so the teachers of physics would probably choose this option.

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IDENTIFYING THE UTILITY FUNCTION OF TRANSPORT SERVICES FROM STATED PREFERENCES

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The aim of this study was to analyze the modal shift of passengers by analyzing their preferences. If the preferences of passengers are known it is possible to build up mathematically their utility function. This is the statistically correct way to simulate the modal shift of the investigated area. To capture the preferences of passengers stated preference method was used in online questionnaire. Five key factors were identified (from the point of passengers): travel cost, travel time, comfort, safety and environmental efficiency. In order to decrease the number of questions three levels were predefined these three questions made the base of the choice model. Every replier got three alternatives and they were told to choose the best for themselves. From the results of the questionnaire the formulas and the parameters of the mode choice utility function was derived. With the help of statistical sample an exponential utility function showed the best matching. For the validation process a probability model was set up to be compared to the proportions of the utilities. With this utility function it is possible to handle the changes in possible future transport services. Based on the introduced statistical approach the described method can be used to identify the effect of transport modes on regional development and tourism. The revealed utility function can help to develop proper regional development plans.

Keywords: Stated preference; Utility function; Modal shift; transport and tourism

1. Introduction

In the literatures stated preference method refers to two different concepts so it is important to define clearly the frames of the examination. Forecast of demands requires knowing the preferences of the consumers. Preferences of customers can be described by utility functions. The direct way to interview consumers is a possible method (which is generally used) but it cannot be said a completely suitable tool to get the preferences. The individuals do not have real interest to reveal their preferences because there are no consequences of the answers. Their decision is just a reaction to a hypothetic situation. An objective evaluation can be given only if the actual decisions are known so the preferences can be revealed only by the observation of the market behaviour. In 1947 P. A. Samuelson (*Samuelson, 1983*) worked out the method of stated preference which makes it possible to simulate approximately the consumer preferences (plus the curves of indifference and the utility function) from factual data (e.g. prices, income, and demanded quantities). Based on Samuelson's work it can be stated that the curves of indifference can be approximately identified from the information of the purchase if exact prerequisites are true *(Karajz, 2008)*.

Nevertheless making interviews and questionnaires seems to be the best way to reveal transport demands of a future transport service (*Heinitz, Fritzlar, 2014*). According to Kroes and Sheldon's definition the term "stated preference method" refers to a family of techniques which use individual respondent's statements about their preferences in a set of transport options to estimate utility function *(Kroes and Sheldon, 1988)*. Different stated preference methods are available under a wide variety of names; the best known methods are:

- Conjoint analysis;
- Functional measurement;
- Trade-off analysis;
- The transfer price method.

These methods were originally developed to marketing researches in the beginning of the 70's but a study from 1978 made them known *(Green and Srinivasan, 1978)*. In this study the authors gave the following description to define the conjoint analysis (which seems to be the most suitable for transport purposes): every method that aims to estimate the structure of the consumer preferences and the consumers evaluate options where the levels of the different quantities have been defined before.

The preliminary results of this method connected to transport related utility functions have already been published (*Andrejszki et. al., 2014a*)

2. Design consideration

The first step of designing a stated preference method examination is to identify the relevant variables (factors) and the values belong to each factor (levels). A related task is here the specification of the mathematical formula of the utility function which refers to the authors' hypothesis about how the integrated preference comes from the individual preferences. The linear, additive, compensational model is the mostly used form which has the following structure:

$$U = \overline{\alpha_n} \cdot \overline{x_n} \quad (1)$$

Here U refers to the complete utility; x_n is a vector of the values of each factor and α_n is a vector of the utility weights of each factor. As it can be seen mathematically utility is the scalar product of the factors and their weights. It is practical if the sum of the utility weights is 1.

The factors can be defined as continuous variables or as a group of discrete variables also. The stated preference method can also be used to test alternative hypothesises *(Kroes and Sheldon, 1988)*.

The next step in planning is the optimization of the mathematical option combinations. According to the experiences it is worth decreasing the number of options because the respondents can be spared by not answering questions that are trivial. If the number of questions is less the willingness of respondents to fill out completely the questionnaire might be higher because it will not need that much time from them. If the number of factors and the belonging levels is given the needed number of combinations can be calculated.

The factorial structure (*Kroes and Sheldon, 1988*) refers to a combinatorial expression. Because of that the full factorial structure means all the possible combinations of the options and the partial factorial structure means an exact part of the full factorial one. There are values belong to the factors; and an exact value of an exact factor is called "quality". In an option of a question there are more qualities but none of them comes from the same factor (e.g. in a question the first option to choose is a travel that takes 10 minutes, worth 3 €-s and has a low comfort level). The full factorial structure generates too much options and combinations at higher number of factors and levels so the partial factorial structure might be better to go on with.

The examination of stated preference method can be done by two possible ways. The first opportunity is when the questioner creates cards from preference possibilities and options and at each question more cards are given to the respondent. The task of the respondent here is to make a sequence from them. The second opportunity is to make choice option cards which contain predefined questions with predefined options so the task of the respondent is to tick the best option of the card that he/she would choose in the given situation *(Kroes and Sheldon, 1988*).

3. Identification of transport utility function

At every question the respondent is asked to choose one (the best) from three options. Based on the international literature in this model five key factors were considered as playing important role in decision making (*Simecki et. al., 2013*): the travel time, travel cost, comfort, safety and environmental friendliness. Each factor has three values (one bad, one middle and one good) so there are 15 qualities which can be seen in Table 1.

Table 1. Factors and qualities

Factor	Abbreviation	Good	Middle	Bad
		qualities		
Travel time	T	30 minutes	20 minutes	10 minutes
Travel cost	TC	4 €	2 €	1 €
Comfort	C	not	more or less	comfortable
Safety	S	not	more or less	safety
Environmental friendliness	E	not	more or less	env. friendly

These exact qualities come from a transport situation that is given to the respondent so they have their meanings. In the situation the respondent lives in a small town and want to get to the train station to go to work in a weekday morning. By car this journey can be done in 10 minutes if there are no traffic jams. Comfort refers to the quality level of the transport service that was used (e.g. a crowded dirty bus means a non-comfortable mode but a clean car or train can represents a comfortable level; but comfort is not linked to any transport mode) (*Duleba et. al., 2013*). Safety in this meaning refers to the number of accidents that happens on the used section of road per one year. On a not safety section there are 12 accidents per year, the middle value is 4 accidents per year and the most safety value is 0.5 accidents per year. At environmental friendliness the emission level of an internal combustion engine was the sample for the so called bad level. This means more or less 179 g from CO_2 per kilometre (*Kok, 2013*). The good level has almost zero emission like walking and cycling.

If we used all the qualities of all the five factors to create the three options of one question, that would cause 360 questions to be asked (if every quality appears maximum once in one question). To reduce this number at the beginning of the questionnaire respondents are asked to choose the three most relevant factors from the enumerated five. After this decision the following questions will just deal with the chosen three factors and count the non-chosen factors with a zero parameter in the individual utility function. According to this operation there are ten versions of the questionnaire:

$$\binom{5}{3} = \frac{5!}{3! \times 2!} = 10 \tag{2}$$

In one question there are always three options. In all the options there are three qualities from three different factors. According to combinatory this means three repeated variation:

$$3^3 \times 2^3 \times 1^3 = 216. \tag{3}$$

But these 216 questions contain same questions with different order of the options. To have the real number of possible question 216 should be divided by the number of possible ordering:

$$\frac{216}{3!} = \frac{216}{6} = 36. \tag{4}$$

These 36 questions are equal to the full factorial structure. For further reduction the trivial questions should be selected. In this case the expression “trivial” refers to those questions that have an option which contains three good qualities or two good qualities and one middle quality. The model handle these questions like these were answered by the respondent in a logical way so they always choose this outstanding option. After the selection of these trivial questions 20 questions remain that can be asked from the respondents. This amount seems to be user friendly and gives the hope of high filling rate.

4. The implemented questionnaire

In the implemented online questionnaire the transport situation was written first. Then the respondent chose the three more relevant factors. From these factors the respondent got 20 questions to answer. The questions were like *Figure 1*. As it can be seen this kind of questions includes partly the appointment of WTP (Willingness to pay) (*Drevs et. al., 2014*).

1. From the following options what would you choose?

O 1) You would pay 4 € to take your journey in 30 minutes in a more or less comfortable vehicle.
O 2) You would pay 2 € to take your journey in 20 minutes in a comfortable vehicle.
O 3) You would pay 1 € to take your journey in 10 minutes in a not comfortable vehicle.

Figure 1. One question of the questionnaire

The questionnaire was filled out correctly by 462 respondents. The ages of the respondents are shown in *Figure 2*. As it can be seen the questionnaire was not representative (at the ages) but because of the time and cost constraints of the examination this was not an expectation.

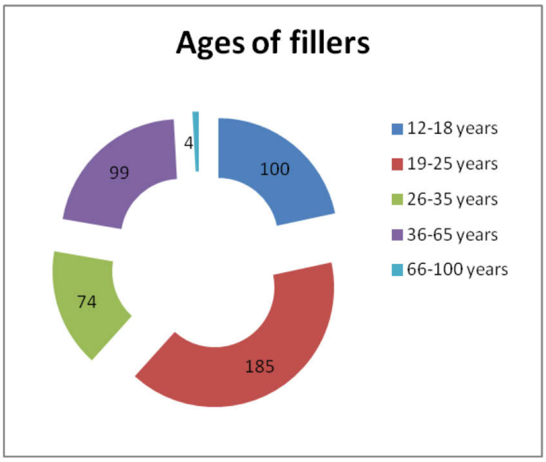

Figure 2. The ages of the respondents

4.1. The algorithm of evaluation

The basis of the evaluation was to give 1-1 point to the qualities of the chosen option and give 0 point to the qualities of the non-chosen options. In this case each quality can gain 20 points as maximum and zero points as minimum. At this moment the 16 questions are added to the real answers then the maximum becomes 36 points. If the given factor is not important for the respondent -so it does not have a high preference – the points of the qualities of this factor will be around the one third of all questions

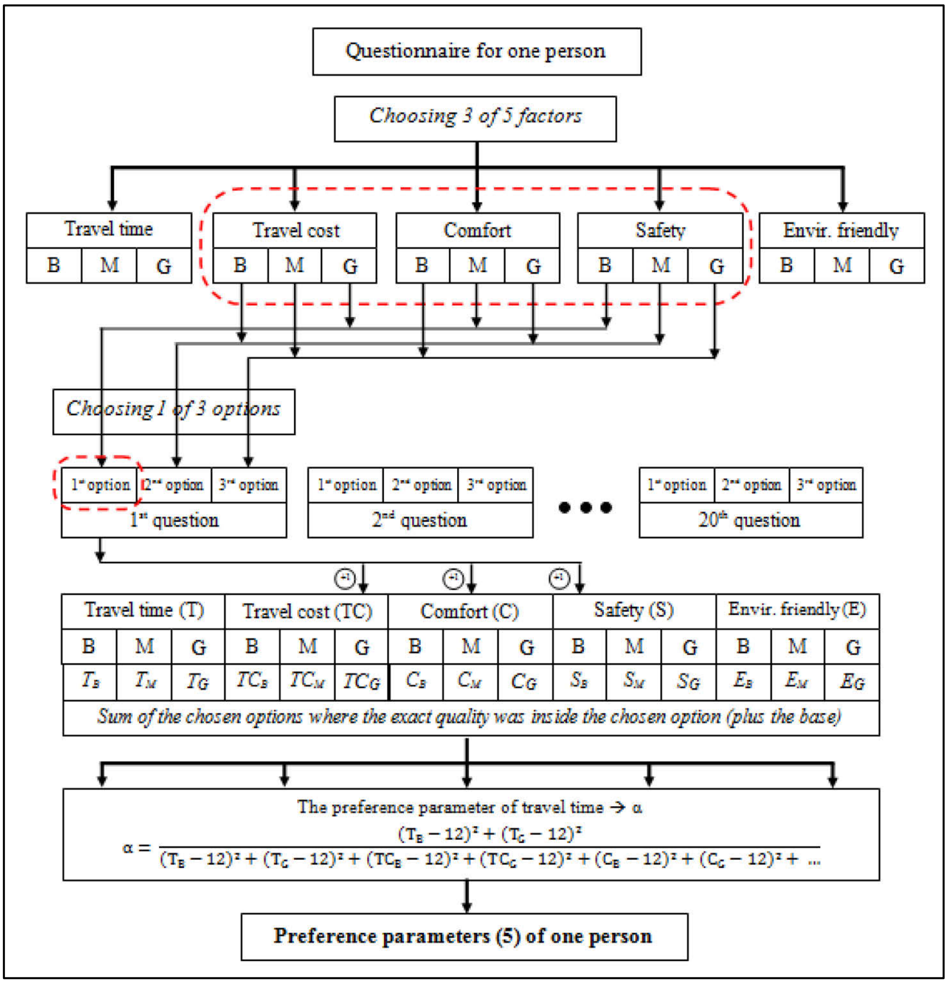

Figure 3. The process of the questionnaire and the evaluation

which is 12. If the factor was relevant for the respondent the good quality might get a higher score or (because avoiding the bad quality of this factor is also a preference) the bad quality might get a lower score. From these values the individual utility function should be calculated. The parameter of one factor of the individual utility function is rational number in the interval of [0; 1] where:

- 0 is the preference parameter if the factor is absolutely not relevant;
- 1 is the preference parameter if the factor is absolutely relevant.

The parameter of factor 1 should be calculated by the following method. After the points of each quality are summarised the next step is to calculate the square of the distances between the good quality and the average value (which is 12 now) and then to add the square of the distances between the bad quality and the average value. It is enough to examine just the good and the bad quality because (as it was mentioned before) the possible strategies of the respondents do not appear in the middle quality. So getting the middle quality into the algorithm would distort the utility function. After each factor has this basic value this value of factor 1 should be divided by the sum of this basic value of each factor. This process causes that the sum of the parameters gives 1. So if factor 1 is absolutely relevant its' parameter will be 1 and the other factors' parameter will be 0. The whole procedure can be seen in *Figure 3*.

The utility weights of the complete utility function come from the averages of the individual parameters. The structure of utility function was also the object of the examination. Linear, exponential and logarithmical models were considered but the most effective was the following structure:

$$U = e^{\overline{a_n} \cdot \overline{x_n}} - e \tag{5}$$

In this formula the same notation is used like in equation (1). The values that are connected to the different levels are 1 for bad qualities, 2 for middle qualities and 3 for good qualities. In this case the worst combination of bad qualities causes the zero utility.

4.2. Process of validation

The accuracy of the model can be validated by the examination of the decision situations. The question is that: what is the ratio between the quotient of the utilities of two options and the quotient that shows how many people preferred the first option against the second.

To prepare the probability matrix the first step is to integrate the 10 versions (*Figure 4*). This is not trivial because the versions were filled out by different amount of people and in one question the complete order is not known because the respondent only chose the best option (so the relation of the two not chosen options is not known). So firstly 10 preference matrixes were created in the sizes of 27*27. In the columns and rows there are all the mathematically possible options so one element means that how many times were the option of the row chosen against the option of the column. The second step is the creation of another 10 matrixes called answered matrixes. Here the elements mean that how many times the respondents chose from the two options.

The probability matrix has $3^5 = 243$ rows and 243 columns because in the integration all the 15 qualities of the five factors should be counted with. Every element is the quotient of choosing the option of the row against the option of the column. These options have five dimensions. In this five-dimension option there are 10 three-dimension options that can be found in the 10 preference matrixes and answered matrixes. So to get one element of the probability matrix the appropriate cells of the 10 preference matrixes should be summarised and then this sum should be divided by the sum of the appropriate cells of the answered matrixes.

In the edge of the utility matrix there are the same 243 options as in the probability matrix. One element means the quotient of the utility of the row option and the utility of the column option. Then the next step is to create a matrix in the same size where the elements show the relation between the utility and the probability matrixes. In this validation matrix the value is 1 if the two quotients are similar and 0 if not. Similarity means the followings:

- The row option is better [0; 0.45]
- The row option is similar to the column option]0.45; 0.55]
- The column option is better]0.55; ∞[

So if the quotients are in the same interval the validation matrix element gets 1 if not it gets 0. After having all the values the average of them will give the accuracy of the model. In this case the accuracy level of 73.12% was reached. This level was accepted for further examinations with the created transport utility function.

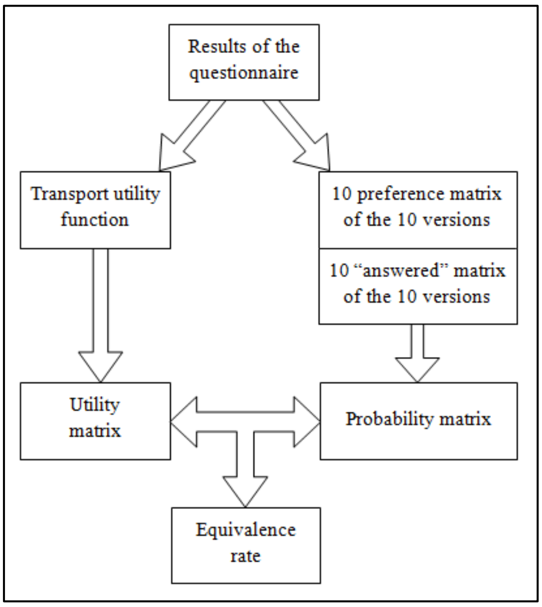

Figure 4. The process of validation

5. Evaluation of transport projects by the utility function - Conclusion

With the above demonstrated process the utility of passengers can be determined. The analysis of this hidden and personal utility can help the professional transport planners to identifying the key parameters that play an important role in transport development or enhance modal shift (*Cerny et. al., 2014*). This could help to find the optimal path of regional development (*Andrejszki et. al., 2014b*).

The aim of this study was to show an easy method to statistically analyse passenger preferences. If the preferences of passengers are known it is possible to stimulate modal shift. To capture the passengers' stated preferences an online questionnaire was built. Five passenger focused key factors were identified: travel time, cost, comfort, safety and environmental friendliness. In these factors three levels was predefined as simplification which made the base of the choice model. Although the statistical sample was not representative, this method gives a clear guideline for cities, companies and planners to create their questionnaires and make their sample representative. From the results of the questionnaire the parameters of the mode choice utility function were statistically estimated. An exponential utility function was used as it had the best fit for the examined sample. For the validation process a probability model was set up to be compared to the proportions of the utilities.

With this utility function it is possible to handle possible future transport services by evaluating the services through the defined five factors. It is feasible to compare the possibilities of transport developments, and the opportunity is given to make the comparison by measurable statistical indicators. Based on the introduced statistical approach the described method can be used to identify the effects of transport modes on regional development.

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NUMERICAL SIMULATION OF MOVING LOAD ON CONCRETE PAVEMENTS

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The knowledge of the development with time of the strain and stress states in pavement structures is needed in the solution of various engineering tasks as the design fatigue lifetime reliability maintenance and structure development. The space computing model of the truck TATRA 815 is introduced. The pavement computing model is created in the sense of Kirchhof theory of the thin slab on elastic foundation. The goal of the calculation is to obtain the vertical deflection in the middle of the slab and the time courses of vertical tire forces. The equations of motion are derived in the form of differential equations. The assumption about the shape of the slab deflection area is adopted. The equations of the motion are solved numerically in the environment of program system MATLAB. The dependences following the influence of various parameters (speed of vehicle motion, stiffness of subgrade, slab thickness, road profile) on the pavement vertical deflections and the vertical tire forces are introduced. The results obtained from the plate computing model are compared with the results obtained by the FEM analysis. The outputs of the numerical solution in the time domain can be transformed into a frequency domain and subsequently used to solve various engineering tasks.

Keywords: numerical simulation, moving load, computing models, concrete pavements, dynamic, tire forces

1. Introduction

The knowledge of the development with time of the strain and stress states in pavement structures is needed in solving various engineering tasks as the design fatigue lifetime reliability maintenance and structure development. The most effective solution of the problem of the vehicle – road interaction is the combination of numerical and experimental methods. The analysis can be performed in the time or in the frequency domain. Numerical analysis demands to pay attention to these separated problems: vehicle computing models, pavement computing models, road profile, solutions of equations of motion, programming, processing and interpretation of obtained results. The finite element method is commonly used. But there are also other possibilities of the solution. In this contribution the computing model of the concrete pavement based on the theory of the thin slab on elastic foundation and space computing model of the truck are introduced. The results obtained from this slab computing model are compared with the results obtained from FEM analysis.

The first analytical solution of the moving load effect on structures is known from literature in connection with the disaster of the Chester Rail Bridge in England in the year 1847. Engineer R. Willis formulated the equation of motion describing the vibration of the elastic mass-less beam induced by moving the mass point with the constant velocity (Willis, 1849). The solution of the above equation of motion was carried out by G. G. Stokes by the development of deflections into the infinite series (Stokes, 1849). These two works started the stage of the analytical and numerical analyses of moving load effect on transport structures. The best known work concerning the moving loads effect on structures in the Czecho-Slovak Republic was published by (Frýba, 1972). Many researchers in the world pay attention especially to the solution of the problems of vehicle – road interaction. For example, the works of (Cebon, 1999) from the University of Cambridge are well-known as well as the works of (Kulakowski, 2009). The work of (Martinček, 1994) from the Slovak Academy of Sciences was especially dedicated to the dynamics of concrete pavements. The works of (Blab, 2004) dedicated to the solution of this problem are also known.

2. Computational model of vehicle

Generally, one, two or three dimensional computational model of vehicle can be adopted for the modelling of the dynamic effect of moving vehicles on the road structures. For the purpose of the task presented in this paper the space computational model of the truck TATRA has been adopted, *Figure 1*.

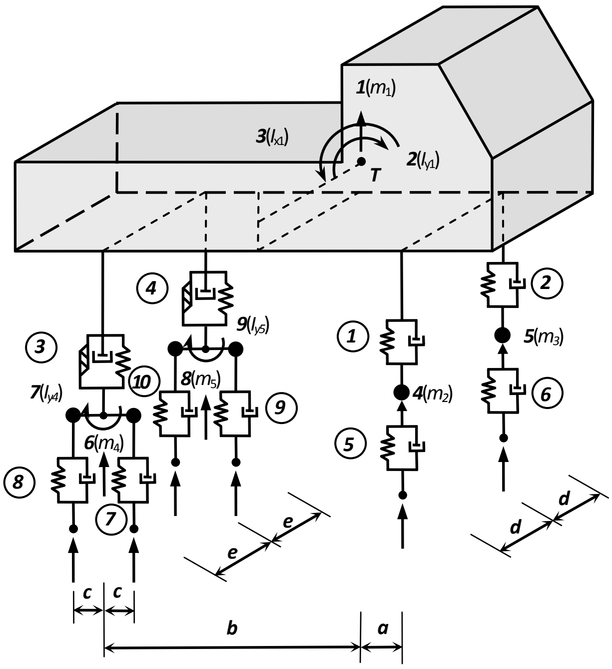

Figure 1. Space computational model of vehicle TATRA

The computational model of the truck has 15 degrees of freedom – 9 mass and 6 mass-less. The mass-less degrees of freedom correspond to the vertical movements of the contact points of the model with the surface of the roadway. The vibration of the mass objects of the model is described by the 9 functions of time $r_i(t)$, (i = 1, 2, 3, 4, 5, 6, 7, 8, 9). The unknown function $r_i(t)$ represent the displacement components of the points corresponding to the individual degrees of freedom of the vehicle. The mass-less degrees of freedom are associated with the tire forces $F_j(t)$, (j = 5, 6, 7, 8, 9, 10) acting at the contact points. It is the discrete computing model, so the equations of motion are in the form of ordinary differential equations and with respect to the used method of numerical solution they can be written in the form (Melcer et al., 2012)

$$[m]\{\ddot{r}\} = \{F\} - [b]\{\dot{r}\} - [k]\{r\} = \{F\} - \{F_d\} - \{F_{re}\} = \{F_v\}, \tag{1}$$

where $[m]$, $[b]$, $[k]$ are the mass, damping and stiffness matrix and $\{F\}$, $\{F_d\}$, $\{F_{re}\}$, $\{F_v\}$ are the vectors of exciting, damping, restoring and resulting forces. Derivation with respect to the time t is denoted by the dot over the symbol.

3. Computational model of the road slab

The computational model of the concrete pavement is based on the Kirchhoff theory of the thin slabs on elastic foundation (Frýba, 1972)

$$D\left(\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4}\right) + Kw + \mu\frac{\partial^2 w}{\partial t^2} + 2\mu\omega_b\frac{\partial w}{\partial t} = p(x,y,t). \tag{2}$$

The desired function $w(x,y,t)$ describing the slab vertical deflections will be expressed as the product of two functions

$$w(x,y,t) = w_0(x,y)\, q(t). \tag{3}$$

The function $w_0(x,y)$ stands for the known function and it is dependent on the coordinates x, y only and the function $q(t)$ stands for the unknown function and it is dependent on the time t. The function $q(t)$ has the meaning of generalized Lagrange coordinate. The assumption about the form of the function $w_0(x,y)$ has been introduced as, *Figure 2*.

$$w_0(x,y) = \frac{1}{4}\left(1 - \cos\frac{2\pi x}{l_x}\right)\left(1 - \cos\frac{2\pi y}{l_y}\right). \tag{4}$$

The meaning of the remaining symbols is as follows: D slab stiffness [N.m^2/m], K modulus of foundation [N/m^3], μ surface mass density [kg/m^2], ω_b circular frequency of damped vibration [rad/s].

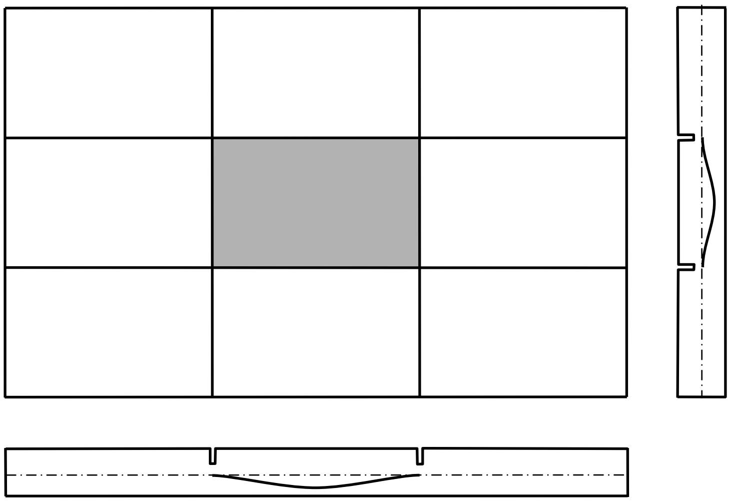

Figure 2. Assumption about the shape of the slab deflection area

$p(x,y,t)$ is the intensity of the dynamic load. In the case of moving vehicles the discrete load, due to the tire forces $F_j(t)$, must be transformed on a continuous load by the procedure proposed by Dirac (Frýba, 1972)

$$p(x,y,t) = \sum_j F_j(t)\delta(x - x_j)\delta(y - y_j), \tag{5}$$

$$p(x,y,t) = \sum_j \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} p_{mn,j}(t)\frac{1}{4}\left(1 - \cos\frac{m2\pi x}{l_x}\right)\left(1 - \cos\frac{n2\pi y}{l_y}\right), \tag{6}$$

where

$$p_{mn,j}(t) = \frac{2}{l_x}\frac{2}{l_y}\int_0^{l_x}\int_0^{l_y} F_j(t)\delta(x - x_j)\delta(y - y_j)\frac{1}{4}\left(1 - \cos\frac{m2\pi x}{l_x}\right)\left(1 - \cos\frac{n2\pi y}{l_y}\right)\mathrm{d}x\mathrm{d}y =$$

$$= F_j(t)\frac{4}{l_x l_y}\frac{1}{4}\left(1 - \cos\frac{m2\pi x_j}{l_x}\right)\left(1 - \cos\frac{n2\pi y_j}{l_y}\right). \tag{7}$$

Then

$$p(x,y,t) = \sum_j \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} F_j(t)\frac{1}{l_x l_y}\left(1 - \cos\frac{m2\pi x_j}{l_x}\right)\left(1 - \cos\frac{n2\pi y_j}{l_y}\right)\cdot$$

$$\cdot\frac{1}{4}\left(1 - \cos\frac{m2\pi x}{l_x}\right)\left(1 - \cos\frac{n2\pi y}{l_y}\right). \tag{8}$$

Regarding to the convergence of the series in equation (8) we can take into account the 1st member of the series only. Then the equation (8) can be rewritten as

$$p(x,y,t) = \sum_j F_j(t)\frac{1}{4 l_x l_y}\left(1 - \cos\frac{2\pi x_j}{l_x}\right)\left(1 - \cos\frac{2\pi y_j}{l_y}\right)\left(1 - \cos\frac{2\pi x}{l_x}\right)\left(1 - \cos\frac{2\pi y}{l_y}\right). \tag{9}$$

For the space truck computing model

$$F_j(t) = -G_j + k_j d_j(t) + b_j \dot{d}_j(t), \quad (j = 5, 6, 7, 8, 9, 10), \tag{10}$$

where G_j is the gravity force of *j-th* axis, k_j and b_j stiffness and damping of the *j-th* tire and $d_j(t)$ is the tire deformation. Derivation with respect to the time t is denoted by the dot over the symbol.

Substituting the assumption (3) and (4) into equation (2) the left side of the equation (2) will change into

$$\ddot{q}(t)\left[\frac{1}{4}\mu\left(1-\cos\frac{2\pi x}{l_x}\right)\left(1-\cos\frac{2\pi y}{l_y}\right)\right]+\dot{q}(t)\left[\frac{1}{4}2\mu\omega_b\left(1-\cos\frac{2\pi x}{l_x}\right)\left(1-\cos\frac{2\pi y}{l_y}\right)\right]+$$

$$+q(t)\frac{1}{4}\left[-D\left(\frac{2\pi}{l_x}\right)^4\cos\frac{2\pi x}{l_x}\left(1-\cos\frac{2\pi y}{l_y}\right)+2D\left(\frac{2\pi}{l_x}\right)^2\left(\frac{2\pi}{l_y}\right)^2\cos\frac{2\pi x}{l_x}\cos\frac{2\pi y}{l_y}-\right.$$

$$\left.-D\left(\frac{2\pi}{l_y}\right)^4\left(1-\cos\frac{2\pi x}{l_x}\right)\cos\frac{2\pi y}{l_y}+K\left(1-\cos\frac{2\pi x}{l_x}\right)\left(1-\cos\frac{2\pi y}{l_y}\right)\right]=p(x,y,t)\,. \tag{11}$$

When we study the deflections at one point of the slab only, for example, in the middle of the slab, than $x = l_x/2$ and $y = l_y/2$ and the equation (2) comes by the definitive form

$$\ddot{q}(t)\mu+\dot{q}(t)2\mu\omega_b+q(t)\frac{D}{2}\left[\left(\frac{2\pi}{l_x}\right)^4+\left(\frac{2\pi}{l_x}\right)^2\left(\frac{2\pi}{l_y}\right)^2+\left(\frac{2\pi}{l_y}\right)^4+2\frac{K}{D}\right]=$$

$$=\sum_j F_j(t)\frac{1}{l_x l_y}\left(1-\cos\frac{2\pi x_j}{l_x}\right)\left(1-\cos\frac{2\pi y_j}{l_y}\right). \tag{12}$$

4. Numerical analysis

4.1. Parameters of the slab computational model

For the purpose of numerical analysis the following slab construction has been considered, *Figure 3*:

1. CS – concrete slab, h_1 = 240 mm, E_1 = 37 500 MPa, v_1 = 0.20
2. CA II – coating aggregate, quality class II, h_2 = 40 mm, E_2 = 4 500 MPa, v_2 = 0.21
3. SC I – soil cement, quality class I, h_3 = 200 mm, E_3 = 2 000 MPa, v_3 = 0.23
4. PC – protective coat, gravel sand, h_4 = 250 mm, E_4 = 120 MPa, v_4 = 0.35
5. SS – sub-soil, h_5 = ∞ mm, E_5 = 30 MPa, v_5 = 0.35

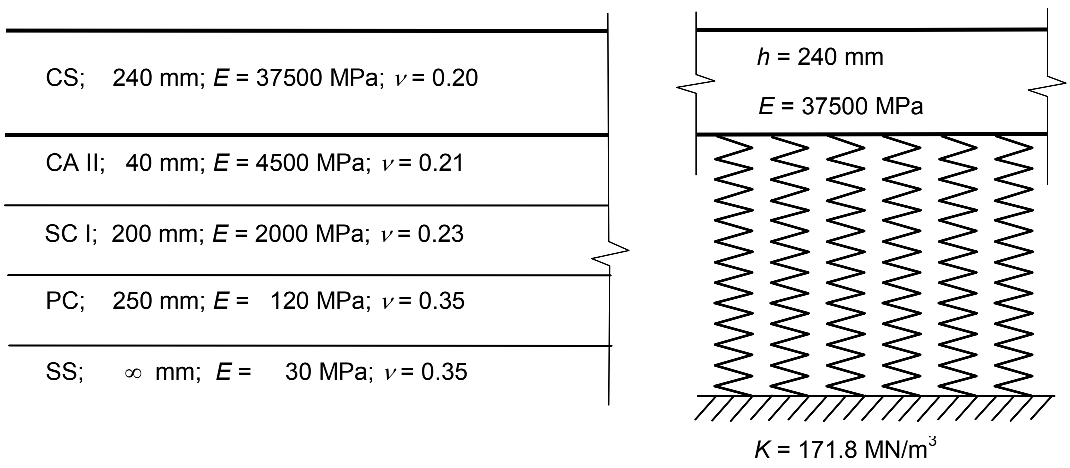

Figure 3. Model of the slab on elastic foundation

The 1st layer of the computing model is the concrete slab of the thickness h = 240 mm, the length l_x = 6.8 m, the width l_y = 4.9 m, modulus of elasticity E = 37 500 MPa, Poisson ratio ν = 0.20. The surface mass density of the slab $\mu = \rho\, h$ = 2500×0.24 = 600.0 kg/m. The circular frequency of damped vibration is taken as ω_b = 0.1 rad/s. The layers 2 – 5 are taken into calculation as Winkler elastic foundation. The modulus of compressibility K = 171.8 MN/m has been obtained as the result of the numerical loading test of the layered half-space, using the program LAYMED (Novorný et al., 1983).

The parameters of the truck computing model are as follows: $k_1 = k_2$ = 143 716,5 N/m, $k_3 = k_4$ = = 761 256 N/m, $k_5 = k_6$ = 1 275 300 N/m, $k_7 = k_8 = k_9 = k_{10}$ = 2 511 360 N/m, $b_1 = b_2$ = 9 614 kg/s, $b_3 = b_4$ = = 130 098.5 kg/s, $b_5 = b_6$ = 1 373 kg/s, $b_7 = b_8 = b_9 = b_{10}$ = 2 747 kg/s, m_1 = 22 950 kg, $m_2 = m_3$ = 455 kg, $m_4 = m_5$ = 1 070 kg, I_{x1} = 22 950 kgm^2, I_{y1} = 62 298 kgm^2, $I_{y4} = I_{y5}$ = 466 kgm^2, a = 3.135 m, b = 1.075 m, c = 0.66 m, d = 0.993 m, e = 0.973 m. The parameters of the truck computing model correspond to the truck TATRA 815.

4.2. Influence of the velocity of the vehicle motion

For the numerical solution of the mathematical apparatus, a computer program in the programming language MATLAB has been created. The program enables to calculate the time dependent change of all kinematical values (displacement, speed, acceleration) at mid-span of the slab and the time dependent change of contact forces under individual axles. The demonstrations of the form of the obtained results at the velocity of vehicle V = 65 km/h are in the *Figures 4, 5, 6, 7*. When the vehicle moves along the axis of the slab symmetry the tire forces on the left and right side of vehicle are the same. Due to this reason the tire forces under the wheels on the right side of vehicle are presented.

The results of the solution are influenced by various parameters of the considered system (velocity of the vehicle motion, stiffness of subgrade, modulus of elasticity of the slab, thickness of the slab, road profile, etc.). The influence of the velocity of the vehicle motion has been analyzed in the interval of speeds V = 0 – 120 km/h with the step of 5 km/h. The maximum of vertical displacements at the monitored point of the slab versus velocity of the vehicle motion are plotted in the *Figure 8*. The position of the vehicle gravity centre at which the maximal slab deflection occurs is also shown in the *Figure 8*. The results are obtained for the smooth road surface.

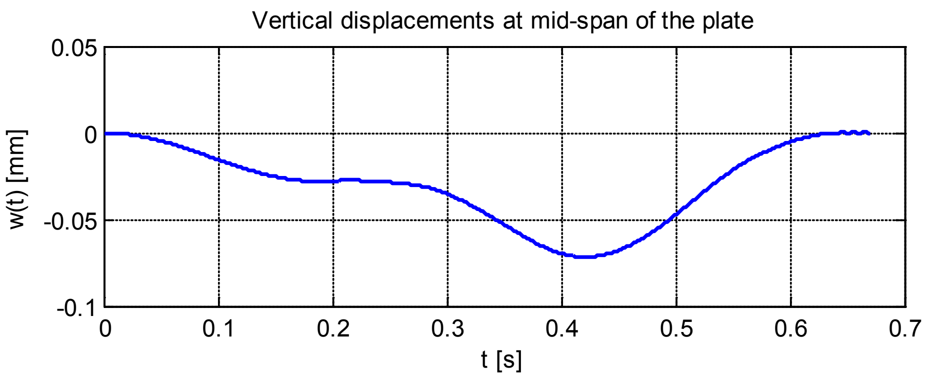

Figure 4. Vertical displacements at mid-span of the slab at the vehicle velocity V = 65 km/h

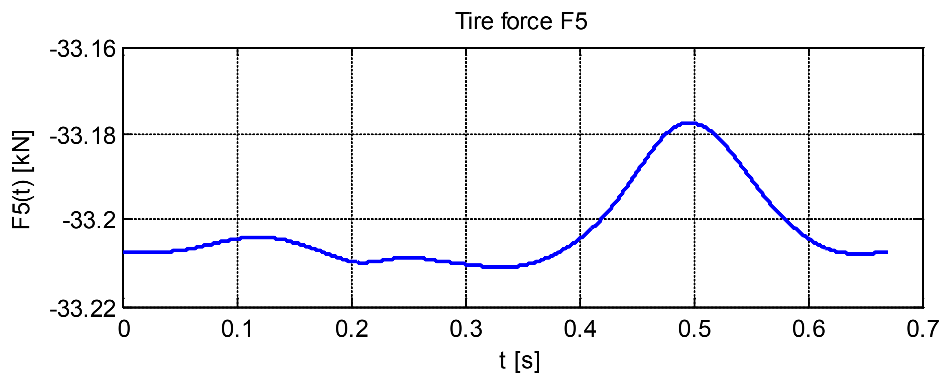

Figure 5. Tire force $F_5(t)$ under the right front wheel at the vehicle velocity V = 65 km/h

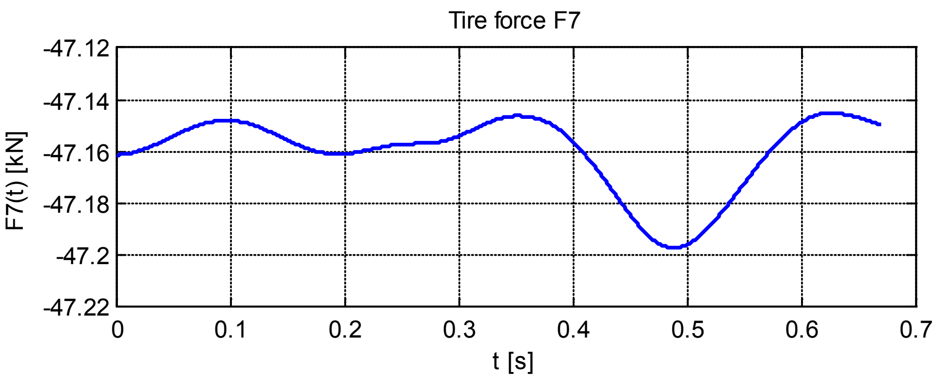

Figure 6. Tire force $F_7(t)$ under the right front wheel of the rear axle at the vehicle velocity V = 65 km/h

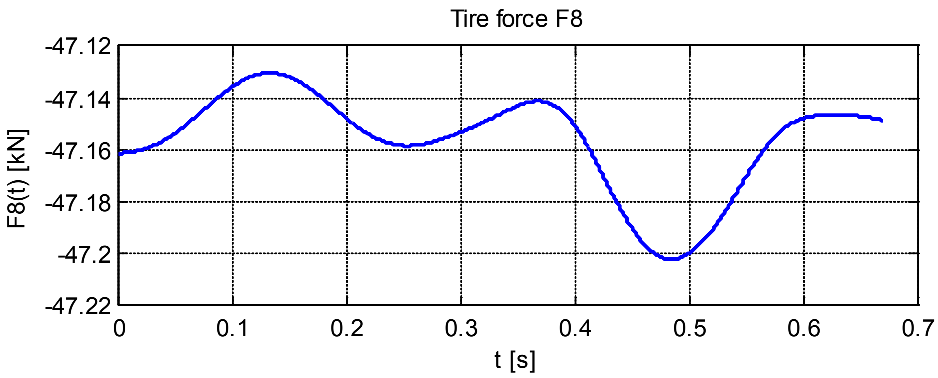

Figure 7. Tire force $F_8(t)$ under the right rear wheel of the rear axle at the vehicle velocity V = 65 km/h

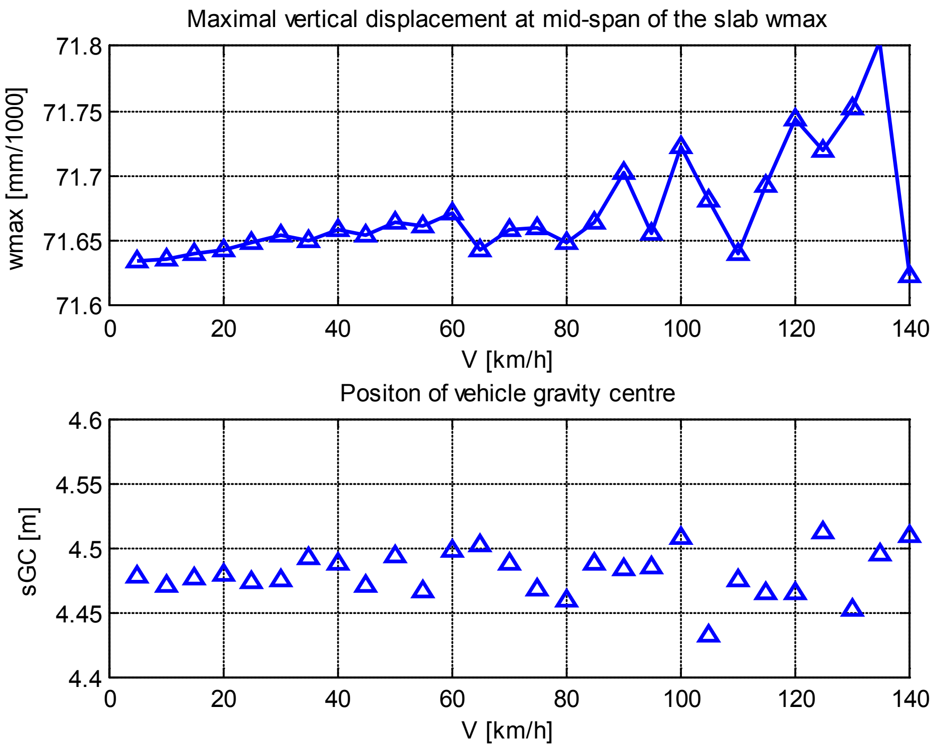

Figure 8. Maximal slab displacement and position of the vehicle gravity centre versus velocity V

The maximal slab displacement w_{max} = 0.0718 mm corresponds to the velocity of the vehicle motion V = 135 km/h. The vehicle gravity center is situated 1.0948 m behind the middle of the slab at this moment.

4.3. Influence of the subgrade stiffness

The influence of the modulus of foundation K was analyzed in the interval 50-200 MPa with the step of 25 MPa and in the interval 200-500 MPa with the step of 50 MPa. The velocity of vehicle motion was V = 65 km/h. The maximum of vertical displacements at the monitored point of the slab versus the modulus of foundation are plotted in the *Figure 9*. The extremes (maximum, minimum) of the tire forces under the wheels on the right side of the vehicle versus the modulus of foundation are plotted in *Figures 10, 11, 12*.

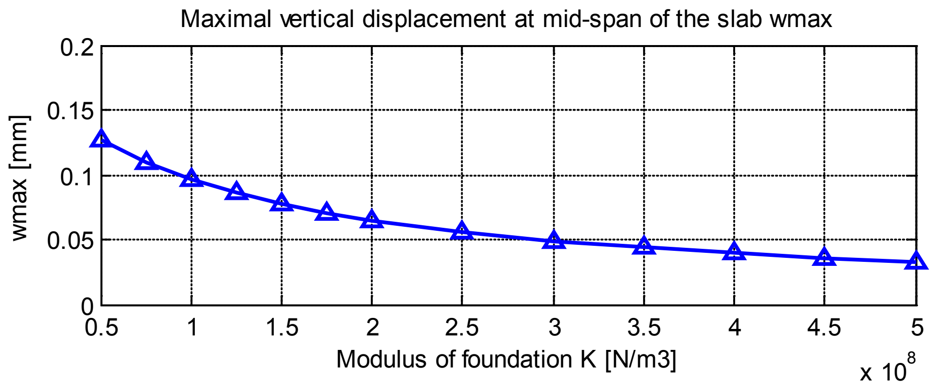

Figure 9. Maximal slab displacement and versus modulus of foundation K

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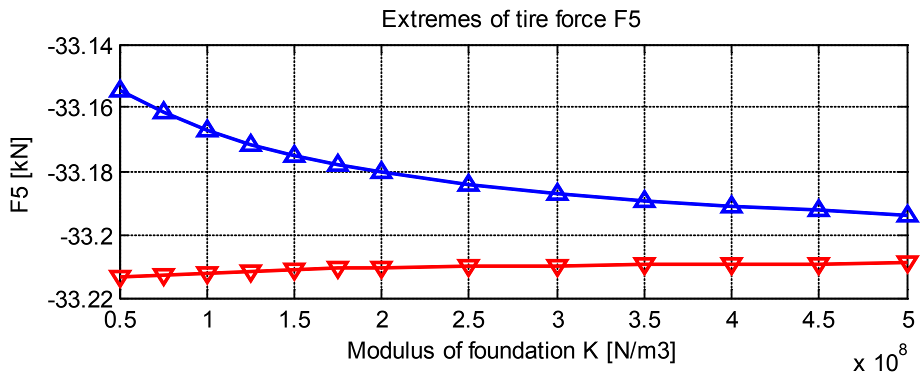

Figure 10. Extremes of tire force $F_5(t)$ versus modulus of foundation K

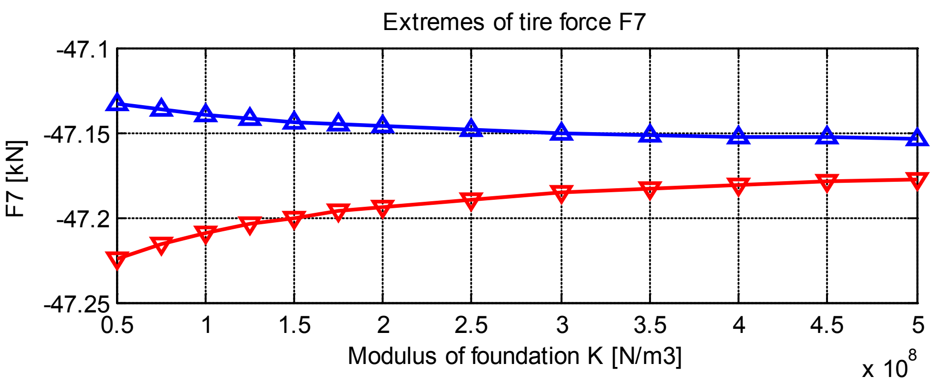

Figure 11. Extremes of tire force $F_7(t)$ versus modulus of foundation K

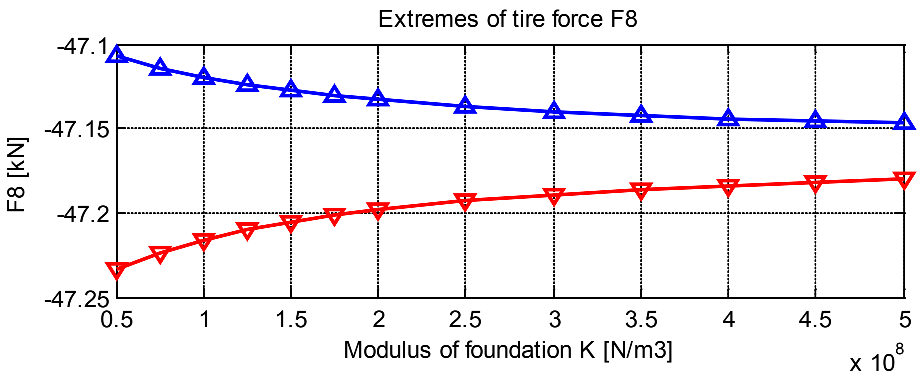

Figure 12. Extremes of tire force $F_8(t)$ versus modulus of foundation K

4.4. Influence of the slab thickness

The influence of the slab thickness h was analyzed in the interval 5–40 cm with the step of 5 cm. The velocity of the vehicle motion was V = 65 km/h. The maximum of vertical displacements at the monitored point of the slab versus the modulus of foundation are plotted in the *Figure 13*. The extremes (maximum, minimum) of tire forces under the wheels on the right side of the vehicle versus the modulus of foundation are plotted in *Figures 14, 15, 16*.

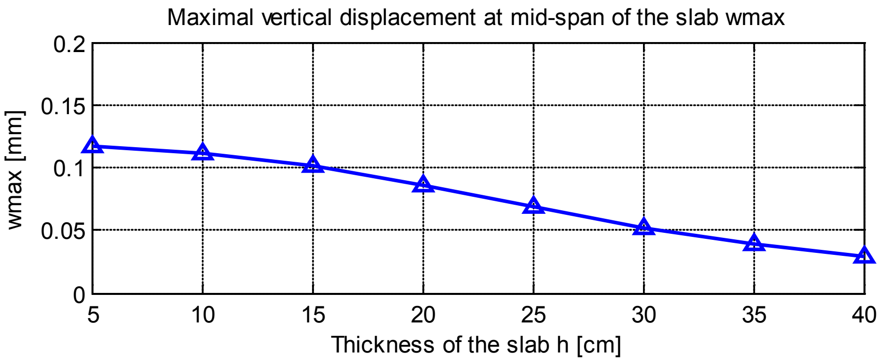

Figure 13. Maximal slab displacement and versus thickness of the slab h

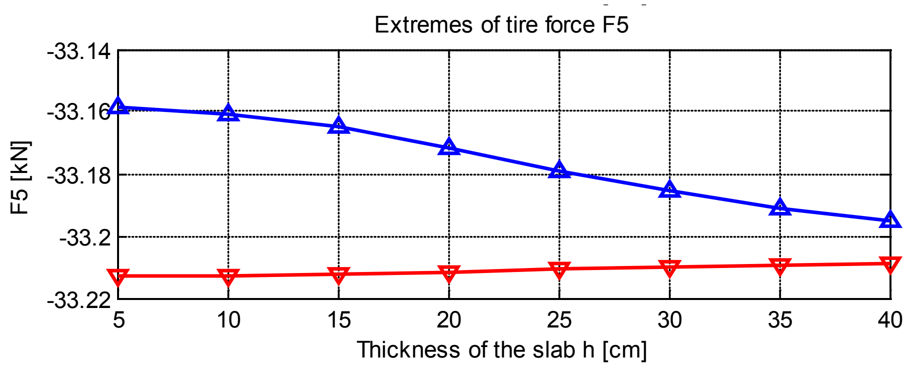

Figure 14. Extremes of tire force $F_5(t)$ versus the thickness of the slab h

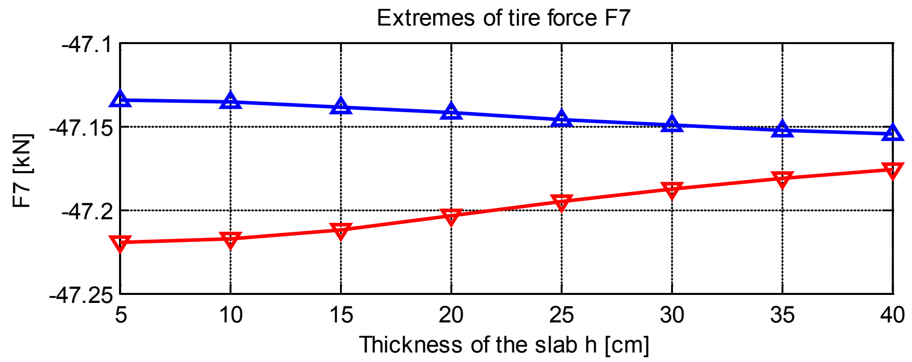

Figure 15. Extremes of tire force $F_7(t)$ versus the thickness of the slab h

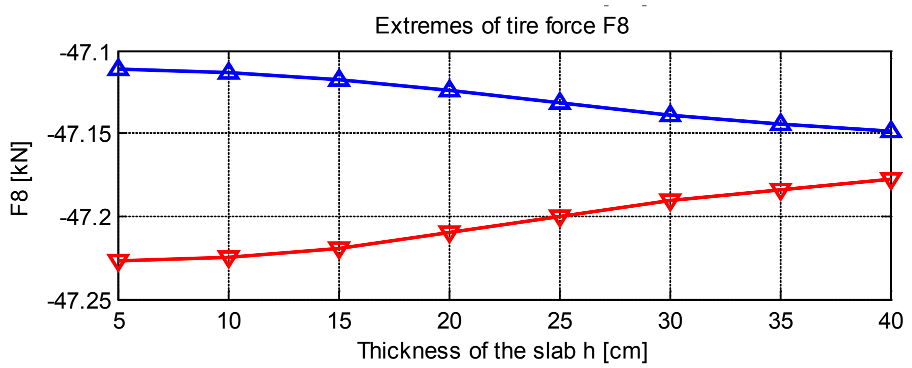

Figure 16. Extremes of tire force $F_8(t)$ versus the thickness of the slab h

It is possible now to carry out the general deduction. When the stiffness of the structure is increased for any reason, the vertical slab deflection is decreased and the range between the maximal and minimal value of the tire force is decreased.

4.5. Influence of the road profile

The above-mentioned results have been obtained for the smooth road profile. The real road profile has random character and it represents the dominant source of the kinematical excitation of the vehicle. Also the vehicle response has random character. The random road profile can be approximated by the Power Spectral Density (PSD) in the form of

$$S(\Omega) = S(1)\times\Omega^{-k}, \tag{13}$$

where $\Omega = 2\pi/L$ in [rad/m] denotes the wavenumber and $S(1) = S(\Omega_0)$ in [m^2/(rad/m)] describes the value of the PSD $S(\Omega)$ at reference wavenumber Ω_0 = 1 rad/m. According to the international directive (ISO 8608, 1995), typical road profiles can be grouped into classes from A to E. By setting the waviness to k = 2, each class it is simply defined by its reference value $S(1)$. Class A with $S(1) = 1\times10^{-6}$ m^2/(rad/m), class E $S(1) = 256\times10^{-6}$ m^2/(rad/m). In the next section the random road profile of a very good quality (class B, $S(1) = 4\times10^{-6}$ m^2/(rad/m)) has been numerically generated by the equation (14)

$$h(x) = \sum_{j=1}^{N} \sqrt{2S(\Omega_j)\Delta\Omega}\cos(\Omega_j x + \varphi_j)\,. \tag{14}$$

In the equation (14) the φ_j is the uniformly distributed phase angle in the range between 0 and 2π. The same road profile has been generated in the left and right wheel trace. The generated road profile is shown in the *Figure 17*.

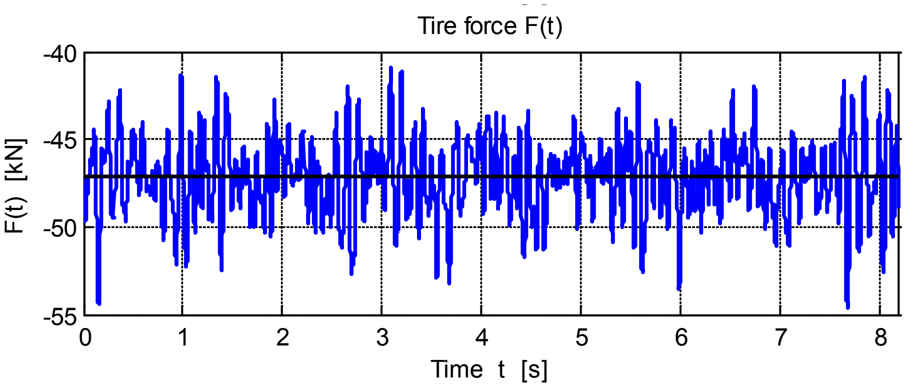

Figure 17. Random road profile, $S_h(\Omega_0) = 4\times10^{-6}$ m^2/(rad/m)

The movement of the vehicle along the road profile with the velocity $V = 36$ km/h has been numerically simulated. The results of the solution can be presented in the time or in the frequency domain. As an example, the tire force under the rear wheel of the rear axle $F_8(t)$ is presented in the *Figure 18*.

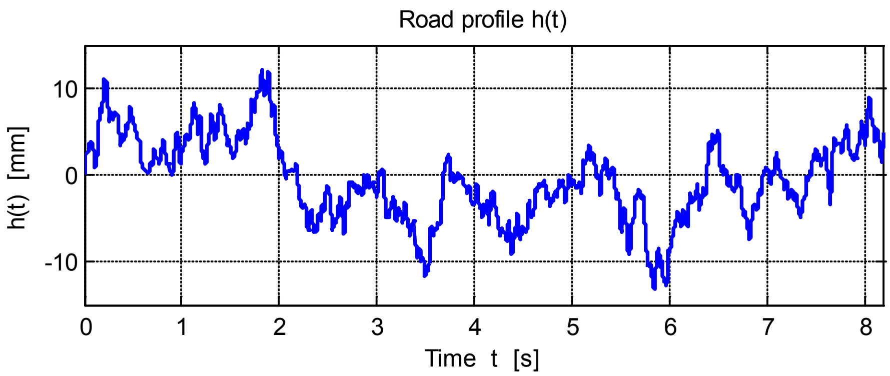

Figure 18. Tire force under the rear wheel of the rear axle $F_8(t)$

Similar results can be obtained for various road profiles and for various speeds of the vehicle motion. The decrease of the quality of the road profile results in the increasing values of the tire forces. In the Table 1 the ranges of the road profile $\Delta h = h_{max} - h_{min}$ and the corresponding ranges of the tire forces $\Delta F = |F_{max}| - |F_{min}|$ are introduced.

Table 1. Ranges of road profiles and tire forces for various road categories

Road category	$S_h(\Omega_0)$ [m^2/(rad/m)]	$\Delta h = h_{max} - h_{min}$ [mm]	$\Delta F = \|F_{max}\| - \|F_{min}\|$ [kN]
A	1×10^{-6}	12.6190	6.8160
B	4×10^{-6}	25.2380	13.6500
C	16×10^{-6}	50.4760	27.3749
D	64×10^{-6}	100.9519	54.5401
E	256×10^{-6}	201.9038	76.9016

At a certain road category, for example, at the category E, the tire forces are theoretically positive. In reality, the contact between the wheel and the road is lost, *Figure 19*. The wheel will bounce off the road and the impact will follow. It is a very bad situation not only for the pavement straining but also for the vehicle. So the quality of the road profile is the main factor within the process of the road maintenance.

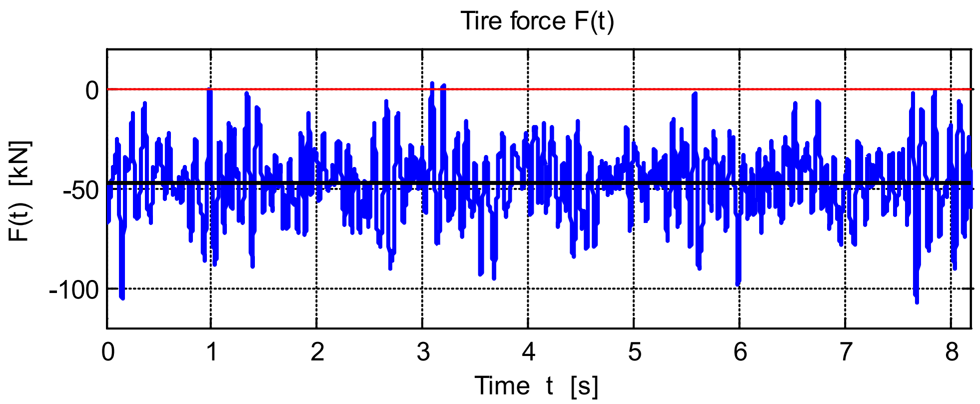

Figure 19. Time history of tire force $F_8(t)$ at the road category *E*

The solution can be carried out in the time domain, as shown above, or in the frequency domain. In the frequency domain, the frequency composition of vibration is interesting. It can be assessed, for example, through Power Spectral Density functions (PSD). The PSD function of the road profile informs us about the frequency composition of the road profile and the PSD of the tire force informs us about the frequency composition of the pavement load. The PSD of the road profile from *Figure 17* is plotted in *Figure 20* and the PSD of the dynamic component of the tire force from *Figure 18* is plotted in *Figure 21*. As we can see, in the frequency composition of the road profile the low frequencies dominate. In the frequency composition of the tire forces the frequencies in the interval from 6 to 12 Hz dominate. It relates to the natural frequencies of the vehicle.

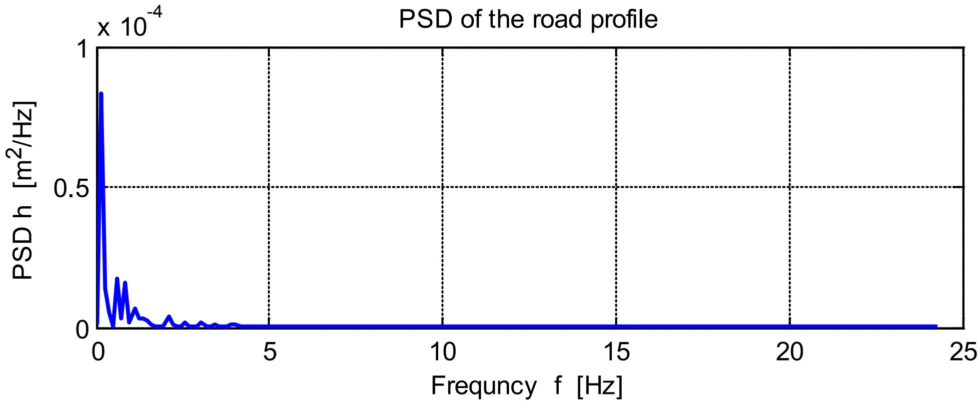

Figure 20. PSD of the road profile

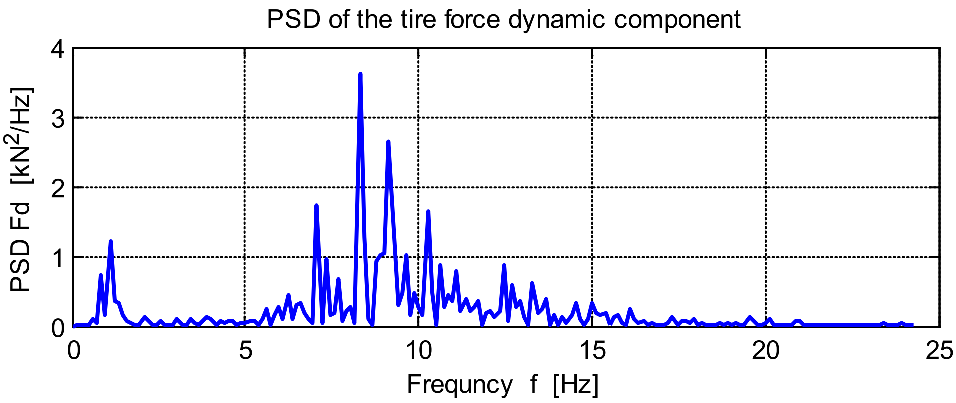

Figure 21. PSD of the dynamic component of tire force $F_8(t)$

5. Comparison of the slab and FEM computing models

The finite element computing model was created for such pavement as the model of the slab on the layer half space. The solved area is 20.4×14.7 m large. It is divided into 48×30 = 1 440 finite elements. The dividing of the structure into finite elements and the state of deformation at a certain time moment are shown in *Figure 22*.

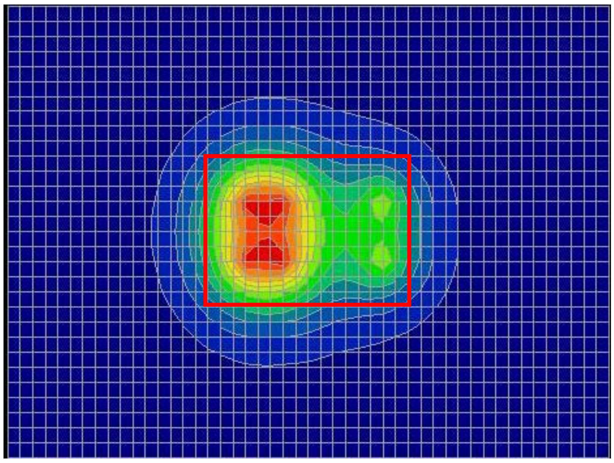

Figure 22. FE model of the slab on the layer half space

With respect to the fact that classical slab computing model on Winkler foundation gives the results in one point only, in the middle of the slab, the deflections in the middle of the slab are compared with the deflections in the middle of the FE modeled area. The comparison of the results in a graphic form is in Fig. 23. The green colour represents the results from the FE model of the slab on the layered foundation (FEM) and the blue colour shows the results from the classical slab model on Winkler foundation (CSM). The plotted curves have two local extremes. In the area of the 1st local extreme the difference of monitored values is Δw_1 = 0.00623 mm and in the area of the 2nd local extreme the difference of monitored values is Δw_2 = 0.00017 mm.

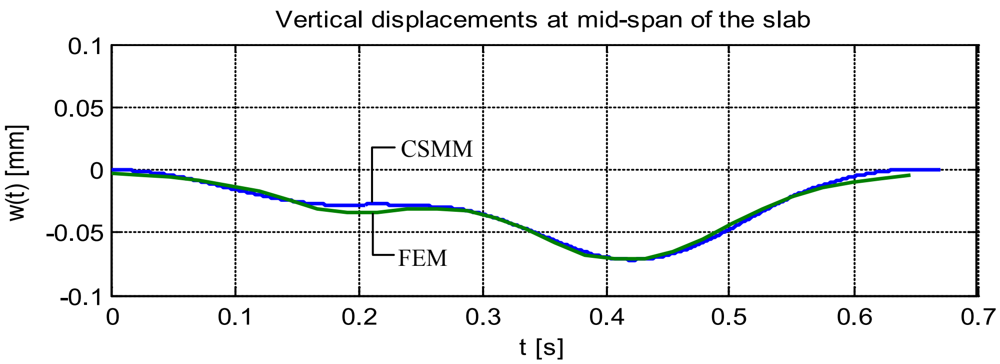

Figure 23. Comparison of the results of FEM and CSM

6. Conclusion

Vehicle – road dynamic interaction is a current engineering problem which can be analysed in a numerical or experimental way. The integral part of the numerical solution is the creation of computing models. The computing models of vehicles are usually created as discrete computing models described by the system of ordinary differential equations. For modelling the pavement structure, the finite element method is commonly used. But there are also other methods of solution. For simulation of the dynamic effect of moving vehicles, concrete pavements can be modelled as the slab on the elastic foundation.

When the stress-strain characteristics are analysed at one point only, for example, in the middle of the slab, the assumption about the shape of the slab deflection area can be adopted. On the basis of this assumption, a partial differential equation of the slab can be replaced by an ordinary differential equation. Such computing model enables us to analyze all kinematic values (displacement, velocity, acceleration) of the vehicle as well as the kinematic values at the monitored point of the slab and tire forces. Various parameters come into account. In this paper, there have been analyzed the influence of the velocity of the vehicle motion and the influence of stiffness characteristics (modulus of foundation, slab thickness). The deflections of the slab and the extremes of contact forces grow with the velocity of the vehicle motion. The influence of stiffness characteristics has the opposite tendency in comparison with the influence of the velocity of the vehicle motion. The deflections of the slab and the extremes of contact forces decline with the growing values of stiffness characteristics. When the slab has good surface without evident unevenness the influence of all parameters on the kinematic and force quantities is very small. A real road profile is usually not ideal. It has a stochastic character and represents the dominant source of the kinematic excitation of the vehicle. Deterioration of the road profile leads to the increase of pavement straining. The analysis in the time domain can be extended to the analysis in the frequency domain which informs us about the frequency composition of all monitored quantities.

Acknowledgements

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CYCLIC FRACTURE TOUGHNESS OF RAILWAY AXLE AND MECHANISMS OF ITS FATIGUE FRACTURE

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The main regularities in fatigue fracture of the railway axle material – the OSL steel – are found in this paper. Micromechanisms of fatigue crack propagation are described and systematized, and a physical-mechanical interpretation of the relief morphology at different stages of crack propagation is proposed for fatigue cracks in specimens cut out of the surface, internal and central layers of the axle.

Keywords: fatigue, fracture, mechanisms of damage, stress-strain state, railway axle

1. Introduction

During the analysis of the effect of the loading cycle stress ratio on fracture toughness of materials, an increase in the loading cycle stress ratio in case of positive asymmetries causes a decrease in the stress amplitude necessary to ensure a certain crack propagation rate (Carlson and Kardomateas, 1994). However, in case of negative asymmetries, the crack propagation mechanism is more complex, and the results of previous years indicate that it is necessary to consider the effect of compressive stresses on the fatigue crack propagation mechanism.

It is known that the effect of the loading cycle stress ratio is connected with closure of the fatigue crack tip during its growth (Silva, 2005; Xiong *et al*., 2008; Zhang *et al*., 2010). In addition, during the construction of a kinetic diagram of fatigue fracture, the negative part of the loading cycle is, as a rule, neglected (ASTM E647-08e1, 2008). However, if we analyze the fatigue crack growth process at the macro- and meso- levels, the process of the crack face closure can influence the stress-strain state at the crack tip and change micromechanisms of its propagation (Plekhov *et al*., 2007; Panin *et al*., 2011). Moreover, it is established that in case of significant negative asymmetries the crack growth can be speeded up. In addition, there is certain ambiguousness in the influence of negative asymmetries of the loading cycle on the fatigue crack growth and fractographic parameters of the fracture surface. On the one hand, compressive strains cause crushing of the relief elements, however, the relief formations make impossible full closure of the crack tip, which might cause an increase in its growth rate. In previous papers, the authors used scanning electron microscopy, optical microscopy and a number of metallographic approaches to study the fatigue crack propagation mechanisms (Maruschak *et al*., 2013). This work allows using the well-established methods for the assessment of the fatigue crack propagation kinetics in the railway axle material at different distances from the surface, i.e. taking into account the technological and operating influence, which affects fracture toughness of the service-exposed steel (Varfolomeev *et al*., 2011; Yasniy *et al*., 2013).

The purpose of this work is to investigate the cyclic fracture toughness of the railway axle steel and the mechanisms of its fatigue failure in case of different loading cycle asymmetries.

2. Materials and research technique

Fracture toughness of the locomotive wheel-set axle material – the OSL steel – was determined using prismatic specimens with the central crack of $155 \times 25 \times 5$ mm. Specimens were cut in the longitudinal direction at a distance of 20, 50 and 81 mm from the center of the axle.

We designate specimens depending on their distance from the axle center as follows, Fig. 1:

- specimens cut at a distance of 20 mm (A);
- specimens cut at a distance of 50 mm (B);
- specimens cut at a distance of 81 mm (C).

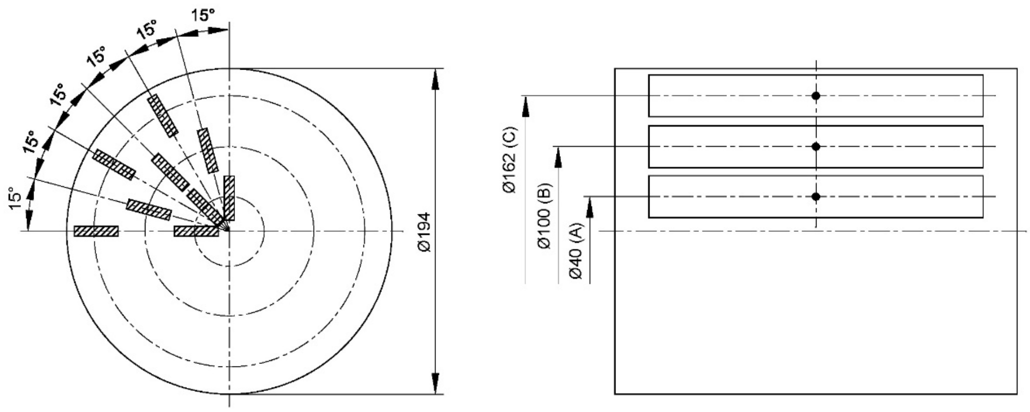


Figure 1. Scheme of cutting specimens with a central opening from locomotive axle at different distances from its surface (GOST 31334-2007)

The stress intensity factor for the prismatic specimen with the central crack was calculated from the following formula (ASTM E647-08e1, 2008):

$$K = \sigma \cdot \sqrt{\pi \cdot a} \cdot Y;$$

$$Y = \left(1 - 0.025 \cdot \left(\frac{2 \cdot a}{W}\right)^2 + 0.06\left(\frac{2 \cdot a}{W}\right)^4\right) \cdot \left(\sec\left(\frac{\pi \cdot a}{W}\right)\right)^{0.5},$$

where K is stress intensity factor; a is the half-length of the crack; W is the specimen width.

In addition, the range of the stress intensity factor was calculated following the recommendation of standard (ASTM E647-08e1, 2008):

$$\Delta K = \begin{cases} (1 - R) \cdot K_{\max} & \text{for } R \geq 0; \\ K_{\max} & \text{for } R < 0, \end{cases}$$

where $K_{\max}$ is the maximum stress intensity factor in the loading cycle; R is loading cycle stress ratio coefficient.

The experimental investigations were carried out under uniaxial tension with the loading cycle stress ratio coefficient $R = -1$ and $R = 0$. The loading frequency was $f = 10$ Hz, the form of the cycle was sinusoidal. The investigations were conducted at a room temperature using the STM-100 servo-hydraulic test setup with computer control and data logging. This setup allows monitoring the loading of test specimens using one channel with a simultaneous recording of measurements by six measurement channels using special software. The optical system based on the MBS-10 metallographic microscope was used for measuring the crack length.

Fracture surfaces with different SIFs were investigated on the REM-106I raster electron microscope in the secondary electrons mode with the following parameters: cathode voltage – 20–30 kV, current – 160–200 μA, focal distance – 9–15 mm. Specialized software KAPPA ImageBase was used for the quantitative analysis of the obtained images.

3. Macroregularities

Studying the effect of the loading stress ratio on the fatigue crack growth kinetics allows for a more precise definition of the residual life of railway axles and formulation of the physical background of diagnostics of the technical condition of the structure. It should be noted that under all the test temperatures the regularities of the fatigue failure of the OSL steel have the "classical view", Fig. 2.

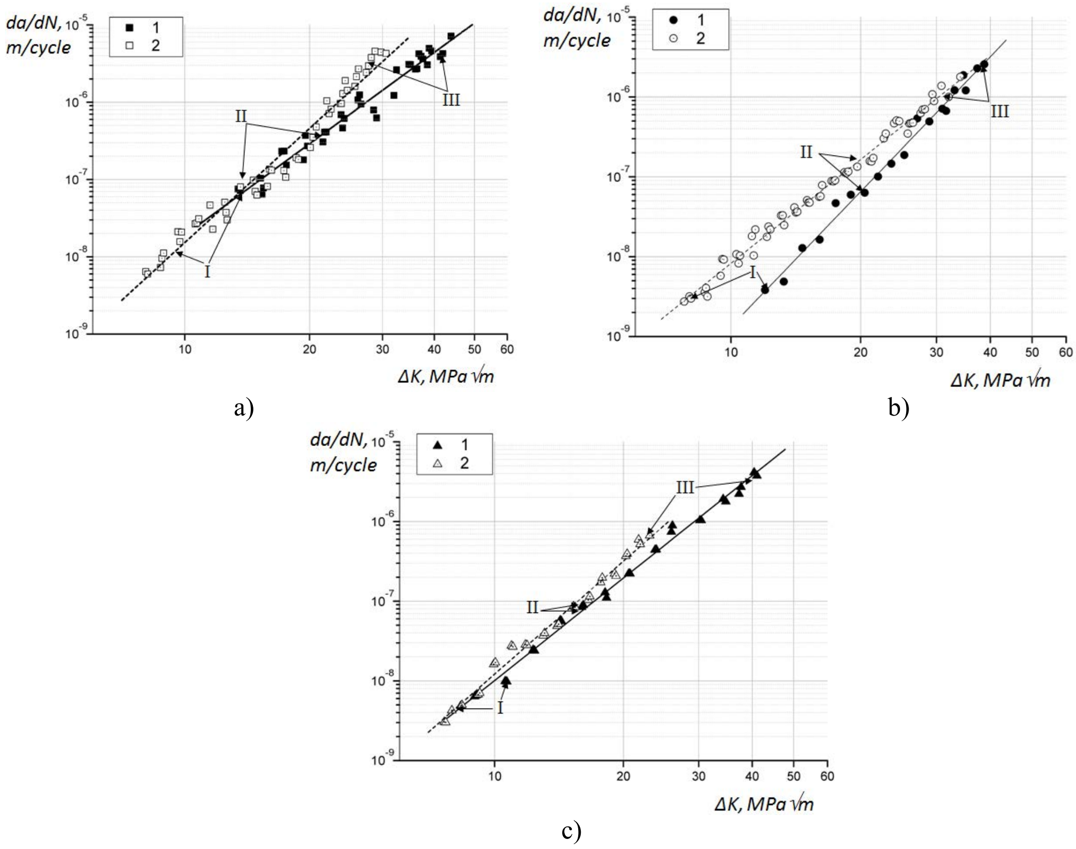


Figure 2. Kinetic diagrams of fatigue fracture of railway axle material cut at different distances from the axle center: a – 20 mm (A); b – 50 mm (B); c – 81 mm (C), under loading cycle stress ratio: 1 – $R = 0$; 2 – $R = –1$; I–III – points of fractographic analysis

Cutting zone A. The results of the investigations into the fatigue crack growth rate (FCGR) in coordinates *da/dN–ΔK* are presented in Fig. 2a. Arrows indicate the moments of conducting the fractographic microanalysis. In this case, the slope of the diagram describes the damage accumulation rate. It is found that the loading cycle stress ratio $R = 0$ and cyclic fracture toughness is 2–4 times lower than the stress ratio $R = –1$ within the SIF range from 20 to 35 MPa√m.

Cutting zone B. The results of the investigations into the FCGR in coordinates *da/dN–ΔK* are presented in Fig. 2b. It is established that at low values ΔK = 10 MPa√m under the loading cycle stress ratio $R = 0$, the cyclic fracture toughness is 8 times higher than at the stress ratio $R = –1$. However, this difference decreases gradually, and at ΔK = 30 MPa√m, the FCGR is the same for both asymmetries.

Cutting zone C. The results of the investigations into the fatigue crack growth rate (FCGR) in coordinates *da/dN–ΔK* are presented in Fig. 2c. The FCGR at ΔK = 10 MPa√m is practically the same, however, with an increase in the SIF excursion, the difference between the above values increases, and already at ΔK = 25 MPa√m the cyclic fracture toughness of the OSL steel under the loading cycle stress ratio $R = 0$ is 2–3 times lower than at the stress ratio $R = –1$.

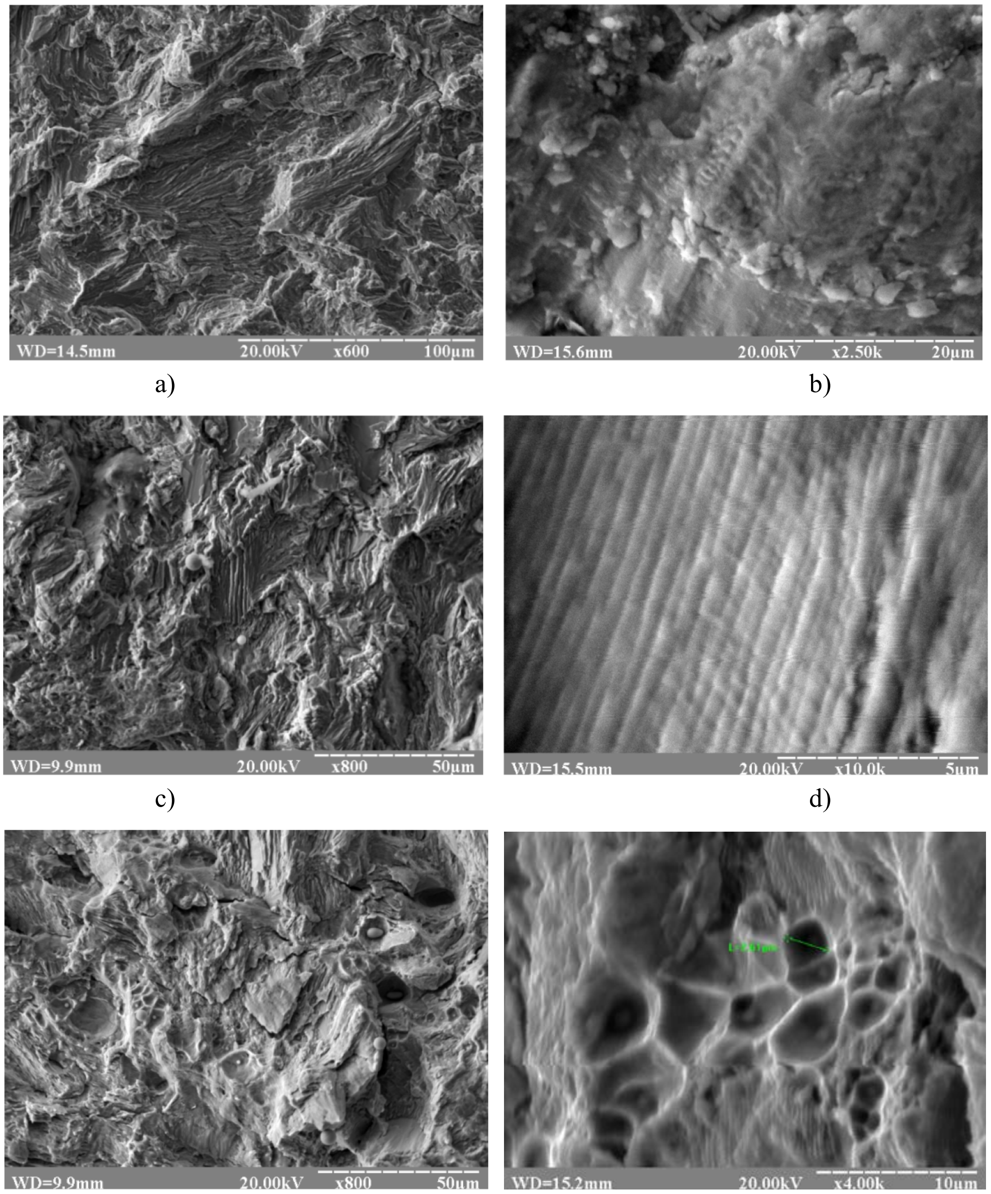
The above regularities indicate the ambiguous effect of the loading cycle stress ratio on the material cut out of various sections of the axle. In our opinion, this can be due to the effect of the structural and mechanical peculiarities of the OSL steel, when the cyclic fracture toughness depends in a complex way on the size and structure of the pearlitic grains and the nature of fracture of the pearlitic structures. In previous works, the complex character of the effect of differences in the dispersion, morphology and the cementite damage was found, as well as the effect of the dislocation hardening mechanisms of the ferritic component on the fracture mechanisms of the ferritic-pearlitic steels (Maruschak *et al*., 2013).

4. Effect of loading stress ratio on micromechanisms of fracture of the OSL steel

The qualitative and quantitative morphological analysis of the peculiarities of the fatigue crack propagation in the railway axle steel is performed.

Specimens A.

Load ratio *R* = 0. Fracture surface is formed by the ductile-brittle mechanism, Fig. 3a,b. Disoriented relief formations are noticeable on the fracture surface (*section I*). However, typical fatigue striations with quite a large step of 1 μm were observed on individual surfaces.



a) b)

c) d)

e) f)

Figure 3. Micromechanisms of fatigue crack growth in the OSL steel in case of loading cycle stress ratio $R = 0$ (a–e) and $R = -1$ (points of fractographic analysis are shown in Fig. 2a)

The specimen surface (*section II*) is fragmented heavily, therefore, we can speak only about the macrodirection of crack propagation. In addition, there is no general crack propagation area at the macrolevel. The crack front moved from one octahedral area to another, forming terraces and steps, due to which the terrace acquired a curvilinear trajectory, Fig. 3c. It should be noted that due to a complex stress state in the cyclic plastic zone in front of the crack tip, the direction of the lines of fatigue striations differ significantly in the neighboring structural elements, Fig. 3c, since the fatigue crack propagates locally in the direction with the minimal fracture energy (Maruschak *et al.*, 2012; Shaniavski *et al.*, 2004).

The fatigue crack growth within *section III* determined the transition of deformation mechanisms to the macroscale level and an increase in the FCR rate. An increase in the crack length had practically no effect on the crack propagation mechanism, only the share of ductile separation was increasing, and the striation mechanism disappeared gradually, Fig. 3d. At high propagation rates and within the zone of static rupture of the specimen material, a typical dimple failure was observed, and some inclusions of the circular and oblong shape were noticeable at the bottom of individual dimples, Fig. 3e. The crack growth mechanisms acquire ductile character, which preconditions the increased strain localization and the effect of rotational plasticity. An increase in the level of plastic deformation causes the localization of plastic strains in the vicinity of the microstructure elements: inclusions, subgrain boundaries, microfailure and separation of coherent links between inclusions and the matrix, which explains the formation of the local zones of dimple separation. In case of a "long" crack, local "tears" of the specimen material were observed at the ends of secondary microcracks, the formation of which was accompanied by shear strains (Shanyavskiy, 2013). Crack propagation is accompanied by the activation of secondary cracking and branching of the main crack.

With an increase in the crack length, the influence of inclusions and disperse particles on the fatigue crack propagation mechanisms increases. Large separation dimples, which were formed due to separation of inclusions from the matrix, are noticeable on the fracture surface, Fig. 3f. Significant strains along the body and within the grains facilitate the development of the plastic zone at the crack tip, thus speeding up failure processes and causing the formation of individual microcracks, which then coalesce with the main crack. The traces of such coalescence create scars on the fracture surface.

Load ratio *R* = –1. Failure of the material took place by the mechanisms similar to stress ratio $R = 0$. The crack propagated in the non-uniform manner, fracture had a ductile-brittle character, Fig. 3a,b. It should be noted that the front of the fatigue crack penetration (*section I*) is fragmented heavily, it is covered with terraces and "steps". This indicates the activation of shear processes within the pearlitic grains (Maruschak *et al.*, 2013; Shanyavskiy and Burchenkova, 2013).

The fracture morphology (*section II*) indicates strength and plasticity of the material. The fracture surface is formed by the "corrugated" relief, Fig. 3c, which is located at different angles relative to the crack propagation direction, the striations are located on the surfaces of terraces, Fig. 3d. The crack front propagated in the non-uniform manner, which indicates strain localization within certain sections of the materials.

Well-developed sections of crushing of the fracture surface were observed, Fig. 3e, which indicates the crack closure. However, like in the previous case, the crack propagated by the striation mechanism, which then changed into the mixed one and had a ductile character within the pre-failure zone (*section III*), Fig. 3f.

Specimens B.

***R* = 0.** Smoothed out facets with traces of the intragranular multiple sliding were observed (*section I*). In addition, stepwise disoriented relief formations covered with fatigue striations were found, Fig. 4a. However, even within individual facets, the orientation of striations was not permanent. The facets of the intragranular failure are covered with striations, which alternate with the split pearlitic grains, whose failure took place by means of spalling across the crack of the cementite plate, Fig. 4b. Moreover, fatigue striations are the only acting mechanism of crack propagation (*section II*). With an increase in the stress intensity factor, the facets lose the expressed ductile-brittle manifestations and acquire the "smoothed-out" shape, which, in our opinion, is the confirmation of a more pronounced manifestation of plastic deformation of the material (dimensions of the plastic zone) at the crack tip, and an increased share of ductile separation on the fracture surface of the OSL steel (*section III*), Fig. 4e.

***R* = –1.** A decrease in the fatigue crack propagation rate at the loading cycle stress ratio $R = -1$ compared to R = 0 is due to the crack branching processes in the pearlitic grains and local blunting of the crack tip in the ferritic component (*section I*), Fig. 4c. Moreover, the formation of facets and separation of the pearlitic grains was observed, Fig. 4d (*section II*). Therefore, an increase in the active loading time during the specimen loading did not ensure the accumulation of structural damage, however, it contributed to the activation of the relaxation processes in the material and, correspondingly, a decrease in the FCG rate. It should be noted that the size of microbranching was less than that of the ferritic grains, which hampered the crack propagation during its growth through the pearlitic grains. Moreover, the fragmentation and milling of the cementite plates took place in the pearlitic grains.

However, with an increase in the size of the pearlitic zone, greater volumes of the material become involved in the deformation process, which preconditions an increase in the intensity of the structural defect accumulation in the grain conglomerates (*section III*). In addition, the crack propagation mechanisms at different asymmetries become more similar, which is depicted on the kinetic curve (Wawszczak and Kurzydłowski, 2009).

Specimens C

During fractographic investigations it was found that the fracture relief morphology of the specimens tested at different loading asymmetries is similar (*sections I* and *II*). The influence of the pearlitic colonies on the fatigue crack propagation kinetics was observed, which was depicted in the presence of the fatigue and ductile-brittle crack propagation sections on the surface, Fig. 5a. In our opinion, the pearlitic colonies, which are situated on the trajectory of the fatigue crack tip, cause the relaxation effects, Fig. 5a. However, an increase in the SIF causes an increase in the share of the ductile propagation of the crack, in particular, the dimple component, which causes a decrease in the size of the separation facets and the appearance of the ductile separation dimples (*section I, II*).

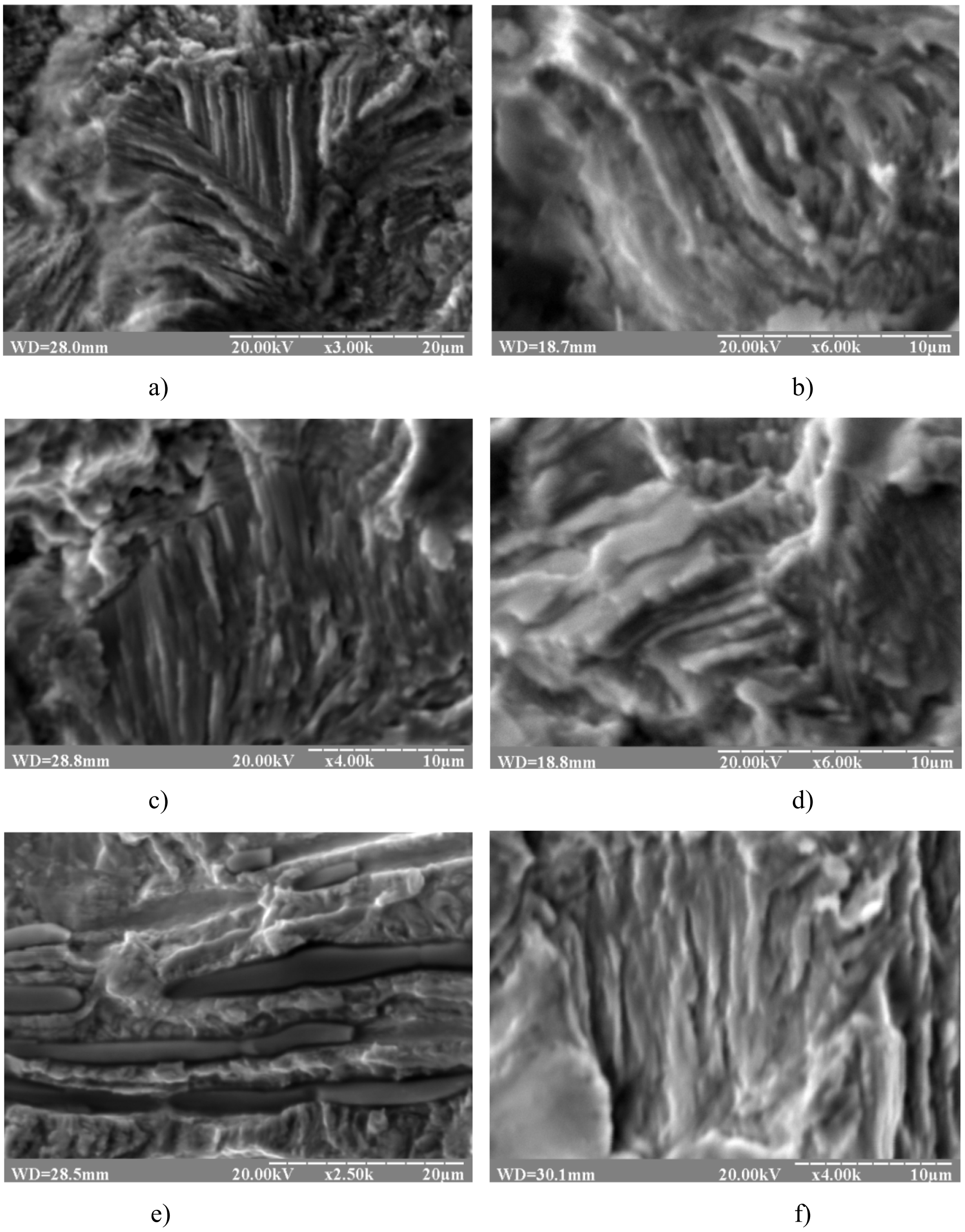
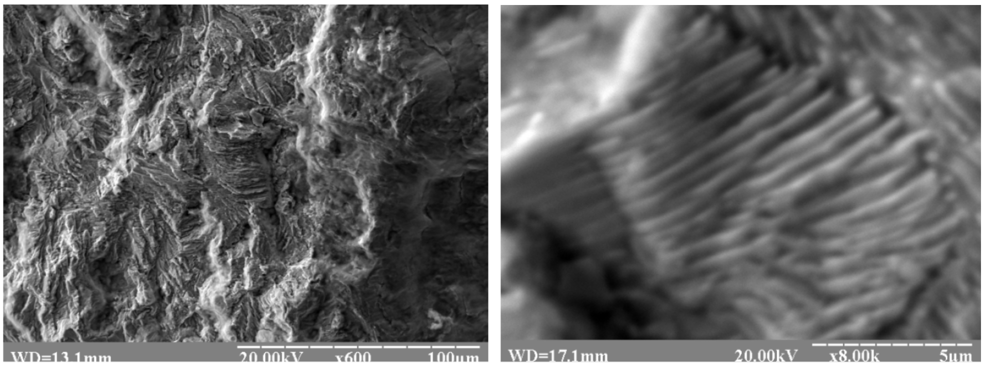


Figure 4. Micromechanisms of fatigue crack growth in the OSL steel in case of loading cycle stress ratio $R = 0$ (a–d) and $R = -1$

The fracture surface consists of numerous terraces decorated with the fragmentarily located series of striations, Fig. 5b. However, there are certain differences in the view of the terraces and “steps”, which are a little bigger than the stress ratio $R = -1$. At the same time, their geometry indicates that during crack propagation they created the local relaxation sections. This causes a decrease in the microrate of crack propagation (step of fatigue striations) on individual sections of the crack front, which was observed on the fracture surface.

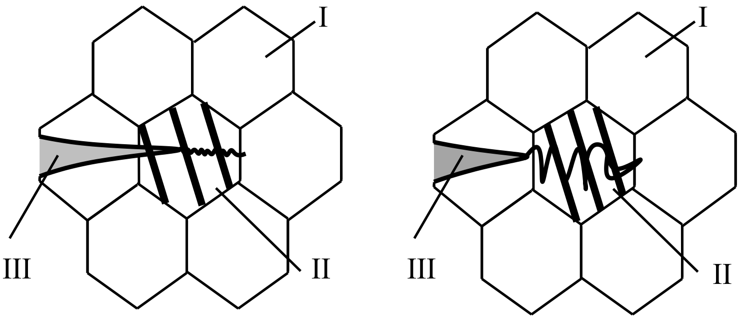


a) b)

Figure 5. Micromechanisms of fatigue crack growth in the OSL steel in case of loading cycle stress ratio $R = 0$

5. Influence of structural nonuniformity of material on its fracture toughness

The analysis of interrelation between the macro- and micromechanisms of fracture allows for a partial understanding of the crack closure effect at the stress ratio $R = -1$ on the ferritic-pearlitic steel OSL. The crack closure in case of compressive loading is not taken into account during the computation of the SIF excursion. However, it exists at the physical level, and its influence on the micromechanisms of crack propagation must be taken into account, Fig. 6.



a) b)

Figure 6. Physical regularities in crack propagation in specimens A, C (a) and B (b);
I – ferritic grain; II – pearlitic grain; III – crack

Based on the results of the fractographic investigations it was found that within the specimens cut out of the A, C zone, the fatigue crack propagation scheme was implemented, Fig. 6a. However, within the specimens cut out of the B zone, the mixed mechanism of crack propagation (fatigue + quasi-spalling) was observed, Fig. 6b.

The influence of the negative asymmetries during the fatigue crack propagation caused two main effects (Larijani *et al*., 2014; Elwazri *et al*., 2005) that were observed in our case:

- crushing of irregularities and an increase in the crack opening range;
- lack of crushing – a decrease in the fatigue crack propagation rate was observed.

Moreover, there are differences within the section of pre-failure and quasi-static rupture. For the specimen with $R = 0$, some empty dimples were found, whose shape is close to the particles of the disperse inclusions torn from the material. For the material tested at $R = -1$, "large" inclusions were found, which are located in the cavities that were formed around them during plastic deformation. These particles are one of the sources of the material anisotropy (Elwazri *et al*., 2005; Černý and Linhart, 2013). While creating the sections of the local plastic strains, they impede the passage of the crack front through them. As a result, the crack front "crushes" and gets covered with the disoriented terraces, Fig. 6b. Based on the experimental results, the values of the *C* coefficients and the *n* degree of the Paris equation for the loading cycle stress ratio $R = 0$ and $R = -1$ are found, Table 1.

The results obtained allow stating that the macro- and micro-regularities of the fatigue crack propagation in the wheel-set axle material depend on the material structure formed during the technological process of manufacturing (Levchenko *et al*., 2010). At the same time, the effect of cyclic loading and microlocalization of deformation processes in the material can be evaluated from the morphological peculiarities of fatigue fracture, Table 2.

Table 1. Cyclic fracture toughness parameters of the OSL steel used in wheel-set axle

R	Cutting distance	C, $\frac{m/cycle}{\left(MPa\sqrt{m}\right)^n}$	n
0	A	$2.26\cdot10^{-12}$	3.923
	B	$3.22\cdot10^{-15}$	5.615
	C	$5.34\cdot10^{-13}$	4.273
–1	A	$1.86\cdot10^{-13}$	4.911
	B	$3.87\cdot10^{-13}$	4.325
	C	$2.35\cdot10^{-13}$	4.710

Table 2. Generalized peculiarities of fatigue crack propagation in the OSL steel

R	Main fracture mechanisms of specimens cut out of different zones of cutting		
	A	B	C
0	Striation mechanism (clear-cut ordered striations); Facets of spalling; Separation dimples.	Facets of spalling; Facets of failure of pearlitic grains; Pseudo-striations.	Striation mechanism (clear-cut ordered striations).
–1	Striation mechanism (clear-cut ordered striations); Large facets of spalling decorated with striations.	Facets of spalling of pearlitic grains; Pseudo-striations; Fracture has a ductile-brittle view similar to quasi-static failure.	Striation mechanism (clear-cut ordered striations).

6. Conclusions

Using the approaches of fracture mechanics and physical mesomechanics the graded nature of the fatigue crack growth in specimens from the OSL steel with the central opening at the loading cycle stress ratio R = 0 and R = -1 is investigated. The fatigue crack growth kinetics at different stages of its propagation are found and described quantitatively.

For the specimens cut out of the center of the axle (A) at the loading cycle stress ratio R = 0, the cyclic fracture toughness is 2–4 times lower than at the stress ratio R = –1within the SIF range from 20 to 35 MPa√m. The cyclic fracture toughness of the specimens cut out of the middle layer of the axle (B) is 2–8 times higher at R = 0 than at R = –1, which is connected with a change of fracture mechanisms. If in the previous case the prevailing mechanism was the fatigue intragranular failure, in this case a significant effect was due to spalling of the pearlitic grains, which caused the crack branching. For the specimens cut out of the axle surface (C), the cyclic fracture toughness of the OSL steel at the stress ratio R = 0 is 1.5–2.5 times lower than at the stress ratio R = –1.

The microregularities of the fatigue crack propagation in the OSL steel are analyzed and generalized. At low SIF values, the specimen fracture surface is formed from terraces with the striation-like relief, and the share of the ductile (dimple) component increases with an increase in the crack length. The pre-failure zone of the specimen has features of the ductile failure followed by separation of inclusions from the material matrix and the formation of dimple relief.

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- **Publications:** over 500 scientific publications, including 30 books published in Springer and Russian editions, most of which is devoted to the study of the Black, Caspian, Aral and Baltic seas.
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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, volume 16, no. 2, 2015 (Abstracts)

Ščerba, M., Apeltauer, T., Apeltauer, J. Portable Telematic System as an Effective Traffic Flow Management in Workzones, *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 99–106.

Traffic infrastructure localities with temporal restrictions for example due to reconstructions, or modernization, are important aspects influencing the traffic safety and traffic flow. On the basis of our research, we can identify main factors, which generate travel time loses, and which often cause traffic accidents in bottlenecks. First of all, it is improper late merge, speeding, tailgating, lower tolerance and consideration to other road users. Nervousness and ignorance of drivers also play an important role in generation of traffic congestions, lower level of service and resulting external economic loses. One of the tools eliminating the traffic restriction negative impacts is usage of portable telematics systems. In 2011 to 2013,project ViaZONE was in progress, which was to design an intelligent system with the aim to eliminate the mentioned risks and reduce economic losses generated by traffic congestions. Using available data and information, we have proved profitability and cost-effectiveness of dynamic systems for traffic control of work zones. Regarding traffic management, the system showed some problems due to indisciplined drivers and the system proved that speeding in these hazardous road segments is a common practice which caused accidents and congestions

Keywords: Workzones, Traffic management, accident, congestion, detectors, portable variable message signs

Beifert, A. Air Cargo Development in the Regional Airports of the Baltic Sea Region Through Road Feeder Services, *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 107–116.

As issued in the Competition Policy Brief on the new state aid rules for a competitive aviation industry by the Competition Directorate–General of the European Commission in February 2014, it will be more difficult for unprofitable airports, to obtain financial public subsidies on EU, national or regional level. Although the positive impact of small airports on the regional development and general accessibility was mentioned, still the operating aid to the airports shall be cut out over a maximum of 10 years. It has been further stated that the vast majority of small and regional airports experience problems to cover their running operative costs, as a result from an intensive market competition and overlapping of airports' catchment areas preventing even some promising airports from growth. Public subsidies are mostly used by the airport management for infrastructural investments, to cover operating losses or to attract price-sensitive airlines. Herewith, among other things, the EU Commission is pointing out at the lack of cooperation structures and network strategies among the regional airports and at rather isolated and individual approach during elaboration of the airport development scenarios. However, the Competition Policy Brief permits public aid to regional airports, among other things if there is sufficient transports need to establish transition periods for small airports; the need for more flexibility of the regional airports in the remote areas has been underlined. The EU Commission is expecting herewith not to close the regional airports, but to stimulate them to operate on cost efficient and profitable basis, and that only the most inefficient airports will be closed.

To cope with the upcoming challenges the regional airports are demanded now to revaluate and reconsider their future development plans. While focusing on the passenger traffic many regional airports ignore or underestimate the benefits of the airfreight market. Although the air cargo has rather a low volume, but very high revenue yield part. Business internationalization is one of the important driving forces for the airfreight nowadays as well as decreasing air transport costs due to improving efficiency and growing competition among the air carriers. Most regional airports in the Baltic Sea region that act totally isolated, do not have a clear picture of the current situation on the international air cargo market, its future perspectives and sustainable development plans. Trying to meet the market demand, the regional airports are making huge and unjustified investments, e.g. improving airport infrastructure. It is not clear till now which elements of the Pan-Baltic cargo market could be managed as an alternative revenue yielding services for consolidated operation by air or what infrastructure is needed to provide the opportunity for an optimal economic mix of road-rail-air-sea transport? Nowadays, to a large degree air cargo traffic relies on scheduled, frequent passenger services in hub-and-spoke as well as in point-to-point traffic. Regional airports are presently suffering from a lack of scheduled uplift capacity. The volume currently transported by air in the regional airports is almost entirely based on the occasional charter flights. However, the growth of the air cargo business is likely to be based not only on cargo charters, but to a larger extend on truck-based services for transit shipments. Onward transportation by truck may occur on road feeder service, so called “flying trucks”, where a real truck substitutes a flight. “Flying trucks” are having flight numbers etc., therefore they must be prioritized in many ways in the BSR transport policy.

This paper investigates the role of Road Feeder Services concept (thereafter named here as “Flying Truck”) as an optional freight value proposition for the development of the regional airports and their possible participation in the air cargo market as a supplement instrument to generate additional revenue, thus making the airports more profitable and attractive.

Keywords: Air cargo, Road Feeder Services (RFS), regional airports, multimodality, air-road concept

Kostianoy, A.G., Bulycheva, E.V., Semenov, A.V., Krainyukov, A. Satellite Monitoring Systems for Shipping and Offshore Oil and Gas Industry in the Baltic Sea, *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 117–126.

Shipping activities, oil production and transport in the sea, oil handled in harbors, construction and exploitation of offshore oil and gas pipelines have a number of negative impacts on the marine environment and coastal zone of the seas. In 2004-2014 we elaborated several operational satellite monitoring systems for oil and gas companies in Russia and performed integrated satellite monitoring of the ecological state of coastal waters in the Baltic, Black, Caspian, and Kara seas, which included observation of oil pollution, suspended matter, and algae bloom at a fully operational mode. These monitoring systems differ from the existing ones by the analysis of a wide spectrum of satellite, meteorological and oceanographic data, as well as by a numerical modeling of oil spill transformation and transport in real weather conditions. Our experience in the Baltic Sea includes: (1) integrated satellite monitoring of oil production at the LUKOIL-KMN Ltd. D-6 oil rig in the Southeastern Baltic Sea (Kravtsovskoe oil field) in 2004-2014; (2) integrated satellite monitoring of the “Nord Stream” underwater gas pipeline construction and exploitation in the Gulf of Finland (2010-2013); (3) numerical modeling of risks of oil pollution caused by shipping along the main maritime shipping routes in the Gulf of Finland, the Baltic Proper, and in the Southeastern Baltic Sea; (4) numerical modeling of risks of oil pollution caused by oil production at D-6 oil rig and oil transportation on shore via the connecting underwater oil pipeline.

Keywords: the Baltic Sea, oil pollution, satellite monitoring, shipping, oil and gas pipelines, environmental risk assessment, numerical modeling

Ondruš, J., Hockicko, P. Braking Deceleration Measurement Using the Video Analysis of Motions by SW Tracker**,** *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 127-137.

This contribution deals with the issue of car braking, particularly with the one of M1 category. Braking deceleration measurement of the vehicle Mazda 3 MPS was carried out by the declerograph XL Meter^{TM} Pro. The main aim of the contribution is to perform comparison of the process of braking deceleration between the decelograph and the new alternative method of video analysis and to subsequently examine these processes. The test took place at the Rosina airfield, the airstrip in a small village nearby the town of Žilina. The last part of this paper presents the results, evlauation and comparison of the measurements carried out.

Keywords: braking deceleration, braking time, braking distance, analysis, decelograph XL Meter^{TM} Pro, SW Tracker

Andrejszki, T., Torok, A., Csete, M. Identifying the Utility Function of Transport Services from Stated Preferences, *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 138–144.

The aim of this study was to analyze the modal shift of passengers by analyzing their preferences. If the preferences of passengers are known it is possible to build up mathematically their utility function. This is the statistically correct way to simulate the modal shift of the investigated area. To capture the preferences of passengers stated preference method was used in online questionnaire. Five key factors were identified (from the point of passengers): travel cost, travel time, comfort, safety and environmental efficiency. In order to decrease the number of questions three levels were predefined these three questions made the base of the choice model. Every replier got three alternatives and they were told to choose the best for themselves. From the results of the questionnaire the formulas and the parameters of the mode choice utility function was derived. With the help of statistical sample an exponential utility function showed the best matching. For the validation process a probability model was set up to be compared to the proportions of the utilities. With this utility function it is possible to handle the changes in possible future transport services. Based on the introduced statistical approach the described method can be used to identify the effect of transport modes on regional development and tourism. The revealed utility function can help to develop proper regional development plans.

Keywords: Stated preference; Utility function; Modal shift; transport and tourism

Lajčáková, G., Melcer, J. Numerical Simulation of Moving Load on Concrete Pavements, *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 145–157.

The knowledge of the development with time of the strain and stress states in pavement structures is needed in the solution of various engineering tasks as the design fatigue lifetime reliability maintenance and structure development. The space computing model of the truck TATRA 815 is introduced. The pavement computing model is created in the sense of Kirchhof theory of the thin slab on elastic foundation. The goal of the calculation is to obtain the vertical deflection in the middle of the slab and the time courses of vertical tire forces. The equations of motion are derived in the form of differential equations. The assumption about the shape of the slab deflection area is adopted. The equations of the motion are solved numerically in the environment of program system MATLAB. The dependences following the influence of various parameters (speed of vehicle motion, stiffness of subgrade, slab thickness, road profile) on the pavement vertical deflections and the vertical tire forces are introduced. The results obtained from the plate computing model are compared with the results obtained by the FEM analysis. The outputs of the numerical solution in the time domain can be transformed into a frequency domain and subsequently used to solve various engineering tasks.

Keywords: numerical simulation, moving load, computing models, concrete pavements, dynamic, tire forces

Sorochak, A., Maruschak, P., Prentkovskis, O. Cyclic Fracture Toughness of Railway Axle and Mechanisms of Its Fatigue Fracture, *Transport and Telecommunication*, vol. 16, no. 2, 2015, pp. 158–166.

The main regularities in fatigue fracture of the railway axle material – the OSL steel – are found in this paper. Micromechanisms of fatigue crack propagation are described and systematized, and a physical-mechanical interpretation of the relief morphology at different stages of crack propagation is proposed for fatigue cracks in specimens cut out of the surface, internal and central layers of the axle.

Keywords: fatigue, fracture, mechanisms of damage, stress-strain state, railway axle

TRANSPORT and TELECOMMUNICATION, 16. sējums, Nr. 2, 2015 (Anotācijas)

Ščerba, M., Apeltauer, T., Apeltauer, J. Portatīvā telemātikas sistēma kā efektīva satiksmes plūsmas vadība darbības zonās, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 99.–106. lpp.

Satiksmes plūsmas infrastruktūras apvidos ar pagaidu ierobežojumiem, kā, piemēram, rekonstrukcijas vai modernizācijas dēļ, ir svarīgs aspekts satiksmes drošības un satiksmes plūsmas ietekmēšanai. Uz mūsu pētījumu pamata mēs varam identificēt galvenos faktorus, kuri veido laika zaudējumus pārvietošanas laikā un , kas bieži izraisa satiksmes negadījumu vietās kur ir mazāka mašīnu caurbraukšanas spēja. Pirmkārt tā ir nepareiza rāvējslēdzēja principa izmantošana, noteikto ātruma ierobežojumu pārsniegšana, distances neievērošana, zems tolerances līmenis un citu satiksmes dalībnieku apzināšana. Vadītāju nervozitāte un ceļu satiksmes noteikumu nezināšana arī spēlē svarīgu lomu sastrēgumu veidošanā, zems servisa līmenis rezultātā veido ārējos ekonomiskos zaudējumus. Viens no darbarīkiem satiksmes ierobežojumu negatīvās ietekmes likvidācija ir portatīvās telemātikas sistēmas izmantošana. 2011. gadā līdz 2013. gadam ViaZONE projekts bija progresā, lai konstruētu inteliģentu sistēmu, kuras mērķis likvidēt minētos riskus un samazināt ārējos ekonomiskos zaudējumus, kuri ir radušies sastrēgumu rezultātā. Izmantojot pieejamos datus un informāciju, mēs esam pierādījuši rentabilitāti un ienesīgumu dinamiskajai sistēmai satiksmes kontrolei darbības zonās. Attiecībā uz satiksmes vadību, sistēma parādīja dažas problēmas dēļ nedisciplinētajiem vadītājiem un sistēma pierādīja, ka noteikto ātrumu ierobežojumu neievērošana šajos bīstamajos ceļa posmos ir ierasta prakse, kas izraisa nelaimes gadījumus un sastrēgumus.

Atslēgvārdi: Darba zona, Satiksmes vadība, nelaimes gadījumi, sastrēgumi, detektori, portatīvās un mainīgās ziņojumu zīmes

Beifert, A. Gaisa kravas pārvadājumu attīstība Baltijas jūras reģiona lidostās ar aviokravas sauszemes piegādes pakalpojumiem, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 107.–116. lpp.

Kā noteikts Eiropas Komisijas Konkurences ģenerāldirektorāta Konkurences politikas apkopojumā 2014.februārī par jaunajiem valsts palīdzības noteikumiem konkurētspējīgas aviācijas industrijai, saņemt finansējumu ES, nacionālajā vai reģionālajā līmenī nerentablajām lidostām būs daudz sarežģītāk. Kaut gan ir atzīmēta nelielo lidostu pozitīva ietekme uz reģionālo attīstību un vispārējo pieejamību, tomēr operacionālā palīdzībai lidostām jābūt nogrieztai uz maksimums 10 gadiem.

Ziņojumā tālāk ir norādīts, ka intensīvās tirgus konkurences un lidostu zonu pārklāšanās dēļ mazajām un vidējām lidostām rodas problēmas savu operacionālo izdevumu segšanā, novēršot izaugsmi no dažām perspektīvajām lidostām. Valsts subsīdijas vairākumā izmanto lidostu vadība infrastruktūras investīcijām, lai segtu operacionālus zaudējumus vai lai piesaistītu aviosabiedrības, kas ir jutīgas pret cenu svārstībām. Ar šo, citu starpā, EK norāda uz sadarbības struktūru un tīklu stratēģiju trūkumu starp reģionālajām lidostām, kā arī norāda uz diezgan izolēto un individuālo pieeju, izstrādājot lidostu attīstības stratēģijas. Konkurences politikas apkopojums pieļauj valsts atbalstu reģionālajām lidostām, cita starpā, ja ir būtiska transporta nepieciešamība veidot pārejas periodu mazajām lidostām, tad ir uzsvērta vajadzība pēc lielākās elastības reģionālajam lidostām attālinātās teritorijās. ES Komisija ar šo sagaida ne reģionālo lidostu aizvēršanu, bet gan stimulēt tās darboties rentabli un uz izmaksu efektīva pamata, un tikai tad visneefektīvākās lidostas tiks slēgtas.

Lai tiktu galā ar tiem izaicinājumiem, kuri sagaida reģionālās lidostas, tās ir aicinātās jau tagad izvērtēt un izlemt par nākotnes attīstības plāniem. Kamēr daudzas lidostas fokusējas uz pasažieru pārvadāšanu, daudzas reģionālās lidostas ignorē vai nenovērtē gaisa kravas pārvadājumu priekšrocības. Kaut gan gaisa kravas pārvadājumiem ir diezgan zemi apjomi, bet sastāda diezgan lielu ieņēmumu daļu. Biznesa internacionalizācija šodien ir viens no virzītājspēkiem gaisa kravas pārvadājumiem, tāpat arī notiek gaisa transporta izmaksu samazināšana, efektivitātes paaugstināšanas un konkurences pieauguma rezultātā starp avio pārvadātājiem. Vairākumam reģionālajām lidostām Baltijas jūras reģionā, kas darbojas pilnīgi izolēti, nav skaidra priekšstata par situāciju starptautiskajā gaisa kravas pārvadājumu tirgū, par nākotnes perspektīvām un ilgtspējīgās attīstības plāniem. Mēģinot atbilst tirgus pieprasījumam, reģionālās lidostas veic lielas un nepamatotas investīcijas, piemēram, uzlabojot lidostas infrastruktūru. Līdz šim nav skaidrs, kurus elementus Pan-Baltijas kravas tirgū varētu pārvaldīt kā alternatīvu ienākumu gūšanas pakalpojumiem konsolidētajai darbībai pa gaisu vai kāda infrastruktūra ir nepieciešama, lai nodrošinātu pēc iespējas ekonomiski optimālu ceļa-dzelzceļa- gaisa-ūdens transporta kombināciju? Mūsdienās, lielā mērā gaisa kravu pārvadājumi balstās uz regulārajiem, biežiem pasažieru pārvadājumiem tīklā sistēmā, kā arī satiksme no viena punkta uz otru. Reģionālās lidostas pašlaik cieš no plānotas augšupejas spējas trūkuma. Apjoms, kas pašlaik tiek realizēts reģionālajās lidostās vairākumā ir balstīts uz neregulāriem čartera lidojumiem. Tomēr gaisa kravas biznesa izaugsme varētu būt balstīta ne tikai uz kravas čarteriem, bet arī uz lielākiem tranzīta sūtījumiem. Tālākie pārvadājumi ar kravas automašīnām, var parādīties avio kravas sauszemes piegādes pakalpojumos, t.s. "Lidojošās kravas mašīnas", kur kravas mašīnu aizstāj lidojums. "Lidojošajām kravas mašīnām" ir lidojuma numuri u.c., tāpēc tām jābūt prioritārām vairākos veidos BSR transporta politikā.

Šis darbs pēta avio kravas sauszemes piegādes pakalpojumu konceptu, kā (turpmāk - "Flying Truck") papildu kravas vērtības piedāvājumu reģionālo lidostu attīstībai, un to iespējama dalība gaisa kravas pārvadājumu tirgū kā papildus instrumentam ienākumu veidošanai, tādējādi pārveidojot lidostas par vairāk konkurētspējīgām un pievilcīgām.

Atslēgvārdi: Gaisa krava, Ceļu uzturēšanas pakalpojumi (RFS), reģionālās lidostas, multimodalitāte, gaisa ceļu koncepts

Kostianoy, A.G., Bulycheva, E.V., Semenov, A.V., Krainyukov, A. Satelītu monitoringa sistēma kuģniecības, ārzonas naftas un gāzes industrijai Baltijas jūrā, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 117.–126. lpp.

Kuģniecības aktivitātei, naftas ražošanai un transportēšanai jūrā, naftas apstrādāšanai ostās, ārzonas naftas un gāzes cauruļvadu sistēmu būvēšanai un izmantošanai ir negatīva ietekme uz jūras vidi un jūru krastu zonu. 2004. gadā līdz 2014. gadam mēs izstrādājām vairākas darbojošās satelīta monitoringa sistēmas naftas un gāzes kompānijām Krievijā un veicām integrēto satelītu monitoringu piekrastu ūdenim no ekoloģiskās puses Baltijas jūrā, Melnajā jūrā, Kaspijas jūrā un Karas jūrā, kas sevī iekļāva naftas piesārņojuma, suspendēto vielu un aļģu ziedēšanas novērošanu pilnā darbībā. Šīs monitoringa sistēmas atšķiras no jau esošajām ar plašu satelītu analizēšanas spektru: meteoroloģiskie un okeanogrāfiskie dati, kā arī numeroloģiskā modelēšana eļļas plankumu transformācija un transportēšana reālajos laika apstākļos. Mūsu pieredze Baltijas jūrā: (1) Integrēts satelīta monitorings naftas ražošanai LUKOIL – KMN Ltd. D – 6 naftas urbšanas tornī Dienvidaustrumu Baltijas jūrā (Kravtsovskas naftas atradnes) 2004-2014; (2) Integrēts satelīta monitorings „Ziemeļu straumes" zemūdens gāzesvada būvniecībā un izmantošanā Somu līcī (2010-2013); (3) Naftas piesārņošanas skaitliskais monitorings, kas tiek izraisīts kuģniecības dēļ gar galvenajiem kuģniecības ceļiem Somu līcī, Baltijas jūras pamatdaļā, Dienvidaustrumu Baltijas jūrā; (4) Naftas piesārņojuma, kas ir izraisīts naftas ražošanas dēļ D – 6 naftas urbšanas tornī un naftas transportēšanas piekrastē caur savienošanu ar zemūdenes eļļas cauruļvadu, risku skaitliskā modulācija.

Atslēgvārdi: Baltijas jūra, naftas piesārņojums, satelītu monitorings, naftas un gāzes cauruļvadu sistēmas, vides risku novērtēšana, numeroloģiskā modelēšana

Ondruš, J., Hockicko, P. Bremzēšanas palēnināšanas mērīšana, izmantojot kustības video analīzi ar zemfrekvences sistēmu, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 127.-137. lpp.

Šajā darbā ir aplūkots jautājums par mašīnas bremzēšanu, īpaši par M1 kategoriju. Bremzēšanas palēnināšanas mērīšana uz mašīnas Mazda 3 MPS bija veikta deleogrāfs XL Meter^{TM} Pro. Galvenais mērķis bija salīdzināt bremzēšanas palēnināšanas procesu starp decelogrāfu un jaunu alternatīvu metodi, kas ietver video analīzi, beigās izpētot šo procesus. Tests tika veikts Rosina lidlaukā, skrejceļā nelielā ciematā netālu no pilsētas Žilina. Šī darba pēdējā daļa prezentē mērījumu rezultātus, novērtējumu un salīdzinājumu.

Atslēgvārdi: bremzēšanas palēnināšana, bremzēšanas laiks, bremzēšanas distance, analīze, delogrāfs XL Meter^{TM} Pro, zemfrekvences sistēma

Andrejszki, T., Torok, A., Csete, M. Transporta servisu noteikto priekšrocību lietderības funkciju identificēšana, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 138.–144. lpp.

Šī pētījuma mērķis bija analizēt pasažieru transporta veidu maiņu, analizējot viņu vēlmes. Ja pasažieru vēlmes ir zināmas , tad ir iespējams matemātiski uzbūvēt viņu lietderības funkciju.

Šis paņēmiens ir statistiski pareizs, lai stimulētu transporta veidu maiņu pētījuma sektorā. Lai attēlotu pasažieru noteiktās priekšrocības, tika izmantota tiešsaistes aptauja. Tika identificēti pieci galvenie faktori (no pasažieru viedokļa): ceļojuma izmaksas, ceļojuma laiks, drošība un vides efektivitāte. Lai samazinātu jautājumu skaitu, tika noteikti trīs līmeņi, kuri noteica trīs jautājumus, kuri izveidoja pamata izvēles moduli. Katrs respondents saņēma trīs alternatīvus variantus, un viņiem vajadzēja izvēlēties vienu, kas viņiem der vislabāk. No anketēšanas rezultātiem tika iegūtas formulas un parametri izvēles lietderības funkcijai. Ar statistikas paraugu palīdzību eksponenciālā derīguma funkcija parādīja labāko saderību. Vērtēšanas procesam tika izveidots varbūtības modelis, lai varētu salīdzināt ar lietderības proporcijām. Ar šo lietderības funkciju ir iespējams paredzēt izmaiņas transporta pakalpojumiem tuvākajā nākotnē. Pamatojoties uz ieviesto statistisko pieeju, aprakstīto metodi var izmantot, lai identificētu transporta veida ietekmi uz reģionālo attīstību un uz tūrismu. Atklāta lietderības funkcija var palīdzēt izveidot attiecīgus reģionālās attīstības plānus.

Atslēgas vārdi: transporta veidu maiņa, transports un tūrisms, lietderības funkcija, noteiktās priekšrocības

Lajčáková, G., Melcer, J. Kustīgas slodzes skaitliskā simulācija uz betona seguma, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 145.–157. lpp.

Zināšanu attīstība par ar laiku betona segumu struktūras deformāciju un spriegumu ir nepieciešama, lai risinātu dažādus inženiertehniskus uzdevumus kā materiāla izturības kalpošanas laiks, uzturēšana un struktūras attīstība. Tiek ieviesta telpas datora modelis, izmantojot kravas mašīnu TATRA 815. Seguma datora modelis ir izveidots, izmantojot Kirhofa teoriju par plāno pamatu uz elastīga seguma. Aprēķinu mērķis ir sasniegt vertikālu novirzi pamata vidū un vertikālo riepu slodzes laika kursus. Kustības vienādojums ir iegūts no diferenciāla vienādojumu. Tiek pieņemts, ka plāksne ir ar izlieces zonu. Kustības vienādojumi tiek risināti ar programmas MATLAB palīdzību. Tiek ieviesti mainīgie, sekojot dažādu parametru ietekmei (transportlīdzekļa kustības ātrums, stinguma koeficients, plātnes biezums, ceļa veids). Iegūtie rezultāti no datora modeļa tiek salīdzināti ar FEM analīzes iegūtiem rezultātiem. Izskaitļotie rezultāti var būt transformēti frekvences jomā un izmantoti, lai risinātu dažādus inženiertehniskus uzdevumus.

Atslēgvārdi: skaitliskā simulācija, kustīga slodze, modelēšana, betona segumi, dinamika, riepas slodze

Sorochak, A., Maruschak, P., Prentkovskis, O. Dzelzceļa ass cikliskā lūzuma stingrība un nodiluma plaisas mehānisms, *Transport and Telecommunication,* 16. sējums, Nr. 2, 2015, 158.–166. lpp.

Dzelzceļa ass nodiluma plaisas materiāla OSL metāla galvenās likumsakarības ir atrodamas šajā rakstā.

Nodiluma plaisas pavairošanas mehānisms ir aprakstīts un sistematizēts, tiek ierosināta fiziski-mehāniskās interpretācijas glābšana morfoloģija dažādajiem posmiem plaisu nodiluma pavairošanā plaisu paraugiem, kas izgriezti no iekšējās un centrālās ass.

Atslēgvārdi: nodilums, plaisa, bojājumu mehānisms, stresa deformācijas stāvoklis, dzelzceļa ass

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1. Gibson, E.J. (1977) The performance concept in building. In: *Proceedings of the 7th CIB Triennial Congress*, Edinburgh, September 1977. London: Construction Research International, pp. 129–136.
2. Kayston, M. and Fried, W. R. (1969) *Avionic Navigation Systems.* New York: John Wiley and Sons Inc.
3. Ministerial Council on Drug Strategy. (1997) *The national drug strategy: Mapping the future*. Canberra: Australian Government Publishing Service.
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5. Osgood, D. W., and Wilson, J. K. (1990) *Covariation of adolescent health problems*. Lincoln: University of Nebraska. (NTIS No. PB 91-154 377/AS).

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