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RELIABILITY EVALUATION OF THE CITY TRANSPORT BUSES UNDER ACTUAL CONDITIONS

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The purpose of this paper was to present a reliability comparison of two types of city transport buses. Case study on the example of the well-known brands of city buses: Solaris Urbino 12 and Mercedes-Benz 628 Conecto L used at Municipal Transport Company in Lublin was presented in details. A reliability index for the most failure parts and complex systems for the period of time failures was determined. The analysis covered damages of the following systems: engine, electrical system, pneumatic system, brake system, driving system, central heating and air-conditioning and doors. Reliability was analyzed based on Weibull model. It has been demonstrated, that during the operation significant reliability differences occur between the buses produced nowadays.

Keywords: reliability, Weibull model, city transport buses

1. Introduction

In municipal transport companies, vehicles reliability is a crucial parameter in the maintenance practice. Choosing the right type of the vehicle, which is adapted to specific operating conditions is very difficult. Currently, on the Polish market a large number of low-floor vehicles of diverse lengths and capacity, and with the accessories adapted to the needs of a particular transport company is offered. Literature shows that a lot of attention is paid to the problem of vehicles reliability. Many authors are professionally engaged in reliability modelling and defects analysis in the tested vehicles, including a.o.th. (Naikan and Kapur, 2006; Chukova, Attardi 2005; Arnold R. et al., 2004; Aksezer, 2011; Kleynera and Sandborn, 2005; or Gong, 2006).

Reliability is also an important parameter, used to evaluate the quality of the municipal transport companies. If there is a possibility to determine the type and the failure number of vehicles, as well as an estimation of the mileage between those failures, fleet readiness problems could be minimized or even eliminated (Majeske, 2007; Murthy et al., 2002; Pecht, 2006; Rymarz et al., 2013; Shafiee et al., 2013). The introduction of new types of vehicles entails knowledge of the operating characteristics of these vehicles. This is necessary not only to assess the suitability of different types of vehicles and determine their operating costs, but also to determine the type and number of components or the appropriate density of maintenance personnel (Grądzki et al., 2015).

Monitoring of operational suitability of vehicles and their main components, especially with separation of "weak points" (Gołąbek, 1993) are basis for rationalization of the technical services range, according to criterion of not exceeding acceptable levels of damage risk.

Selection of the reliability analysis method depends on the type of the analyzed technical object and the required accuracy of the estimate. The method should take into account all of the possible factors affecting the reliability of the analyzed system, and at the same time the simplest procedure for registration and calculation as possible (Matuszak, 2010).

2. Studies process

The study included 22 buses of Mercedes-Benz 628 Conecto LF and 20 buses of Solaris Urbino 12. All buses were observed from the first day of the operation (January 2009 for Mercedes-Benz and June 2008 for Solaris) to the 48 and 54 months for Mercedes and Solaris buses, respectively. The studies were conducted under natural conditions.

The analysis covered damages of the following systems: engine (US) (including engine, cooling and supply system), electrical system (UE), pneumatic system (UP), brake system (UH), driving system (UN) (including suspension and steering gear), central heating and air-conditioning (UOK) and doors (UD). Damages were recorded in the range of vehicle mileage failures occurrence. Reliability was analyzed based on Weibull model (Kleynera et al., 2005).

3. Study results

Figures 1 and 2 present frame charts of the failure-free operation of the selected structural systems, for Mercedes and Solaris buses, respectively. Median of the mileage between damages of the analyzed systems of both types of buses was calculated. Average mileage between damages for Mercedes buses for the central heating and air-conditioning, and doors was about 100 thousand km, for electrical system, engine and driving system was about 50 thousand km and for the pneumatic and brake system above 165 thousand km. In case of Solaris buses median mileage between damages was higher than for the Mercedes buses, and amounts respectively 165 thousand km for the driving system, 214 thousand km for the braking system, 110 thousand km for the brake system, 196 thousand km for the doors and 245 thousand km for heating and air-conditioning.

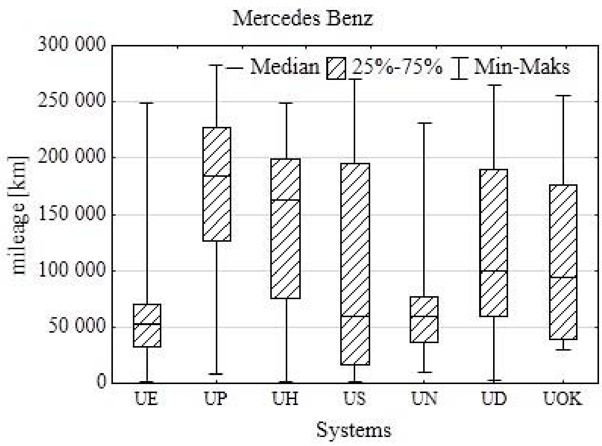

Figure 1. Box plots presenting failures occurrence of the selected Mercedes Benz buses systems: engine (US), electrical system (UE), pneumatic system (UP), brake system (UH), driving system (UN), central heating and air-conditioning (UOK) and doors (UD)

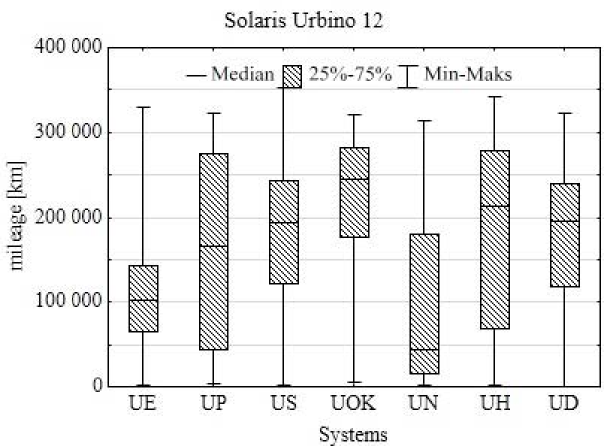

Figure 2. Box plots presenting failures occurrence of the selected Solaris Urbino buses systems: engine (US), electrical system (UE), pneumatic system (UP), brake system (UH), driving system (UN), central heating and air-conditioning (UOK) and doors (UD)

4. Reliability function analysis

In reliability evaluation a Weibull model was used. A parameter estimation of a two-parameter Weibull distribution was performed by a maximum likelihood method (Table 1) (Chukova et al., 2004; Kaplan, Meier, 1958). A shape parameter is equal to slope coefficient of the fitted regression line, whereas the scale parameter can be calculated as the quotient (intercept/slope). Nonparametric methods of this type are used a.m. in assessment of the expected warranty time of vehicles (Gong, 2006).

Different shape parameter values indicate a diversity of reliability distribution. In case of engine and doors for Mercedes buses and brake, driving and pneumatic systems for Solaris buses, the shape parameter value was below one, and it can be interpreted as a result of after production damages. In case of brake and pneumatic systems for Mercedes buses, the shape parameter value was close to unity. It indicates predominance of it means that there is a domination of misfortune damages. In case of driving system, where c=1.3981 and electrical systems c=1.4043 or central heating and air-conditioning c=1.4208 for Mercedes buses, and electrical system where c=1.6406 for Solaris buses, the shape parameter value was above one. It means that systems damages are a deciding factor for determined by operational wear of parts.

Table 1. Scale and shape parameters of a two-parameter Weibull distribution according to types of buses and their systems

Bus type	**Structural systems**	Shape parameter [c]	Scale parameter [b]
Mercedes Benz	all systems	1.1312	100 800
Solaris Urbino 12		1.3057	171 200
Mercedes Benz	engine (US)	0.81404	98 912
Solaris Urbino 12		1.2770	217 600
Mercedes Benz	brake system (UH)	1.1844	182 400
Solaris Urbino 12		0.84815	211 100
Mercedes Benz	driving system (UN)	1.3981	88 642
Solaris Urbino 12		0.81336	89 965
Mercedes Benz	electrical system (UE)	1.4043	67 541
Solaris Urbino 12		1.6406	127 600
Mercedes Benz	pneumatic system (UP)	1.1877	203 900
Solaris Urbino 12		0.87703	179 100
Mercedes Benz	central heating and air-conditioning (UOK)	1.4208	122 100
Solaris Urbino 12		1.1767	290 100
Mercedes Benz	doors (UD)	0.96552	134 500
Solaris Urbino 12		1.3422	222 000

The scale parameter (characteristic ability) indicates how long (mileage) 63.2% of the observed buses break down. For the pneumatic and brake system in both types of buses, more than 63% of buses have failed at mileage about 200 thousand km. For the driving system this was half of the value - 90 thousand km. In turn of the systems: central heating and air-conditioning, doors and engine 63.2% of the analyzed Solaris busses have more than two times longer mileage failsafe comparing to the Mercedes buses.

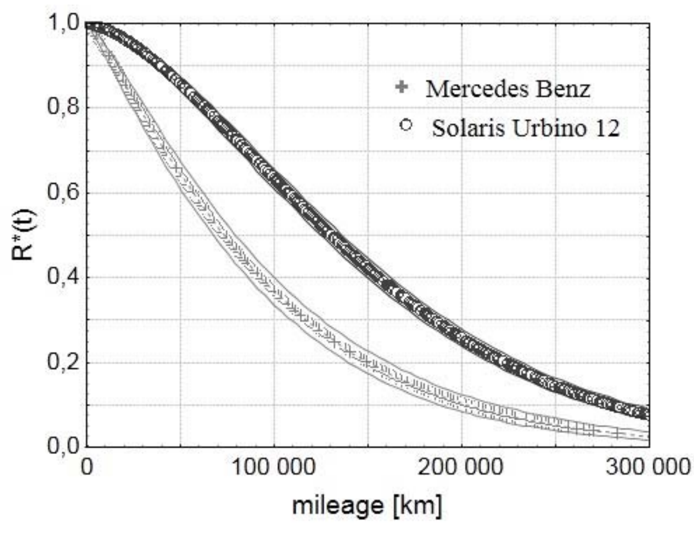

Figure 3. Reliability function diagram of all studied systems of Solaris Urbino and Mercedes Benz buses

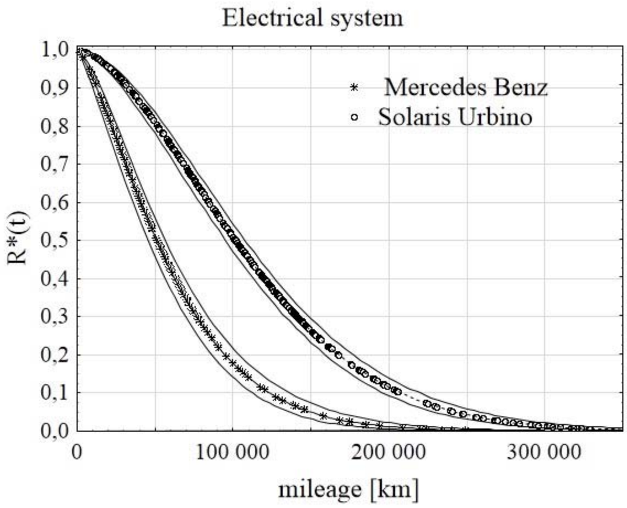

Figure 4. Reliability function diagram of the electrical system of Solaris Urbino and Mercedes Benz buses

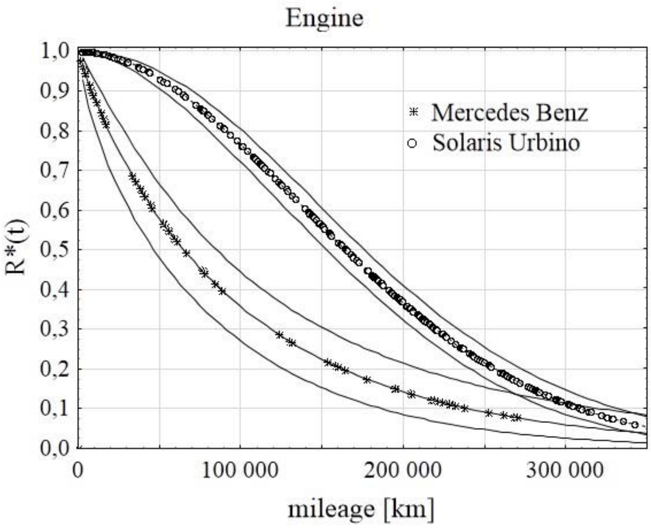

Figure 5. Reliability function diagram of the engine of Solaris Urbino and Mercedes Benz buses

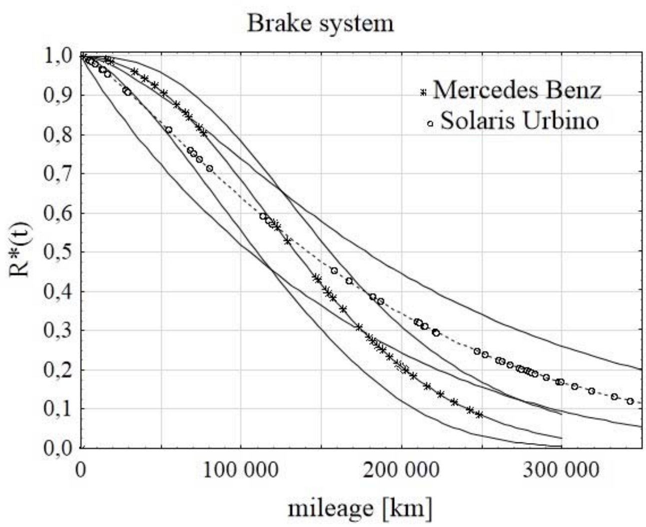

Figure 6. Reliability function diagram of the brake system of Solaris Urbino and Mercedes Benz buses

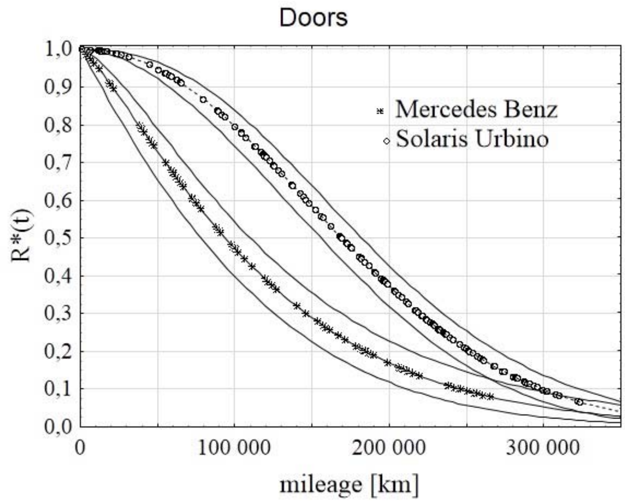

Figure 7. Reliability function diagram of the doors of Solaris Urbino and Mercedes Benz buses

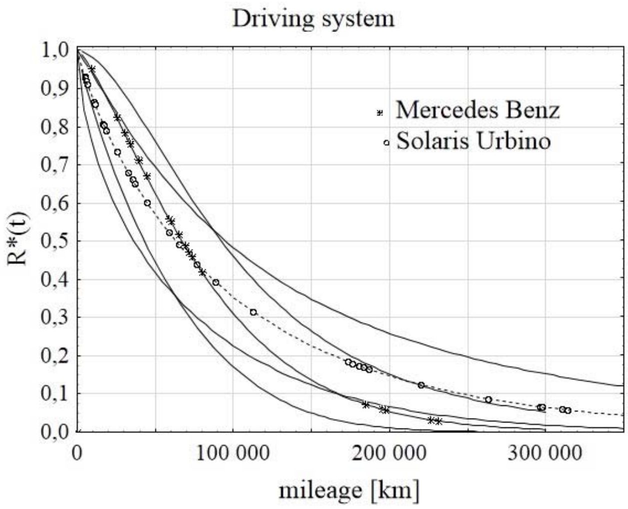

Figure 8. Reliability function diagram of driving system of Solaris Urbino and Mercedes Benz buses

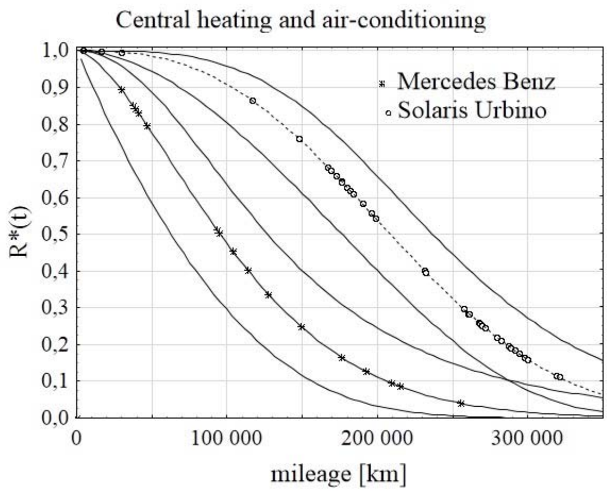

Figure 9. Reliability function diagram of the central heating and air-conditioning system of Solaris Urbino and Mercedes Benz buses

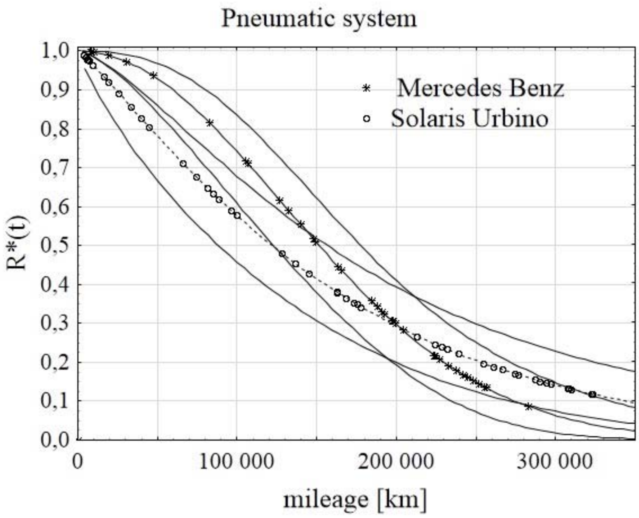

Figure 10. Reliability function diagram of the pneumatic system of Solaris Urbino and Mercedes Benz buses

A reliability analysis of all analyzed bus systems for Solaris and Mercedes buses according in relation to their operating mileage is presented in figure 3. A significant decrease in reliability of Mercedes buses began to appear after 28 thousand km (R*(t)=0.8), and after 100 thousand km reliability is just 0.37. However for Solaris buses respective level of reliability can be observed in the longer mileage R*(t)=0.8 with more than 63 thousand km, and R*(t)=0.37 is equal 164 thousand km. The graph also presents the line fitted to the data points. The boundary lines of the confidence interval of 95% are indicated.

Figures 4 -10 present the results of reliability analysis of all studied systems of Mercedes and Solaris buses. In case of the electrical system of Solaris buses the decrease in reliability occurs after the mileage of 51.6 thousand km (R*(t) = 0.8). The level of R*(t) = 0.5 is reached after 101 thousand km mileage. The level of R*(t) = 0.8 states at the mileage of 23 thousand km for Mercedes buses. In case of Mercedes buses in the first 51 thousand km mileage the reliability decreases half of the value. Similar tendency is observed in case of the driving system, where reliability R*(t) = 0.8 occurs at the mileage of 30 thousand km and 18 thousand km, respectively, for Mercedes and Solaris buses, and R*(t) = 0.5 after the mileage of 65 thousand km for both types of buses.

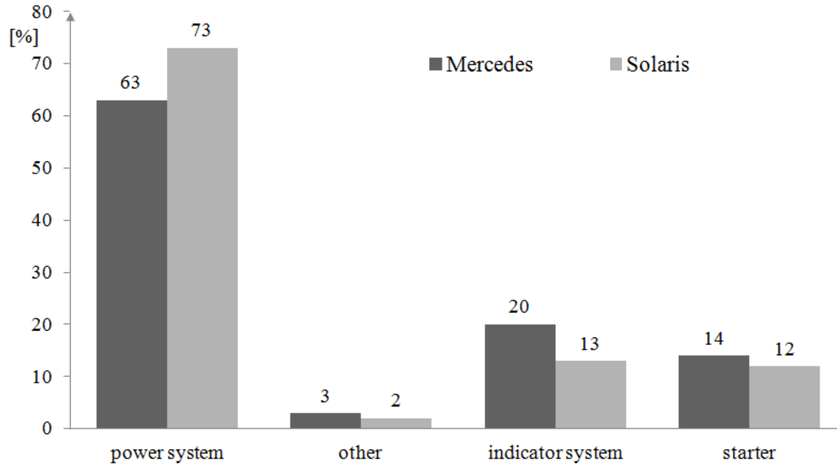

Figure 11. The failures percentage of individual components of the electrical system of Solaris Urbino and Mercedes Benz buses

The reliability analysis of the brake and pneumatic system of both types of buses decreases in the range of vehicle mileage. A slight decrease in reliability of Mercedes buses began to appear between 0-60 thousand km, and after 100 thousand km the reliability of Solaris buses is higher than in Mercedes.

The reliability results of the door and central heating and air-conditioning system of the Solaris buses show it's significant advantage over Mercedes buses. In case of the central heating and air-conditioning system the reliability level R*(t)=0.8 was observed at 47 thousand km mileage for Mercedes buses and at 136 thousand km mileage for Solaris buses.

A similar situation appears in case of the door system, where reliability decreases to the value of R*(t) = 0.8 after 38 thousand km and 95 thousand km for Mercedes and Solaris buses, respectively, and to the level of R*(t) = 0.5, after 91 thousand km and after 169 thousand km.

Figure 11 presents the failure percentage of the electrical system, where the number of failures is the highest from all of the analyzed systems. Failure of power system was responsible for about 70% of all failures, and indicator system just 20% and 13% for Mercedes and Solaris buses respectively. Other failures (alternator, starter and battery) constitute about 15% of all electrical system failures.

5. Conclusion

The article presents a reliability comparison of city transport buses on the example of Solaris Urbino 12 and Mercedes-Benz 628 Conecto LF at Municipal Transport Company in Lublin. The analysis covered damages of the selected construction systems. This analysis is used to better organized the operating system at Municipal Transport Company, so that the number of failures could be minimized.

Damages were recorded in the range of specific vehicle mileage. Each vehicle travelled on average 350 thousand km in the analyzed period (54 months of observation).

It can be said that Solaris buses stands out higher failures' mileage and higher total reliability in comparison to the Mercedes buses. Moreover, it has been shown, that the reliability of the various structural systems differs and depends on the brand of the bus. In case of the two analyzed brands the most unreliable systems were electrical system, engine and door mechanisms. However, the highest risk of failure was found in the case of driving system and central heating and air-conditioning system.

References

1. Aksezer, C. S. (2011) Failure analysis and warranty modelling of used cars. *Engineering Failure Analysis*, 18, 1520–1526. DOI: 10.1016/j.engfailanal.2011.05.009
2. Attardi, L., Guida, M., Pulcini, G. (2005) A mixed-Weibull regression model for the analysis of automotive warranty data. *Reliability Engineering and System Safety*, 87, 265–273. DOI: 10.1016/j.ress.2004.05.003
3. Bocchetti, D., Giorgio M., Guida M., Pulcini G. (2009) A competing risk model for the reliability of cylinder liners in marine Diesel engines. *Reliability Engineering and System Safety*, 94, 1299–1307. DOI: 10.1016/j.ress.2009.01.010
4. Chukova, S, Arnold, R, Wang, DQ. (2004) Warranty analysis: an approach to modelling imperfect repairs. *International Journal of Production Economy,* 89(1), 57–68. DOI: 10.1016/S0925-5273(03)00200-7
5. Gołąbek, A. (1993) *Niezawodność autobusów*. Wrocław: Wydawnictwo Politechniki Wrocławskiej
6. Gong, Z. (2006) Estimation of mixed Weibull distribution parameters using the SCEM-UA algorithm: Application and comparison with MLE in automotive reliability analysis. *Reliability Engineering and System Safety,* 91, 915–922. DOI: 10.1016/j.ress.2005.09.007
7. Grabski, F., Jaźwiński, J. (2009) *Funkcje o losowych argumentach w zagadnieniach niezawodności, bezpieczeństwa i logistyki*. Warszawa: *WKiŁ*
8. Grądzki, R., Lindstedt, P. (2015) Method of assessment of technical object aptitude in environment of exploitation and service conditions. *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, vol. 17, no. 1, 54-63. DOI: dx.doi.org/10.17531/ein
9. Kaplan, E.L., Meier, P. (1958) Nonparametric estimation from incomplete observations. *Journal of American Statistical Assocation*, 53, 457-481. DOI: 10.1080/01621459.1958.10501452
10. Kleynera, A., Sandborn, P. (2005) A warranty forecasting model based on piecewise statistical distributions and stochastic simulation. *Reliability Engineering and System Safety,* 88, 207–214. DOI: 10.1016/j.ress.2004.07.016
11. Majeske, K. D. (2007) A non-homogeneous Poisson process predictive model for automobile warranty claims. *Reliability Engineering and System Safety*, 92, 243–251. DOI: 10.1016/j.ress.2005.12.004
12. Matuszak, Z. (2010) Estimation of the availability of the power-propulsion and technological system of a fishing vessel at selected operational model. *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, vol. 45, no. 1, 49-58. DOI: dx.doi.org/10.17531/ein

13. Murthy, D.N.P., Djamaludin, I. (2002) New product warranty: A literature review. *International Journal of Production Economics,* 79, 231–260. DOI: 10.1016/S0925-5273(02)00153-6
14. Naikan, VNA, Kapur, S. (2006) Reliability modelling and analysis of automobile engine oil. *Journal of Automobile Engineering,* 220(2), 187–94. DOI: 10.1243/095440706X72637
15. Pecht, M. (2006) Establishing a relationship between warranty and reliability. *Electronics Packaging Manufacturing, IEEE Transactions,* 29(3), 184–90. DOI: 10.1109/TEPM.2006.881765
16. Rymarz, J., Niewczas, A., Pieniak, D. (2013) Reliability analysis of the selected brands of city buses at municipal transport company, *Journal of KONBiN* 2(26), 111-122. DOI: 10.2478/jok-2013-0087.
17. Shafiee, M., Chukova, S. (2013) Maintenance models in warranty: A literature review. *European Journal of Operational Research,* 229, 561–572. DOI: 10.1016/j.ejor.2013.01.017
18. Vališ, D., Žák, L., Pokora, O. (2015) Contribution to system failure occurrence prediction and to system remaining useful life estimation based on oil field data. Proceedings of the Institution of Mechanical Engineers, *Part O: Journal of Risk and Reliability*, vol. 229, no. 1, 36-45. DOI: 10.1177/1748006X14547789

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"BUS LANE WITHIN THE AREA OF INTERSECTION" METHOD FOR BUSES PRIORITY ON THE INTERSECTIONS

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The primary objective of this article is to formalize the "special bus lanes within the area of intersection" method that allows providing buses with space-time priority at signalized intersections (mostly of the isolated type), including those with no more than two traffic lanes in each direction at the approaches to the intersection. The article establishes the limits for efficient application of this method, and describes the results of a simulation experiment conducted in the VISSIM environment to investigate the functioning of the method on an actual intersection. The most critical phase of implementation of this method is to determine the optimum length of the special bus lane at the approach to the intersection. The optimum length of special bus lanes at the approaches to isolated or coordinated intersections is determined based on the maximum length of queued vehicles which is computed using the simulation models developed in the Objective-C language. The article covers the basic characteristics of those models, their structure and building principles, and also provides the model validation results. Simulation models can be used both for determination of the optimum length of special bus lanes at the approaches to signalized intersections and for analysis of intersection performance based on the maximum length of queued vehicles.

Keywords: bus lanes, bus signal priority, priority at the intersection, maximum length of queued vehicles

1. Introduction

Today the search for new ways to reduce the street network load in the cities is as important as ever. This problem can be addressed either by redesigning such networks or by streamlining their operations through use of Intelligent Transportation Systems (ITS). However, these two approaches aren't always effective in urban conditions. The first one is time-consuming, requires significant capital investments and depends on the functional characteristics of the street network, and the second one doesn't always produce the desired results because it simply optimizes the situation instead of resolving it on a fundamental level. There is, however, an alternative in the form of a third approach which focuses on efficient operation of public transport. Ultimately, it allows reducing the usage of personal vehicles which account for a dominant share in the existing traffic flows and, therefore, decreasing the street network load.

Out of all types of public transport currently used in Ukrainian cities, the urban commuter buses (trolleybuses) are in critical need of development, since they are the most common mode of passenger transport used by the urban population. Giving them priority in traffic at signalized intersections is one of the primary factors that can improve the transport service within the urban street network, since such intersections cause the most significant delays.

Bus rapid transit, (2007) mentions that, in order to ensure priority for buses at signalized intersections, the special bus lanes allocated within the street segments should not be interrupted at the intersections, allowing buses to cross them in the same phase as non-priority traffic flows. Passage of buses in the same phase with non-priority traffic flows can be implemented by prohibiting certain types of turns at the intersection (usually left or right turns) or arranging bypasses (such as a channelizing island bypass, loop-shaped left turn in the intersection area or U-turn outside the intersection area). The intersection conditions do not always allow using such methods without altering the signal control at the intersection. Therefore, they are generally utilized at those intersections where buses cross the intersection in the forward direction, and the non-priority traffic flows making the turns are of low intensity and, therefore, can be prohibited.

Skabardonis (2000), Przhibyl, Svitek (2003), Lin at al. (2015) propose methods of providing passive and active priority for buses. Passive priority is implemented by increasing the green time duration (Shelkov, 1995), reducing the cycle length (Bus rapid transit, 2007) or introducing an additional phase (Klinkovshtein, Afanasiev 2001; Kremenets, Pechersii 2005). It is suggested to increase the green time duration in the direction of bus travel in cases where there is no bus traffic in other directions. Such approach improves the traffic capacity in the target direction and raises the probability of buses crossing the intersection during the green time. Reduced cycle length is used when the conditions at the intersection allow prohibiting certain maneuvers for non-priority traffic flows. This allows using fewer phases and, therefore, making the inefficient part of the cycle (number and total duration of intergreen times) shorter, thus reducing the amount of delays both for non-priorty traffic flows and for buses. Introduction of an additional bus phase depends on the intensity of bus traffic in the given direction. A disadvantage of such additional phases is that they increase the total duration of intergreen times, making them generally undesirable in terms of optimizing the traffic control at the intersection.

All active priority methods are implemented by detecting buses at the approach to the intersection using special detectors and altering the signal control modes accordingly. To implement active priority, Angus (2001), Ma, Yang (2008), Ekeila at al. (2009) propose a green time extension algorithm triggered when a bus approaches the intersection at the end of the green time. To provide priority for the buses arriving at the intersection during the red time, Shelkov (1995), Garrow, Machemehl (1997), Wie at al. (2013) suggests using an early red time termination algorithm. This algorithm is especially difficult to implement when there is intensive pedestrian traffic during the phase that needs to be terminated early. Balke at al. (2000), Przhibyl, Svitek (2003), Lin at al. (2015) believe that the most efficient way of providing active priority is to invoke a special phase that can be activated at any time during the cycle length. When using such an algorithm, efficient signal control at the intersection is maintained through so-called “compensation” techniques: after a bus is granted priority passage with the help of the special phase, the time lost by non-priority traffic flows is compensated by increasing the green time duration in their respective directions.

Vikovych, Zubachyk (2013a) refer to all passive and active priority algorithms as time-priority methods, and to those described above – as space-priority methods. They also define a separate group of space-time priority methods. Use of special bus lanes and corresponding adaptation of the traffic light signal control algorithms are considered to be integral components of space-time priority.

To provide space-time priority, Scnabel (1997) proposes introducing bus “gates”. This method is based on placing two traffic lights at the approach to the intersection, with the space between them forming a “gate”. When the red signal is active at the second traffic light, the “gate” opens for buses traveling in the special bus lane. As an additional benefit, the buses can easily complete turning maneuvers regardless of the location of the special bus lane on the traffic way (leftmost or rightmost lane). When the green time begins, the buses become the first vehicles to cross the intersection in the target direction. This method should be implemented in cases when there are no stops in the intersection area, and is efficient only when two-phase signal control is used.

The (Abdelghany at al., 2007; Example collection, 2010; Ding at al., 2014) proposes using special bus lanes and active priority algorithms to provide space-time priority. Application of these methods produces the best results in terms of ensuring absolute priority (non-stop travel) for the buses.

Individual space and time priority methods can be utilized efficiently only in case of low-intensity bus and non-priority traffic flows. On the other hand, the space-time priority methods can ensure priority passage even at higher traffic (especially bus traffic) loads. The determinant criterion for implementation of methods that provide space-time priority for buses at signalized intersections is the availability of at least three lanes running in the same direction in the streets forming the intersection. Conditions where such priority is difficult to implement include signalized intersections with no more than two traffic lanes in each direction at the approach, which is especially relevant for urban street networks characterized by compact planning. For example, in Lviv (Ukraine) 95% of the streets have no more than two lanes in each direction.

2. Background of the space-time prioritization method

To provide the buses with space-time priority at signalized intersections with two or less approach lanes, the authors propose a method called “special bus lanes within the area of intersection” (Vikovych and Zubachyk, 2013a). This method is based on creating additional expansions in certain directions at the approach to and after the intersection, and arranging a special bus lane for priority traffic within such expansions, including the area of intersection between them. Establishment of such a spatial “corridor” within the intersection area provides free access to the stop line as well as a dominant position in space on the traffic way without reducing the number of approach lanes for non-priority traffic. If there are no stops at the intersection or if stops are located before the intersection, the additional expansions are created at the approaches only.

For isolated X-intersections, six basic types of special bus lanes divided into two groups are proposed to be implemented within the intersection area. The first group is designed for intersections with no stops or stops located before the intersection (Fig. 1a-b – pedestrian crossings not shown), the second one – for those cases where stops are located after the intersection (Fig. 1c-f). However, if there are no pedestrian crossings at the intersection, it may sometimes be advisable to implement special bus lanes from the second group at intersections with no stops or stops immediately before them. This would simplify the space-time prioritization and help optimize the operation of the intersection.

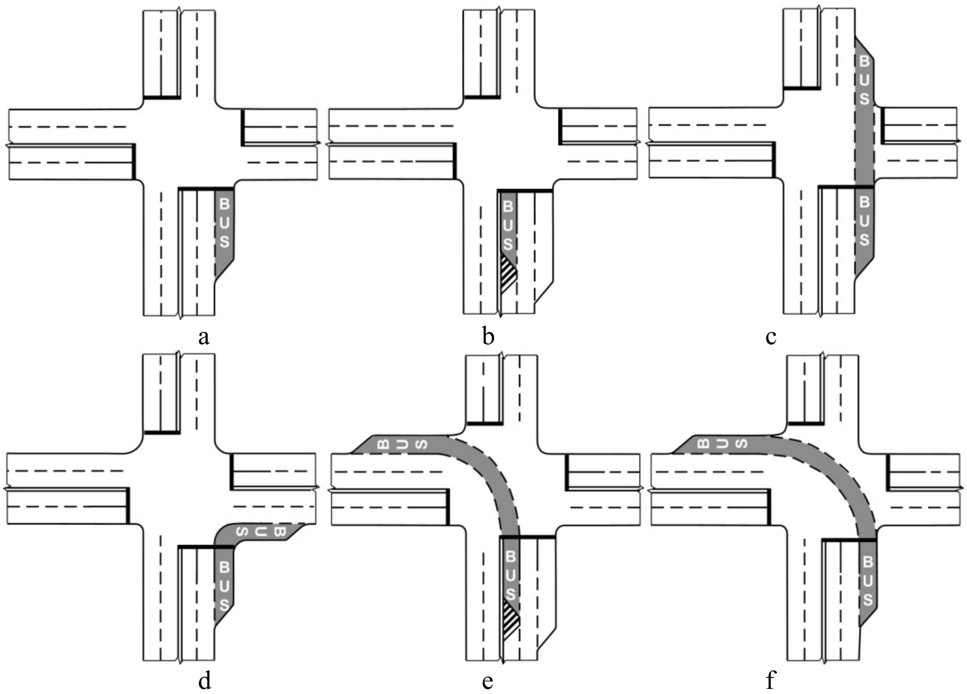


Figure 1. Special bus lane types within the intersection area broken down into two groups:
a – type 1.1; b – 1.2; c – type 2.1; d – 2.2; e – type 2.3; f – 2.4

In addition to traffic prioritization at isolated intersections, special bus lanes may also be implemented at intersections operating under a coordinated control system. This is especially relevant for cases where stops are located after two adjacent intersections with coordinated control, and the coordination area covering those intersections has two traffic lanes in one or both directions. In such conditions, delays may occur at the adjacent intersection due to lack of synchronization between the movement of buses from stop to stop and the green time in the coordinated direction. In other words, it is virtually impossible to ensure non-stop bus traffic between the two adjacent stops without disrupting the coordinated control. Therefore, to reduce bus delays at both upstream and downstream intersections, it would be practical to implement special bus lanes of type 2.1 in such areas (Fig. 1c).

One of the key stages of implementing this method is determination of the optimum length of the special bus lane at the approach to the intersection which is calculated based on the maximum length of queued vehicles in the lane adjacent to the special bus lane during the cycle.

3. Determination of the maximum length of queued vehicles at a signalized intersection

3.1. On isolated intersection

To determine the maximum length of queued vehicles at an isolated intersection which is needed to calculate the optimum special bus lane length at the approach to the intersection, a simulation model of intersection approaches described in (Vikovych and Zubachyk, 2013b) was developed. The model was written in the Objective-C language using the Xcode software environment. It is based on simulation of vehicles arriving at the intersection, waiting in the queue, and departing from the queue during the green time. The main component of this model is the vehicle arrival times expressed as time intervals between the vehicles and distributed according to the Hyper-Erlang and log-normal distribution laws (Inose, Khamada, 1983; Polischuk, Dzyuba, 2008). The Hyper-Erlang distribution density is defined by the following expression:

$$f(x) = \beta \cdot \lambda_1 e^{-\lambda_1 (x-\tau)} + (1-\beta) \cdot \frac{\lambda_2^a}{(a-1)!} x^{a-1} \cdot e^{-\lambda_2 x}, x \in (0;+\infty) \tag{1}$$

where a, λ_1, λ_2 distribution law parameters; $a > 0$; $\lambda_1 > 0$, $\lambda_2 > 0$; $\lambda_1 = \frac{1}{\bar{x}}$, $\lambda_2 = \frac{a}{\bar{x}}$; $\bar{x}$ – average time interval between the vehicles; τ – minimum interval between the vehicles (ranging from 0,5 to 1,5 s); β – share of vehicles arriving freely at the approach to the intersection.

The log-normal distribution density is defined by the following formula:

$$f(x) = \frac{1}{x \cdot \sigma \sqrt{2\pi}} \cdot e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}} \qquad x \in (0;+\infty) \tag{2}$$

where μ, σ^2 – mean and variance; $\sigma > 0$, $\mu = \bar{x}$.

The simulation model the interface of which is shown in Fig. 2 can also run on mobile iOS devices (iPhone, iPad), and is implemented in such a way so that the user can to easily change the simulation conditions by modifying the input parameters: duration of the simulation period; number of approaches to the intersection (≤ 4) and number of traffic lanes within each approach (≤ 3), including the traffic pattern; geometric approach parameters (traffic lane width, longitudinal gradient, right and left turn radius); traffic control parameters (cycle length, green and yellow time); traffic conditions (traffic intensity, breakdown by primary directions, share of trucks and buses in the flow) etc.

The model produces the maximum length (in vehicles and meters) of the queue formed at the beginning of the green time and during the cycle. The queue length per cycle is the number of vehicles in the queue formed at the beginning of the green time plus the number of vehicles that arrive at the intersection during the dissipation of the queue until the last vehicle departs from the initial queue. The queue length at the beginning of the green time can also be used to evaluate the signal control efficiency, while the queue length per cycle can be used to determine the length of the additional expansion at the approach to the intersection designed to increase the intersection capacity or provide space-time priority for the buses ("special bus lanes within the area of intersection" method).

Figure 2. Interface of the model used to determine the length of queued vehicles

Application of this model allowed identifying how the pattern of arrival of vehicles at the intersection affects the maximum length of queued vehicles. If the vehicle arrival times are distributed in the model according to the Hyper-Erlang distribution with $a = 3$, the simulated queue values are similar to those obtained using the German standard formula (*Manual for the design, 2001*) and close to those produced by VISSIM. On the other hand, analysis of the maximum length of queued vehicles showed that the time intervals between the vehicles arriving at the intersection match the actual values if they are distributed according to this law.

Based on the maximum length of queued vehicles generated by this model, the optimum special bus lane length at the approach to an isolated intersection was determined for a homogeneous traffic flow with the car length of 6 m and flow ratios of $X_i = 0{,}9$ and $X_i = 0{,}95$. The latter corresponds to the upper limit of normal traffic conditions at the intersection approach (*Scnabel, 1997*). The results are shown in Fig. 3.

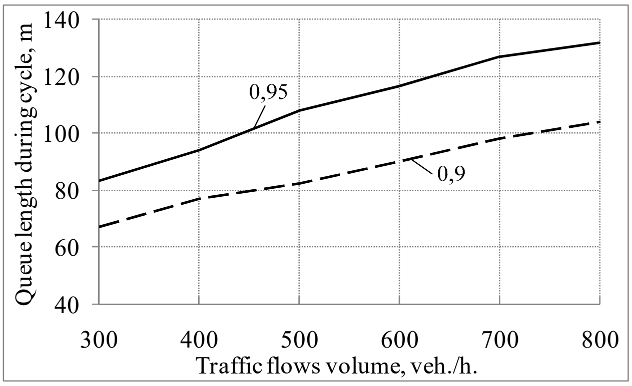


Figure 3. Maximum length of queued vehicles per cycle in meters (numbers on the curves are the flow ratios)

The results provided in Fig. 3 show that the optimum special bus lane length at the approach to an isolated intersection ranges from 59 m to 135 m.

3.2. On coordinated intersection

To determine the maximum length of queued vehicles at an adjacent intersection in the coordinated direction, a simulation model described in (Vikovych and Zubachyk, 2013c) was developed. This model which simulates the operation of a coordinated area for two adjacent intersections was also written in the Objective-C programming language. The input parameters for the model are: duration of the simulation period; upstream intersection type (crossing or junction); coordinated area length; traffic volume at the upstream and secondary approaches with breakdown by traffic lanes, traffic directions and flow composition (cars, trucks, buses); share of vehicles coming from the secondary approaches in the traffic lanes within the coordinated area; cycle, phases and greet time duration at both intersections; coordinated speed.

The output parameters of the model are the average maximum lengths of queued vehicles per k simulations at the adjacent intersection in the coordinated direction for queues formed by vehicles from the upstream approach and secondary approaches as well as their total value.

The model is implemented in such a way so that the user can easily change all input parameters. However, it is suitable only for coordinated street areas with two traffic lanes in one or both directions where the upstream and secondary approaches are isolated and both adjacent intersections have the same cycle length.

The simulation model was created based on the analytical research of the vehicle queue formation process at the adjacent intersection in the coordinated direction described in (Vikovych and Zubachyk, 2013c). According to the research data, the queue at the adjacent intersection is formed by vehicles entering the coordinated area from the upstream approach and secondary approaches.

Whether all or some of the vehicles from the secondary approaches enter the queue depends on the control parameters between the adjacent intersections, including the green time duration in the coordinated direction at both intersections as well as the phase shift value.

In view of the above, the length of the queue formed by vehicles coming from the secondary approaches is determined by the following formula:

$$Q_{S_i}^k = \begin{cases} \int\limits_{(k-1)\cdot T_c}^{k\cdot T_c} \left(\lambda_U(t)\cdot\beta_L + \lambda_D(t)\cdot\beta_R\right)dt & (k=\overline{1,M}) \\ \int\limits_{(k-1)\cdot T_c}^{k\cdot T_c} \left(\lambda'_U(t)\cdot\beta_L + \lambda'_D(t)\cdot\beta_R\right)dt & (k=\overline{1,M}) \end{cases}, \tag{3}$$

where $Q_{S_i}^k$ – length of the queue in the i^{th} lane of the adjacent intersection formed by vehicles coming from secondary approaches p_U and p_D during the k^{th} signal control cycle, vehicles; $\lambda_U(t)=\dfrac{N_U(t_g)}{T_c}$, $\lambda'_U(t)=\dfrac{N'_U(t_{g_{\Delta 2}})}{T_c}$, $\lambda_D(t)=\dfrac{N_D(t_g)}{T_c}$, and $\lambda'_D(t)=\dfrac{N'_D(t_{g_{\Delta 2}})}{T_c}$ – flow ratio in secondary approaches p_U

and p_D at t_g and $t_{g_{\Delta 2}}$, respectively; $N_U(t_g)$, $N_U(t_{g_{\Delta 2}})$, $N_D(t_g)$, $N_D(t_{g_{\Delta 2}})$ – exit flow volume in the secondary approaches during t_g and $t_{g_{\Delta 2}}$, respectively; t_g– green time duration; $t_{g_{\Delta 2}}$ – green time period during which the vehicles join the queue at the adjacent intersection (determined by the formulas provided in (Vikovych and Zubachyk, 2013c); β_L and β_R – share of vehicles arriving from secondary approaches p_U and p_D to the i^{th} lane of the adjacent intersection; T_c – cycle length; $M = T/T_c$ – number of cycles during the simulation period T.

The following formula is proposed to determine the length of the queue formed by vehicles coming from the upstream approach:

$$Q_{U_i} = \begin{cases} \dfrac{(\tau_d + \tau_{\max} - t_{ps} - t_{g_{p1}}) \cdot N_{vg}(t)}{\tau_d + (\tau_{\max} - \tau_{\min})} & \text{in case } Q_{U_i} > 0 \\ 0 & \text{in case } Q_{U_i} < 0 \end{cases}, \tag{4}$$

where Q_{U_i} – length of the queue in the i^{th} lane of the adjacent intersection formed by vehicles coming from the upstream approach, vehicles; $\tau_{\min}$, $\tau_{\max}$ – time of travel through the coordinated area for the first and last vehicle in the group, respectively; $\tau_d = N_{vg}(t) \cdot h_{p_0}$ – duration of vehicle group dissipation at the upstream approach; $N_{vg}(t)$ – number of vehicles in the group at the upstream approach; h_{p_0} – average interval between the vehicles during the queue dissipation at the upstream approach p_0; t_{ps} – phase shift duration; $t_{g_{p1}}$ – green time duration at the adjacent intersection in the coordinated direction.

Formula (4) is based on the time it takes for the vehicles in the group to travel through the coordinated area which is distributed normally (normal distribution) in the simulation model according to the following expression:

$$\tau_i = a + \sqrt{2\sigma^2} \cdot erf^{-1}\left(2y_i - 1\right) \qquad y_i \in \left(0;1\right) \tag{5}$$

where a – time of travel through the coordinated area at the coordinated speed; σ – standard deviation of the vehicle travel time in the coordinated area.

The standard deviation of the vehicle travel time in the coordinated area depends on whether each vehicle in the group maintains the recommended speed while passing through the coordinated area, which, in turn, is influenced by many factors. The value of σ is primarily affected by the length of the coordinated area, number of vehicles in the group, group composition, and share of turning maneuvers from the upstream intersection. The influence of these factors on the vehicle travel time in the coordinated area was determined using the VISSIM software. As a result of the simulation, the corresponding values of the σ were obtained, and the nature of their dependence on the above factors was identified.

In the simulation model, the standard deviation of the vehicle travel time in the coordinated area is determined using the following equation:

$$\sigma = 0{,}9281 - 0{,}0256 N_{vg} + 0{,}0009 N_{vg}^2 + 0{,}6214 L + 2{,}5695 L^2 + 0{,}0332 N_t - 0{,}2363 \beta_{ST} \tag{6}$$

where N_{vg} – number of vehicles in the group in a single lane; L – coordinated area length, km; N_t – number of trucks in the group; β_{ST} – straight flow share.

Application of this model showed that it capable of accurately reproducing the actual processes occurring at the adjacent intersection, and allows determining the maximum length of queued vehicles with the results closely matching the values generated by VISSIM (deviation does not exceed 22%).The largest deviations were observed in cases with a relatively small share of homogeneous flow and long coordinated area(500 m and more).The adequacy of these results proves the hypothesis that the length of the queue formed by the vehicles from the upstream approach is directly proportional to the size (measured in time) of the group that arrives at the adjacent intersection during the red time, and inversely proportional to the average interval between the vehicles in the group.

The most important results of this research are not the calculated values of the actual maximum length of queued vehicles, since those can be easily determined using the currently available software, but rather the analytical description of the queue formation process at the adjacent intersection and the newly developed algorithm for computation of the maximum queue length through simulation modeling.

4. Analysis of performance of the “Special bus lanes within the area of intersection” method in terms of time prioritization

To ensure proper functioning of the “special bus lanes within the area of intersection” method, it is crucial to supplement it with effective means of providing priority passage through the intersection area which is achieved with the help of traffic light signal control algorithms, first of all – of the adaptive type. Algorithms that rely on green time extension or early red time termination upon arrival of a bus at the approach are suitable only for special bus lanes belonging to the second group, and only in cases where buses and non-priority traffic flows can cross the intersection within the same phase without any conflicts. The special phase activation algorithm allows providing absolute and conditional priority for all types of special bus lanes in the intersection area. However, it can create problems for other road users, and its efficiency depends on the traffic conditions at each approach as well as the interval between the buses arriving at the intersection.

Efficiency of this algorithm in combination with a special bus lane in the intersection area under different traffic conditions was verified in the VISSIM environment using a model of an X-shaped signalized intersection with a single traffic lane at all approaches in both directions and with a type 2.1 special bus lane 2.1 (*Vikovych at al., 2014*). The simulation showed that changes in the approach conditions expressed quantitatively through the flow ratio affect the average vehicle delay at the approach. In particular, the delays become longer as the approach flow ratio increases and the interval between the buses decreases (Fig. 4).

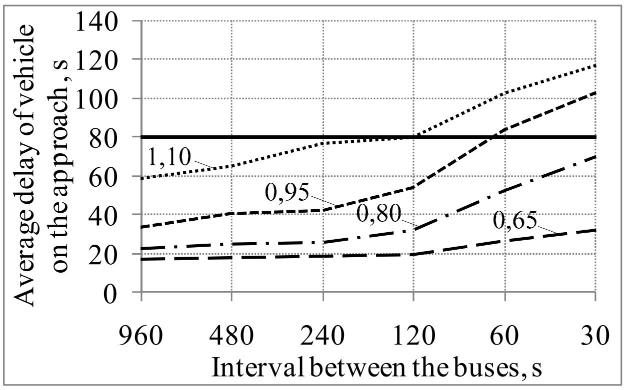


Figure 4. Dependence of the average approach delay for other vehicles on the interval between the buses (numbers on the curves are the approach flow ratios)

The effective range for application of the “special bus lanes within the area of intersection” method was determined based on the above findings using regression analysis subject to the upper limit of the average vehicle approach delay equal to 80 s in accordance with the American regulations (Highway Capacity Manual, 2000). The results show that, for example, the interval between the buses should be at least 57 s provided that the normal traffic conditions at each approach are not exceeded (flow ratio of 0,95 or below).

These results enable the engineers to easily determine the feasibility of implementation of the “special bus lanes within the area of intersection” method at intersections where time priority is provided using the adaptive special phase activation algorithm.

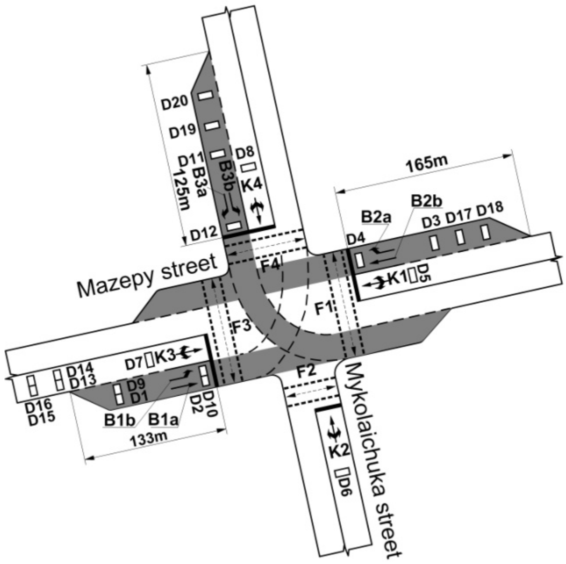
5. Testing of the research results

To verify the “special bus lanes within the area of intersection” method under actual conditions, the isolated signalized X-intersection between Mazepy and Mykolaichuka Streets (Lviv) with one traffic lane in each direction at each approach was used as an example. 13 bus routes and 1 trolleybus route pass through this intersection in different directions. The longest interval between the buses traveling through the intersection is 24 m, while the shortest interval is 65 s.

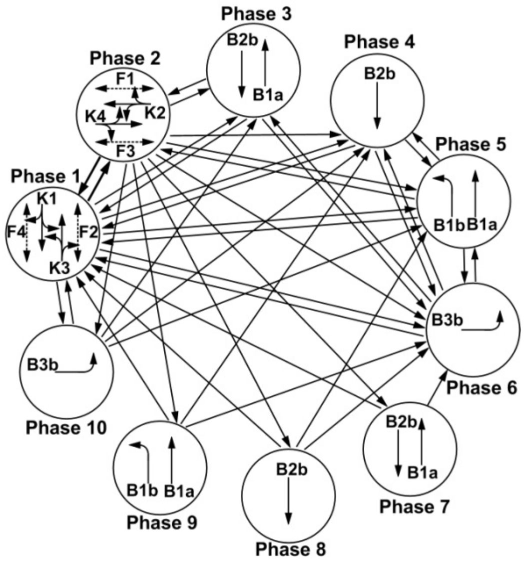
To reduce the bus delays at this intersection, it is proposed to implement the following special bus lanes in the intersection area: type 2.1on Mazepy Street in both directions, and types 2.2 and 2.4 at one of the approaches on Mykolaichuka Street (Fig. 5a).

The length of the special bus lane elements in the intersection area, including the optimum length of the special bus lane element at the approach, is to be determined using the method described above.

Time priority is to be provided using an algorithm based on special phase activation. At the same time, to ensure optimum control of non-priority traffic flows at the intersection, it is proposed to combine this algorithm with a time gap search algorithm and a variable phase alternation algorithm. The ways of combining signal groups into phases and possible phase alternation options are shown in Figure 5b.



a



b

Figure 5. Proposed changes to the intersection between Mazepy and Mykolaichuka Streets: a – geometric parameters of the intersection with special bus lanes added to the intersection area; b – phase alternation sequence

The efficiency of these proposals is verified by creating a simulation model of the intersection between Mazepy and Mykolaichuka Streets in the VISSIM software environment. The vehicle and pedestrian traffic volume values corresponding to the existing conditions at the intersection during the rush hours are entered into the model. It is assumed that the desired speed of cars and trucks is 50 km/h, while the desired speed of buses and trolleybuses is 40 km/h.

Eight phases (3 through 10) are used to provide the buses with priority passage through the intersection by activating a special phase. These phases are skipped if there are no buses at the approaches (Fig. 5b). Phases 4, 6, 7, 8, 9 and 10 are always followed by phase 1 (unless they were activated), while phases 3 and 5 may change either to phase 1 or to phase 2.

Arrival of buses from signal group B1a is detected by means of detectors D1, D2, D13 and D15; signal group B1b – D9, D10, D14 and D16; signal group B2b –D3, D4, D17 and D18; signal group B3b – D11, D12, D19 and D20 (Fig. 5a). Buses from signal groups B2a and B3a are not detected upon arrival, since they do not require time priority to be given by traffic light signals (as they turn right from the special bus lane). Detectors D5, D6, D7 and D8 are used to identify time gaps in non-priority traffic flows belonging to signal groups K1, K2, K3 and K4, respectively.

The model uses the average approach delay for buses and other vehicles and queue length (average and maximum) at the intersection as the criteria for quantitative evaluation of efficiency of the above proposals.

In addition, to enable comparison of these results with those that can be obtained with no priority passage through the intersection, an additional model of the same intersection with the same input data, but without the special bus lanes in the intersection area was created in the VISSIM environment. In this case, the traffic light signals operate in the adaptive mode using the traffic flow gap search algorithm for all approaches with dual-phase vehicle and pedestrian traffic flow dissipation (similar to phase 1 and 2 in

Figure 5b). The average delay and queue length simulation results for both scenarios are provided in Tables1 and 2.

Table 1. Intersection performance indicators with implemented space-time prioritization

Traffic flows of signal groups	Average delay, s	Queue length, veh.	
		average	maximal
K1	70,02	9,3	22,5
K2	69,83	7,8	22,1
K3	29,03	3,2	14,2
K4	79,71	7,1	23,0
B1	3,91	–	–
B2	4,85	–	–
B3	6,07	–	–

Table 2. Intersection performance indicators with adaptive control (no prioritization)

Traffic flows of signal groups	Average delay, s		Queue length, veh.	
	vehicles (without buses)	buses	average	maximal
K1	63,28	66,24	8,6	20,4
K2	53,16	71,30	5,4	17,8
K3	27,69	21,77	2,7	13,7
K4	60,39	58,28	5,7	19,5

Tables 1 and 2 show that implementation of space-time priority at the selected intersection allows reducing the bus delays by 82, 93 and 90% for routes belonging to signal groups B1, B2 and B3, respectively. At the same time, this prioritization results in a minor increase in the delay values and queue length for other vehicles. In particular, vehicle delays in signal groups K1, K2, K3 and K4 are increased by 11, 31, 5 and 32%, respectively; average queue length is increased by 8, 44, 19 and 25%, respectively; and maximum queue length is increased by 10, 24, 4 and 18 %, respectively.

The average bus delay at the intersection with implemented space-time prioritization is reduced by 87 % compared to adaptive control with no prioritization (from 47,22 to 6,24 s), and the average delay for other vehicles is increased by 19 % (from 50,53 to 60,07 s).

Significant reduction of the bus (trolleybus) delays at the intersection allows reducing their route circulation time and fuel consumption, which ultimately improves the efficiency and comfort of passenger transportation.

6. Conclusions

This article formalizes the “special bus lanes within the area of intersection” method used to provide buses with space-time priority at signalized intersections (mostly of the isolated type). The results of a simulation experiment conducted in the VISSIM environment show that application of this method at an actual isolated signalized intersection allows achieving an 87% decrease in the average bus delay compared to non-prioritized adaptive control. This proves that the “special bus lanes within the area of intersection” method can be efficiently used in practice, especially at signalized intersections with no more than two traffic lanes in each direction at the approaches.

The most critical phase of implementation of this method is to determine the optimum length of the special bus lane at the approach to the intersection based on the maximum length of queued vehicles. The article covers the characteristics of the simulation models designed to calculate the maximum length of queued vehicles at the approach to isolated and coordinated intersections.

The simulation model developed for determination of the maximum length of queued vehicles at the approach to an isolated intersection differs from the existing models in that it uses hyper-Erlang law for distribution of time intervals between the vehicles arriving at the intersection. This improves the adequacy of the simulation results (queue values are similar to those obtaining using the German standard formula (Manual for the design, 2001) and close to those produced by VISSIM). The way the model is implemented allows using it on portable devices (iPhone, iPad) and easily changing the simulation conditions by modifying the input parameters.

The simulation model used for calculation of the maximum length of queued vehicles at the approach to a coordinated intersection was created based on the analytical research of the vehicle queue formation process at the adjacent intersection in the coordinated direction. Such research was presented for the first time.

Both simulation models can be used for determination of the optimum length of special bus lanes at the approaches to signalized intersections as well as for analysis of intersection performance based on the maximum length of queued vehicles.

References

1. Abdelghany, K. F., Mahmassani, H. S., Abdelghany, A. F. (2007) A Modeling Framework for Bus Rapid Transit Operations Evaluation and Service Planning. *Transportation Planning and Technology*, vol. 30, issue 6, pp. 571-591.
2. Angus, P. Davol. (2001) *Modeling of traffic signal control and transit signal priority strategies in a microscopic simulation laboratory*. Massachusetts institute of technology, 118.
3. Balke, K., Dudek, C., Urbanik II T. (2000) Development and evaluation of intelligent bus priority concept. *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1727, pp. 12-19.
4. Bus rapid transit / Planning guide (2007) New York.: 3ed edition, 825.
5. Ding, L., Zhang, N., Qian, Z. D. (2014) Analysis of Managed Bus Lane Strategies Based on Microcosmic Traffic Simulation. *Advanced Materials Research*, vol. 1079-1080, pp. 440-447.
6. Ekeila, W., Sayed, T., Esawey, M. E. (2009) Development of dynamic transit signal priority strategy. *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2111, pp. 1-9.
7. Example collection about the guidelines for traffic signal systems (2010). *Research society for roads - and Transportation*, Cologne, 92.
8. Garrow, M., Machemehl R. (1997) *Development and evaluation of transit signal priority strategies.* Center for Transportation Research, The University of Texas at Austin, 147.
9. Highway Capacity Manual (2000) TRB, Washington, DC, 1134 p.
10. Inose, H., Khamada, T. (1983) *Road traffic control*. Moscow, USSR, Transport, 248.
11. Klinkovshtein, H. I., Afanasiev, M. B. (2001) *Traffic management.* Moscow, Transport, 247.
12. Kremenets, Y. A., Pechersii, M. B. (2005) *Technical means of traffic management.* Moscow, 279.
13. Lin Y., Yang X., Zou N., Franz M. (2015) Transit signal priority control at signalized intersections: a comprehensive review. *Transportation Letters: the International Journal of Transportation Research*, vol. 7, issue 3, pp. 168-180.
14. Manual for the design of road traffic facilities (2001) *Federal Highway Research Institute*. October, 370.
15. Ma W., Yang X. (2008) Efficiency Analysis of Transit Signal Priority Strategies on Isolated Intersection. *Journal of System Simulation*, issue 12, pp. 184-191.
16. Przhibyl, P., Svitek, M. (2003). *Telematic in transport (translation from Czech)*. Moscow, 540.
17. Polischuk, V. P., Dzyuba, O. P. (2008) *Theory of traffic flow: models and methods of traffic management.* Kyiv, 175.
18. Shelkov, Y. D. (1995) *Traffic management in the cities.* Moscow, 143.
19. Scnabel, W. (1997) *Fundamentals of traffic engineering and transport planning*. Volume 1: Traffic Systems, 2nd edition, Berlin, publisher of Construction mbH, 590.
20. Skabardonis, A. (2000) Control Strategies for Transit Priority. *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1727, pp. 20-26
21. Vikovych, I. A., Zubachyk R. M. (2013a) Development of method for bus priority on the intersection. *Eastern-European Journal of Enterprise Technologies.* Scientific Journal, no. 6/4 (54), pp. 28-34.
22. Vikovych, I. A., Zubachyk R. M. (2013b) Development of simulation model for determination of the maximum length of queued vehicles. *Herald of the National Technical University "Kharkiv Polytechnic Institute", Kharkiv*, no. 65, pp. 27-33.
23. Vikovych, I. A., Zubachyk R. M. (2013c) Simulation model development for determination of the maximum length of queued vehicles on adjacent direction to coordinated intersection. "*Technology audit and production reserves" journal. Scientific Journal*, no. 6/1(14), pp. 19-26.
24. Vikovych, I. A., Zubachyk R. M., Bespalov D. O. (2014) Efficiency determination of method "bus lane within the area of intersection" from the standpoint of priority in time. "*Technology audit and production reserves" journal. Scientific Journal*, no. 5/1(19), pp. 40-45.
25. Wie, L., Zhang, L., Wang, Z. (2013) Cellular automata moderl on bus signal priority strategies considering resource constraints. *Practical application of intelligent systems: Proceedings of the eighth international conference on intelligent systems and knowledge engineering, Shenzhen, China*, pp. 689 -706.

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KPI BUILDING BLOCKS FOR SUCCESSFUL GREEN TRANSPORT CORRIDOR IMPLEMENTATION

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The green transport corridor concept represents a cornerstone in the development of integrated and sustainable transport solutions. Important properties of green corridors are their transnational character and their high involvement of large numbers of public and private stakeholders, including political level, requiring sophisticated approaches for implementation, management and governance. The current scientific discussion focusses on Key Performance Indicators (KPI) for monitoring and management of green transport corridor performance emphasizing the operational aspects.

The green corridor balanced scorecard approach tried to mitigate the strategic weakness of KPI concept by integrating cooperative and long-term views in order to come closer to a comprehensive green corridor control system. Until now all discussed KPI sets are too small and narrow for a successful implementation of green corridors so there is a need for the development of an user-oriented model for green corridor control systems based on building blocks integrating existing KPI sets.

The building block approach for implementation has been successfully used for implementation and simulation in supply chain management. Based on these results the paper will present a holistic control system for successful implementation of green transport corridors based on building blocks integrating recent results about KPIs and balanced scorecards approaches. The research will empirically be verified by empirical results from European green corridor projects.

Keywords: green transport corridors, management control systems, networks, key performance indicators, corridor governance

1. Introduction

Green transport corridors (GTC) have gained attention in recent years and their main properties can be characterized as European trans-shipment routes with concentration of freight traffic between major hubs and relatively long distances of transport marked by reduced environmental and climate impact, while increasing safety and efficiency with application of sustainable logistics solutions, inter-modality, information and communication technology infrastructure, common and open legal regulations and strategically placed trans-shipment nodes. The theoretical foundations of GTC are related to sustainable aspects, multimodality, network and supply chain concepts (Hunke and Prause, 2013; Prause and Hunke, 2014).

Since the GTC concept was initiated by EU Commission within the Freight Transport Logistics Action Plan in 2007 and the EU White Paper on Transport in 2011 implementation of green transport corridor concepts was started in several EU-funded regional development projects in order to realise and compare different approaches and ideas of this concept (FTLAP, 2007; COM, 2011). One important aspect of implementations of GTC is the assessment and comparison of existing corridor concepts and monitoring and evaluation of GTC performance and development.

The current scientific discussion about performance monitoring of green corridors focusses on different sets of Key Performance Indicators (KPI) which are emphasizing operational and neglecting aspects but a general concept for a GTC management control systems, shortly called a green corridor controlling system (GCCS), is still missing (Prause, 2014). Another important shortcoming of the existing KPI approaches is related to their narrow scope restricting the KPI sets mainly to sustainable aspects.

Monitoring and assessment of business processes lead to different evaluation and measurement approaches where systems of KPI are considered to be an appropriate tool for organisational decision making, system control and performance assessment (Reichmann, 2001; Gladen, 2005; Parmenter, 2010).

Popular KPI systems like DuPont system, balanced scorecard, ZVEI system, RL system, pyramid of ratios or tableau de bord are structured in forms of thematically grouped indicators which are called fields, sectors or perspectives (Brem et al., 2008). Such a thematic set of indicators will be called a KPI building block in this paper.

The current scientific discussion stresses different sets of KPI for monitoring and management of GTC mainly covering sustainable and operational aspects of the corridor performance (Hunke and Prause, 2013). Strategic aspects of KPI sets linked to network-orientation, infrastructural aspects or strategic risks are neglected (Prause, 2014; Schröder and Prause, 2015). A literature review reveals that only little research has been carried out on the role of GCCS, including building blocks of KPI for GTC and their relationship to the context of GTC implementation. For this reason, the paper tries to tackle this research gap by addressing the research questions what KPI building blocks might be important as components of a GCCS as well as for implementation of Green Transport Corridors, how they can be classified and how these building blocks are linked. The aim is to compile and construct KPI building blocks in the context of GCCS for the implementation and management of Green Transport Corridors and to point out the relationship of those building blocks.

In the remainder of the paper, at first the theoretical background is provided for Green Transport Corridor and their KPI systems. Afterwards, the research methodology for the empirical part is described. Since the paper resorts to empirical data of existing green transport corridor initiatives in the Baltic Sea region, the empirical results of the conducted expert interviews and workshops are presented. They show which building blocks of KPI might occur in the context of Green Transport Corridors.

2. Literature Review

2.1. Management control systems and Green Transport Corridors

Foundations of logistics and supply chain management control systems have been discussed by several scholars. In his work about competitive advantage Porter (1998) developed in the context of his value chain theory the importance of specific company activities and he stressed the specific profile of activities as source for the long-term competitive advantage of a company. These specific company activities which he used as synonyms for processes comprise also logistics and supply chain processes due to the cross-company character of value chains. These process-oriented aspects of logistics and supply chain issues have also been in the centre of the theoretical approach of Blum (2006) and Pfohl (2010) who proposed system and process theory as a fundament for logistical flow systems which comprise supply chains. Meanwhile, important management and controlling instruments for logistics process analysis and assessment like the SCOR model have proven the potency of the underlying process-oriented approach in supply chain management (Weber and Wallenburg, 2010).

Horvath (2011) pointed out that process orientation depicts an extension of the system approach and that logistics represents the flow perspective of the system approach which is in line with the view of Hahn (1999) who defines supply chain management as the "process- oriented interpretation of a company as activity centre". Based on these consideration Göpfert (2013) emphasized that logistics control system have to follow three global objectives, namely enhancement of effectivity, the increase of efficiency and the safeguarding of adaptability and viability of logistics management. A literature review about the appearance of KPIs in the context of logistics and supply chains leads to the issue of management control systems for supply chain, also called supply chain controlling (Weber, 2002; Göpfert, 2003, 2013; Jehle, 2005; Seuring and Müller, 2008).

By following Seuring (2006) is can be concluded that several supply chain controlling topics have been discussed by scholars but no integral theory or conceptual framework papers about supply chain controlling exist in the leading English speaking supply chain journals which contrasts to the German situation where different supply chain controlling concepts are deeply discussed explaining the dominance of references of German scholars in this field. Related KPI systems in German journal articles can be found in the context of logistics ratio systems as well as in supply chain balanced scorecards (Seuring and Müller, 2008; Göpfert, 2013; Prause, 2014).

KPI evaluate the performance or the success of structures or specific activities but the crucial point is to find and define the right KPIs which require a good understanding of the structure and the underlying processes together with their related key activities. The application of KPI approaches in business world often choose KPI according to a corresponding management framework like the DuPont system, the ZVEI system or the balanced scorecard (Reichmann, 2001; Gladen, 2005; Parmenter, 2010). The underlying sets of KPIs are ordered and grouped in sets of thematically related indicators reflecting related issues in certain business areas like sales, finance or logistics. These thematic sets of KPIs will be called in the sequel KPI building blocks and they represent in classical KPI systems sectors or perspectives (Brem et al., 2008).

Parmenter (2010) conducted a large empirical study about KPIs in public and private sectors and was able to define seven characteristics of effective KPIs:

- Non-Financial, i.e. KPI should represent non-financial measures
- Timely, i.e. KPI should be measured frequently
- Management focus, i.e. KPI should be acted upon by the management team
- Simple, i.e. all staff members are able to measure and correct if required
- Team-based, i.e. the KPI responsibility can be assigned to teams
- Significant impact, i.e. KPI should affect several critical success factors
- Limited dark side, i.e. the positive impact of KPI related actions must be safeguarded.

Since the findings of Parmenter are of general nature they also apply to supply chain management.

The GTC concept lies an emphasis is laid on a minimization of environmental impact, the creation of safe and sustainable logistics solutions by promoting trans-nationality and co-modality as well as on network concepts, Hunke and Prause (2013) pointed out that green SCM represents one important source for theoretical foundations since green SCM reveals interdependency between conventional SCM and eco-programs (Sarkis, 2001; Prause and Hunke, 2014). In this understanding an important approach for the performance evaluation of GTC as well as for the comparison of existing Green Corridor implementations can be conducted by management control systems for supply chains comprising ecological aspects as well as the assessment of its international network environment by taking into account the international and cross-company aspects (Sydow and Möllering, 2009).

The current scientific discussion stresses different sets of Key Performance Indicators (KPI) for monitoring and management of green transport corridors by emphasizing green and operational aspects and neglecting infrastructural, strategic and network-oriented issues (Hunke and Prause, 2013). Consequently, Prause (2014) proposed a management control system in form of a Green Corridor balanced scorecard approach by integrating different sets of cooperative and network-oriented KPIs.

Schröder and Prause (2015) extended these existing considerations by adding risk management aspects from supply chain management to the Green Transport Corridor concept which makes it necessary to develop a comprehensive management control system, shortly called green corridor controlling system (GCCS), to safeguard an efficient, innovative, safe and environmental friendly implementation and long-term development for green transport corridors. Such a GCCS should comprise building blocks of KPIs as well as other important strategic controlling elements.

2.2. Performance indicators and balanced scorecards for Green Transport Corridors

An important breakthrough towards a holistic and consistent monitoring concept for multi-modal sustainable transport has been developed by the consortium of the EU-funded project "East-West-Transport-Corridor (EWTC2)" within the BSR Interreg IVB Programme, where for the first time a "Green Corridor Manual" based on the experiences and empirical evidences of the East-West-Transport-Corridor was presented including a KPI set for measuring different aspects of the performance of transport chains (Hunke and Prause, 2013). This KPI set can be separated into two subsets of indicators measuring enabling and operational criteria.

Table 1. Performance Indicators

Performance areas	Operational indicators	Enabling indicators
Economic efficiency	Total cargo volumes On time delivery	Corridor capacity
Environmental efficiency	Total energy use Greenhouse gases, CO_2e Engine Standards ISO 9001 dangerous goods	Alternative fuels filling stations
Social efficiency	ISO 31000 ISO 39000	Safe truck parking Common safety rating Fenced terminals

Table 1 gives an overview about the KPIs which were selected from the East-West-Transport-Corridor project and were also tested during the project duration. This set of KPIs has parallels in the economic and environmental areas with the proposed KPI set of the project "SuperGreen: Supporting EU's Freight Transport Logistics Action Plan on Green Corridors Issues" which was supported by the European

Commission in the context of the 7th Framework Programme and which has been launched between 2010 and 2013 in order to promote the development of European freight logistics in an environmentally friendly manner (SuperGreen, 2013). Additional or different KPI of the SuperGreen project are related to logistics processes within GTC, namely frequency, transport costs and transport time (EWTC, 2012).

EWTC separates among four key corridor stakeholders who are directly involved in the corridor performance, consisting of the corridor service providers, the transport service providers, the transport shippers and the infrastructure providers, i.e. regional or national governmental institutions. For all of these four key stakeholders characteristic performance indicators are specified (EWTC, 2012).

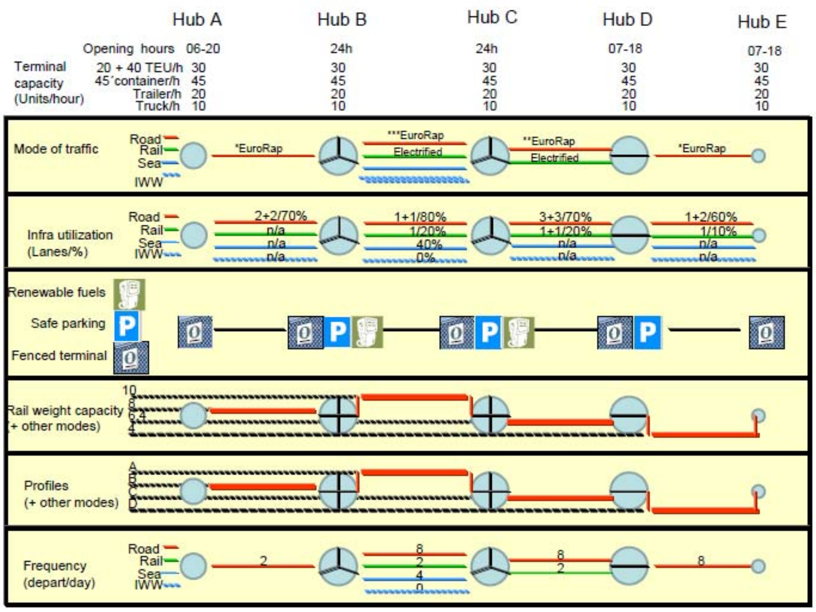
In addition to the KPI set the “Green Corridor Manual” proposes to use a corridor dashboard in order to connect the short-term KPIs and the enabling KPIs by visualizing capacity, accessibility and performance (EWTC, 2012). An important characteristic of the dashboard is that it is hub-oriented, i.e. that the dashboard depicts the main characteristics of the corridor hubs together with their infrastructural links. By doing so the dashboard consolidates already the logistics data to hub level, i.e. to meso level, and outlines the network situation of the corridor where the nodes represent the corridor hubs and the edges are the logistical links between them.

In this sense the dashboard visualises the size of the terminal or the hub, the number of modes of a terminal or a hub can serve, which can be between one and four modes, as well as the terminal capacity comprising:

- Opening hours
- Transit time
- Max number of lifts between rail and road
- Max number of container lifts
- Max number of arrivals and departures
- Max size of trains/vehicles/vessels

Under this consideration a dashboard represents a simple labelling system for the underlying green transport corridor infrastructure by linking and visualising relevant KPIs for operational control with enabling factors comprising capacity, redundancy and performance.

Table 2. Dashboard



Thus, the dashboard stimulates improvements of the corridor infrastructure and facilitates the cooperation of all stakeholders along the corridor in order to improve total performance (EWTC, 2012).

But an approach based only on the KPI set together with the dashboard of the EWCT project is too narrow to cope with the requirements of a green corridor management control system which has to be taken under account the network and supply chain characteristics of a corridor so that flexible management control systems are needed which reflects the dynamic structures of a corridor as well as with the collective processes and strategies of the heterogeneous set of GTC stakeholders. Consequently, Weber (2002) developed a cross-company balanced scorecard for supply chains which keeps the two traditional perspectives of a balanced scorecard, namely the finance and process perspective, but he replaced other two traditional perspectives by two new ones, which he called cooperation intensity and cooperation quality, i.e. Weber’s supply chain balanced scorecard comprised the financial perspective, the process perspective, the cooperation intensity and the cooperation quality (table 3).

Table 3. Weber‘s modified Supply Chain Balanced Scorecard (Source: Sydow and Möllering, 2009)

Perspective	Strategic target	Indicator	Measures
Financial perspective	Increase return of Supply Chain	Increase RoA of Supply Chain by x%	Outsource warehousing Reduce working capital
	Try to achieve cost leadership	Recued logistics costs in Supply Chain per unit by x%	Bundling of partner capacities
Process perspective	Max. lead time client: 10 days	Reduce Supply Chain lead time to 10 days	Cross partner process optimization
	Increase flexibility of operations	Increase freezing point in % of lead time of Supply Chain	Flexible parts, Postponement
Perspective of cooperation intensity	Increase data exchange between Supply Chain partners	Number and frequency of exchanged data sets	Improve IT – Networking of Supply Chain Partners
	Increase coordination between Supply Chain partners	Number of necessary coordination meetings	Systematic management of notes and minutes
Perspective of cooperation quality	Increase trust and satisfaction	Establish indicators for trust and satisfaction	Define common visions and guidelines
	Increase cooperation quality	Number of uncooperative solved conflicts	Establish “referee” for the Supply Chain

Based on a Weber’s concept for a supply chain balanced scorecard, Prause (2014) proposed a green corridor balanced scorecard by taking under account the empiric results of already existing green corridor projects. Accordingly, this green corridor balanced scorecard integrated the KPI sets for monitoring and management of Green Transport Corridors as well as cooperative and network-oriented concepts from supply chain management and has four perspectives (Table 4):

Table 4. Green Corridor Balanced Scorecard

Sustainability perspective	Economic efficiency Environmental efficiency Social efficiency
Growth perspective	Innovation activities New services Green Corridor stakeholder fluctuation Turnover of new services
Cooperation intensity	Data exchange Coordination needs
Cooperation quality	Openness Trust level Transparency level Conflict level

This balanced scorecard includes all important perspectives for GTC and focusses on the underlying network properties of a corridor. Furthermore, it constitutes the KPI system of the EWTC2 project. The set of indicators is not complete and also the type of measurement and evaluation of the indicators is still open, but nevertheless the presented concept for a green corridor balanced scorecard is a further development and in line with a controlling concept for supply chains.

2.3. Risk Management issues for Green Transport Corridors

A consideration of the current management control systems and existing KPI systems for GTC reveals that they are emphasising sustainability, growth and inter-organizational cooperation aspects by neglecting risk issues which are related to the supply chain characteristics of a corridor (EWTC, 2012; Hunke and Prause, 2013; Prause, 2014). Already the multi-modal challenges within a GTC which are related to the green SCM issues to choose the right mode of transportation, to use the right equipment, and to use the right fuel have to consider risks related to costs, lead time, environmental performance and availability (Dekker et al., 2012). Consequently, a lot of risks with a negative impact on the supply chain may occur within the multi-modal transportation chains in GTC (Giunipero and Eltantawy, 2004). The multitude of actors integrated into transport services and GTC as well as their diversity even increases the number of potential risks.

Risks may have an influence on the flows of products, services, finance and information so that supply chain risk is *"the damage – assessed by its probability of occurrence – that is caused by an event within a company, within its supply chain or its environment affecting the business processes of more than one company in the supply chain negatively"* (Kersten et al., 2011). In order to cope with risks and to achieve corporate goals, it is necessary to implement risk management. Due to several corporate crises and insolvencies, specific pronouncements as well as regulatory requirements exist in numerous countries relating to the analysis, communication and monitoring of risks (Kajüter, 2003).

Schröder and Prause (2015) focused on risk identification and risk handling in the context of GTC. Based on the results of expert interviews the authors clustered the risks in main categories describing the sources of risks. The main categories were chosen in accordance with the three pillars of sustainability that are essential for the success of the GTC concept (Hunke and Prause, 2013). Consequently, the risks that might occur in each of the three main categories can be further differentiated into subcategories (Figure 1).

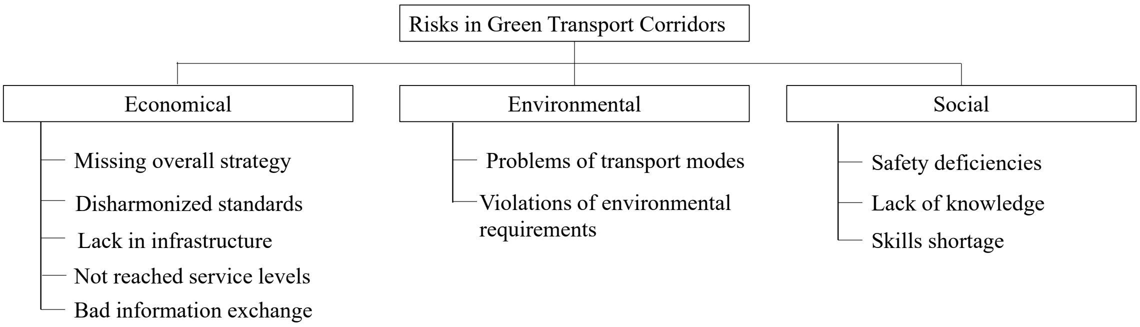


Figure 1. Risks in Green Transport Corridors

For risks regarding "economical" aspects Schröder and Prause (2015) proposed the five subcategories *missing overall strategy*, *disharmonized standards, lack in infrastructure, not reached service level* and *bad information exchange.* The second main category "environmental aspects" consists of the two subcategories *problems of transport modes* and *violations of environmental requirements* whereas the third main category "social risks" was divided by the authors into the three subcategories *safety deficiencies, lack of knowledge* and *skills shortage*. These risk categories are linked with operational and strategic issues of GTC and they are touching beyond economic, ecological and social topics also process-oriented, growth and cooperation topics so that risks aspects are strongly linked to all parts of green corridor control system including a related KPI based performance measurement system.

In addition to these issues Christopher and Holweg (2011) emphasized the importance of volatility in SCM due to quickly and constantly changing global business environment in recent years so they argue that the assumption of stability no longer holds. Consequently, they presented an empirically composed supply chain volatility index and they proposed the use of key business parameters for volatility to be able to measure turbulences in supply chains and to adapt the supply chain structures. Weber et al. (2012) pointed out that supply chain volatility indicators arrived in the business world of SCM and they have to be considered in the context of KPIs due to their important role.

2.4. Building Blocks for Green Transport Corridors

Giannakis and Louis (2011) stressed that the high level of complexity of supply chains and the inherent risks that exist in both the demand and supply of resources – especially in economic downturns – are recognized as major limiting factors in achieving high levels of supply chain performance. The use of modern information technology (IT) decision support systems is fast becoming an indispensable tool for designing and managing complex supply chain systems today. This paper develops a framework for the design of a multi-agent based decision support system for the management disruptions and mitigation of risks in manufacturing supply chains.

Building blocks are well known constructs in supply chain modelling and simulation. High competition enhances the strategic relevance of supply chain design together with the need for contingency plans to be able to deal with disruptions (Mourits and Evers, 1995). An important and cost-effective way to assess supply chain performance, to validate robust and reactive supply chain designs and to understand the dynamics of supply chains are simulation methods based on agent-based models (Manzini et al., 2005).

Lopez (2012) pointed out that supply chains are complex structures and agent-based simulation models are powerful enough to holistically evaluate supply chain complexity and its impact on performance as well as to understand the supply chain's structural and behavioural characteristics. His generic supply chain agent-based modelling is based on Supply Chain Building Blocks (SCBB) characterizing supply chain stakeholders as agents whose internal structure aligns with the SCOR management processes. The SCBB possess the capability to holistically assess the supply chain performance and for controlling the development of supply chain complexity across its structure. Existing methodologies for agent-based systematic modelling are founded on blocks to identify, define and specify the required information for the model in order to be able to execute the model for analysing the systems phenomena aiming to support the decision process of the stakeholder.

Relating to the high importance of process orientation of SCM mentioned by Hahn (1999) special attention should be dedicated to the process perspective in the context of performance measurement. Performance metrics are required to be able to describe and understand the complexity and the properties of the underlying processes for supply chains. Such metrics in form of KPI systems aim to support the on-time assessment of emergent behaviour, as well as the later analysis for identifying complexity's causes and effects on performance (Lopez, 2012). For this reason logistics performance indicators have been discussed intensively in scientific literature and lists of logistics related KPI systems which are used in theory and practice have been published (Reichmann, 2001; Weber, 2002; Weber et al., 2012).

Göpfert (2013) presented an empirically founded list of 80 logistics performance indicators with a short list of outstanding logistics KPIs to control logistics processes and to benchmark logistics performance. This short list of outstanding KPIs includes average inventory in days, logistics service degree (lead time, reliability, readiness, flexibility), share of logistics costs per total costs. Thematically grouped sets of KPIs will be called in the sequel KPI building blocks and they enjoy all properties of performance metrics in supply chain management.

It has to be kept in mind that the overall goal of the supply chain KPI system is the effective and efficient management of all activities associated with the flow and transformation of goods from raw materials to the final product to be delivered to the end customer (Milgate, 2001). The performance of these goals is assessed by looking into the system's characteristics reflected in the metrics affected by complexity (Seuring et al., 2004). Since all these considerations also apply to GTC due to their underlying supply chain structures.

3. KPI building blocks for Green Transport Corridors

3.1. Research Questions and Design

It is not the aim of this paper to focus on KPI building blocks which only have an effect on one company but to also look at KPI building blocks for the entire GTC concept. Therefore, the research questions are:

RQ 1: What kind of KPI building blocks might be relevant for the implementation of a GTC?
RQ 2: How are these KPI building blocks related and how can they be ordered?
RQ 3: Which role play the KPI building blocks in the context of a GCCS?

This study targets at KPI building blocks for the implementation of GTC, based on the literature review and the identified research gap. In addition, the gained KPI building blocks will be investigated according to their relationship. Finally, the KPI building blocks will be ordered and their role within a comprehensive GTC control system will be discussed. For these purposes, the research design constitutes as follows: The empirical evidence in this paper is based on the qualitative research style (Blaxter et al., 2006).

Here, the complexity of the research question requires personal interviews and a qualitative approach. The willingness to answer questions in a greater depth and in an open discussion can only be achieved by personal and individual conversations with selected interview partners. Furthermore, performance assessment addresses a sensitive issue. Hence, it is of great importance to build trust with the different stakeholders.

The authors conducted case studies, expert interviews and workshops between 2006 and 2013 within several national and European projects comprising the BSR projects LogOn Baltic, EWTC II and BSR Transportcluster to get a better understanding of the risks that might occur during transport services in general and in supply chains within GTC (Schröder and Prause, 2015). For this, surveys, interviews and workshops that have been conducted by the authors during the European projects together with corridor managers, transport service providers, shippers and infrastructure provider have been analysed.

3.2. Identification of KPI building blocks for Green Transport Corridor implementation

The definition of the right KPIs requires a good understanding of the structure and the underlying processes together with their related key activities. The KPI approaches in business world often choose indicator sets according to a corresponding management framework and order these sets of KPIs into thematic groups of indicators reflecting related issues, processes or sub-systems like in well-known ratio systems or balanced scorecards (Reichmann, 2001; Gladen, 2005; Parmenter, 2010).

Thus, in different workshops, surveys and interviews the experts were asked about success factors for GTC implementation and which indictors for a comprehensive performance measurement of a GTC might include. Since the interviews took place during different projects and in different contexts the results lead to different sets of indicators like mentioned already in the part of the literature review. By combining the empiric results with other results from the literature review it is possible to highlight eight thematic sets of performance indicators for GTC implementation comprising finance, sustainability in three dimensions, logistics processes, cooperation intensity and quality, growth, risks as well as the infrastructural dashboard.

In accordance with the results of the EWTC project it should consider that these eight thematic sets of indicators are related to four different views of the key corridor stakeholders so that the underlying sets of KPI can differ in structure and composition among the stakeholders. A visualization of these KPI building blocks leads to figure 2.

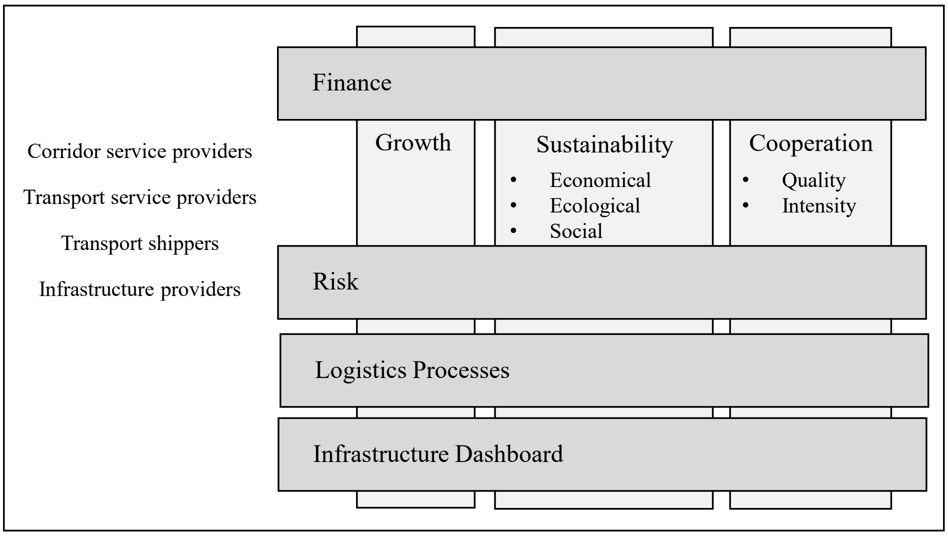


Figure 2. KPI building blocks for Green Transport Corridors

All these building blocks appear four times due to the fact that there are four key corridor stakeholders so that for each key stakeholder exists a specific layer yielding a cube or a brick structure of this KPI-system.

3.3. Performance indicators for implementation of Green Transport Corridors

The KPI building blocks frame only the thematic groups for the performance indicators which have to measure current status of a GTC. Based on the literature review together with the results of the empirical activities a set of KPI for each building block shall be discussed by considering already established indicators. For each presented indicator it has to be stressed that the final set of performance indicators has to be specified in accordance with the needs of the type of corridor stakeholder. The largest list of KPIs exists in the case of the EWTC project for the transport service providers (EWTC, 2012; table 6).

Table 6. Tentative Performance indicators for transport service providers

Tentative Performance Indicators	Unit	Building Block
Total goods volume	Tons, Tons/year	Economic Sustainability
On time delivery / Reliability	Number & % of on time services	Economic Sustainability / Process
Corridor ability and capacity	0/1	Economic Sustainability
Used capacity	% of used corridor capacity	Economic Sustainability / Process
Energy use	KWh, KWh/tkm	Ecologic Sustainability
GHG, CO2e	Tons, g/tkm	Economic Sustainability
Engine standards	Number, %	Ecologic Sustainability
ISO 9001dg	0/1	Ecologic Sustainability
Alternative fuels filling stations	Number, #/1000 km	Ecologic Sustainability
ISO 31 000	0/1	Social Sustainability
ISO 39 000	0/1	Social Sustainability
Fenced terminals used	0/1	Social Sustainability
Safe parking use	0/1	Social Sustainability
Innovation activities	% innovative companies	Growth
New services	# per year	Growth
Green corridor stakeholder fluctuation	% of stakeholders	Growth
TO of new services	% of TO	Growth
Availability of qualified workforce	% open jobs by qualification level	Growth / Risk
Data exchange	# exchanged data sets	Cooperation Intensity
Coordination needs	# coordination meetings	Cooperation Intensity
Openness	Openness indicator	Cooperation Quality
Trust level	Trust indicator	Cooperation Quality
Transparency level	Transparency indicator	Cooperation Quality
Conflict level	# uncooperative solved conflicts	Cooperation Quality
Transport costs	€/tkm	Process / Finance
Frequency	# services per day/week	Process
Lead time	# of days	Process / Financial sustainability
Return on Assets	Return/TO per assets	Financial
Logistics costs	Logistics costs per total costs	Finance / Economic sustainability
Readiness	% immediately delivered services	Process / Economic sustainability
Quality	% of complains of delivered services	Process/ Risk / Economic sustainability
Flexibility	% fulfilled special services	Process / Economic sustainability
Cargo bundling	% bundled transports	Economic sustainability
Strategy implementation	# of open strategic aims and enabling criteria	Risk/ Growth / Economic sustainability
Disharmonized standards	# used standards	Risk / Cooperation Quality
Lack in Infrastructure	# hot spots in dashboard	Risk / Process / Economic sustainability
info exchange failures	% of info exchanges	Risk / Cooperation Intensity
Accidents	# accidents	Risk, Growth
Theft and crime	Numbers	Risk
Knowledge level	# of human caused disruptions of SC	Risk/ Growth
Environmental violations	# per year	Risk / Economic Sustainability
Volatility	Volatility indicators	Risk

This list of tentative performance indicators is not complete but it represents the majority of the most important KPIs from literature review and empirical measures. The discussed performance indicators are linked to one or more thematic build blocks underpinning figure 1.

4. Conclusion and Implications

Green Transport Corridors are imbedded into an international network environment composed of different stakeholders acting along a defined geographical area in order to achieve their different goals within the frame of common corridor objectives. This requires new concepts and instruments for multi-dimensional assessment of collective strategies and processes by taking into account international and cross-company aspects. Network-oriented management control systems for GTC are still in evolution due to their underlying dynamic structures and their high complexity (Sydow and Möllering, 2009; Prause and Hunke, 2014).

A literature review revealed that KPI sets play an important role in the frame of GCCS but the existing approaches are too narrow for a successful implementation and management of corridors. Consequently, the paper proposes the use of KPI building blocks in the context of GCCS due to wide scope and higher flexibility of building blocks. The thematic focusses of the different building blocks are covered by KPI and the building blocks are linked by semantic intersections. Nevertheless the use of performance indicators for GTC is related to several open questions touching the frame conditions (Prause and Hunke, 2014).

Firstly, it has to be mentioned that the green corridor KPI are reflecting the situation on corridor level so that underlying data from stakeholder level must be collected and aggregated to corridor level. Both tasks, collection and aggregation, are not clarified until now since transparency of sensible stakeholder data as well as specifications for calculations of consolidation of values are still open. Prause and Hunke (2014) even point out that sensible internal company data are protected by corridor stakeholders.

Another open question is related to the fact that even all data would be available and even aggregation procedures for calculating corridor indicators from stakeholder data would be feasible a problem of delimitation still exists. A GTC integrates different stakeholders along a certain limited geographical area which can be described as a tubular service cluster so that logistics services between destinations outside the corridor which are using only parts of the corridor have to be taken into account for performance assessments. But how to delimit the performances and how to get the necessary data from companies outside the corridor are fully open.

Under these considerations the research open new directions towards the performance assessment of GTC and the discussed KPI building blocks represent a step forward in the evolution of green transport controlling systems. Furthermore the building blocks are pathing the way for the use of simulation in green transport corridors since they represent the link to agent based corridor simulation. For the development of a green corridor simulation platform based on building blocks more research is needed. Also the connection of KPI building blocks and existing corridor governance models have to further investigated since each governance model is linked with specific thematic emphasises.

Reference (German titles translated by the authors)

1. Blaxter, L., Hughes, C., and Tight, M. (2006) *How to Research*, 3rd ed. Berkshire: Open University Press.
2. Blum, H. (2006). *Logistics Controlling.* Wiesbaden: Dt. Universitätsverlag.
3. Brem, A.; Kreusel, N.; Neusser, C. (2008) Performance measurement in SMEs: literature review and results from a German case study. *International Journal of Globalisation and Small Business*, 2(4), 411-427. DOI: 10.1504/IJGSB.2008.018102
4. Christopher, M.; Holweg, M. (2011) Supply Chain 2.0: managing supply chains in the era of turbulence. *International Journal of Physical Distribution and Logistics Management*, 41(1), 63-82, DOI: 10.1108/09600031111101439.
5. COM (2011). *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*. Commission of European Communities. Brussels, 28.03.2011.
6. Dekker, R.; Bloemhof, J.; Mallidis, I. (2012) Operations Research for green logistics – An overview of aspects, issues, contributions and challenges. *European Journal of Operational Research*, 219 (3), 671-679, DOI 10.1016/j.ejor.2011.11.010.
7. EWTC. (2012) *Green Corridor Manual* – Task 3B of the EWTC II project.
8. FTLAP. (2007) *Communication from the Commission: Freight Transport Logistics Action Plan*. Commission of European Communities. Brussels, 18.10.2007.
9. Göpfert, I. (2013) *Logistics*, 3rd ed., München: Franz Vahlen.
10. Giannakis, M.; Louis, M. (2011). A multi-agent based framework for supply chain risk management, *Journal of Purchasing and Supply Management*, 17(1), 23-31. DOI 10.1016/j.pursup.2010.05.001.
11. Giunipero, L.C. and Eltantawy, R.A. (2004) Securing the upstream supply chain: a risk management approach. *International Journal of Physical Distribution & Logistics Management*, 34 (9), 698-713. DOI 10.1108/09600030410567478.
12. Gladen, W. (2005) *Performance Measurement - Controlling mit Kennzahlen*. 3rd ed. Wiesbaden: Gabler-Verlag.
13. Hahn, D. (1999). Thesis for the future of procuring within an integrated supply chain management. In: Hahn, D.; Kaufmann, L. (eds.): *Handbook of industrial supply management*, Wiesbaden: Gabler, 851-855.
14. Horvath, P. (2011) *Controlling*, 12th ed., Munich: Vahlen.
15. Hunke, K.; Prause, G. (2013) Management of Green Corridor Performance. *Transport and Telecommunication*, 14(4), 292-299. DOI 10.2478/ttj-2013-0025.
16. Jehle, M. (2005) *Value-oriented Supply Chain Management und Supply Chain Controlling.* Frankfurt: Lang.
17. Kajüter, P. (2003) Risk management in supply chains. In: Seuring, S., Müller, M., Goldbach, M., and Schneidewind, U. (eds.), *Strategy and Organization in Supply Chains*, Heidelberg: Physica, 321-336.

18. Kersten, W., Hohrath, P., Böger, M., and Singer, C. (2011) A Supply Chain Risk Management Process. *International Journal of Logistics Systems and Management*, 8 (2), 152-166. DOI: 10.1504/IJLSM.2011.0386
19. Lopez, A. (2012) *Agent Based Simulation Approach to assess Supply Chain Complexity and its Impact on Performance*, Lohmar: EUL.
20. Manzini, R.; Ferrari, E.; Gamberi, M.; Persona, A.; Regattieri, A. (2005) Simulation performance in the optimisation of supply chain. *Journal of Manufacturing Technology Management*, 16(2), 127-144. DOI 10.1108/17410380510576796.
21. Milgate, M. (2001) Supply chain complexity and delivery performance: an international exploratory study. *Supply Chain Management: An International Journal*, 6(3), 106-118. DOI 10.1108/13598540110399110.
22. Mourits, M.; Evers, J. (1995) Distribution Network Design: An integrated planning support framework. *International Journal of Physical Distribution and Logistics Management*, 25(5), 43-57. DOI 10.1108/09600039510089703.
23. Parmenter, D. (2010) *Key performance indicators: Developing, implementing, and using winning KPIs*, 2nd ed. Hoboken: John Wiley & Sons.
24. Pfohl, H. (2010) *Logistics systems*, 8th ed., Berlin: Springer.
25. Porter, M.E. (1998) *On competition*. Boston: Harvard Business School Publishing.
26. Prause, G. (2014). A Green Corridor Balanced Scorecard. *Transport and Telecommunication*, 15(4), 299-307. DOI 10.2478/ttj-2014-0026.
27. Prause, G.; Hunke, K. (2014) Secure and Sustainable Supply Chain Management: Integrated ICT-Systems for Green Transport Corridors. *Journal of Security and Sustainability Issues*, 3(4), 5-16. DOI 10.9770/jssi.2014.3.4(1)
28. Reichmann, T. (2001) *Controlling with performance indicators and management reports*. 6th ed. Munich: Vahlen
29. Sarkis, J. (2001) Introduction. *Greener Management International*, 35(3), 21-25.
30. Schröder, M.; Prause, G. (2015) Risk Management for Green Transport Corridors. *Journal of Security and Sustainability Issues*, 4(4), forthcoming.
31. Seuring, S., Goldbach, M.; Koplin, J. (2004) Managing time and complexity in supply chains: two cases from the textile industry. *International Journal of Integrated Supply Management*, 1(2), 180-198. DOI 10.1504/IJISM.2004.004864.
32. Seuring, S. (2006) Supply Chain Controlling: summarizing recent developments in German literature. *Supply Chain Management: An International Journal*, 11(1), 10-14. DOI 10.1108/13598540610642420.
33. Seuring, S.; Müller, M. (2008) From literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, 16 (15), 1699-1710. DOI 10.1016/j.jclepro.2008.04.020.
34. SuperGreen (2013) *SuperGreen*. Available at http://www.supergreenproject.eu, (15/08/04).
35. Sydow, J.; Möllering, G. (2009) *Production in networks*, 2nd ed., Munich: Franz Vahlen.
36. Weber, J. (2002) *Logistics and Supply Chain Controlling*, 5th edition, Stuttgart: Schäffer-Poeschel.
37. Weber, J.; Wallenburg, C. (2010) *Logistics and Supply Chain Controlling*, 10th ed., Stuttgart: Schäffer-Poeschel.
38. Weber, J.; Wallenburg, C.; Bühler, A.; Singh, M. (2012) *Logistics Controlling with ratio systems,* BVL/Otto Beisheim School of Management, Koblenz: Görres-Druckerei.

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ANALYSIS OF THE LOGISTICS INTERMEDIARIES CHOICE METHODS IN THE SUPPLY CHAINS

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The increase of the supply chains efficiency requires optimization of all types of logistic operations and functions. One of such functions is the choice of intermediaries (carriers, freight forwarders, suppliers, service enterprises etc.) and, according to some specialists, it is a major strategic decision in management supply chains. The methods of choosing the logistic intermediaries are considered in many works, however, some questions remain debatable. The article discusses the analytical and expert approaches which serve as a basis to choose the intermediaries; along with it, in the article a comparative evaluation of choice expert methods is done: point-rating assessment, analytic hierarchy process and the general algorithm for selecting; the conclusions have been drawn about the applicability of each method.

Keywords: choice of intermediaries, point-rating assessment, analytic hierarchy process (AHP), general algorithm for selecting intermediaries

1. Introduction

The increase of the supply chains efficiency requires optimization of all types of logistic operations and functions. One of such functions is the choice of intermediaries (carriers, freight forwarders, suppliers, service enterprises etc.) and, according to some specialists, it is a major strategic decision in management supply chains. It is important to point out that there are some other tasks related to this, for example, infrastructure (warehouse) object choosing, distribution centre location, motion routes, type of transportation, etc.

The logistics development tendencies analysis has shown that in all supply chains sections one can see multi-variance and uncertainty which is expressed in a big amount of intermediaries that can carry out the required conditions and in the presence of the alternative solutions, as well. The logistics intermediaries' choice problem is quite urgent and its correct solution will contribute to the risks decrease and the hardening of the company position at the market.

The article discusses the analytical and expert approaches which serve as the basis to choose the intermediaries; along with it, in the article a comparative evaluation of choice expert methods is done: point-rating assessment, analytic hierarchy process and the general algorithm for selecting; the conclusions have been drawn about the applicability of each method.

2. Literature review

We consider it appropriate to draw a quotation of Thomas L. Saaty at the beginning of the review: 'What is the best way of making decision? There are almost half a dozen methods of making decisions which give controversial results for the same data. How can we judge the approach advantages?' (Saaty, 2015, p. 25).

According to (Kopytov and Abramov, 2013), there are various methods that have been developed and implemented to analyse and choose from a range of alternatives using different criteria. The existence of this variety of methods makes the issue of choosing the most suitable one rather difficult.

The issues related to the selection of logistic intermediaries (LI) which are considered almost in all the works on logistics differ mostly by the insight into the matter and the availability of the calculated data. In most works the choice of logistic intermediaries is made under the conditions of certainty and considered to be a single-criterion or multi-criterion problem brought to a single-criterion problem.

Having analyzed the works of (Bowersox and Closs, 1996; Madera, 2010; Lukinskiy et al., 2012; Saaty, 1994; Taha, 2011 and others) one may distinguish two approaches determining the choice of intermediaries:

- the analytical approach: the choice is based on the formulas with a number of parameters specifying LI (unfortunately, this approach is almost not used in logistics and SCM);
- the expert approach is based on the experts appraisals for the parameters specifying LI and the procedures of obtaining integral expert judgements (ratings).

The expert approach includes at least three main methods:

- point-rating assessment (PRA);
- analytic hierarchy process (AHP);
- general intermediaries choice algorithm (ICA).

The point-rating assessment method (PRA). This approach is based on the attribution of some certain 'weight' to every criterion that reflects its relative importance and alternatives effectiveness evaluation (of the carriers, suppliers, freight forwarders). Rating on every criterion is determined by the multiplication of 'relative importance' and 'effectiveness' evaluations, and the final rating is determined by evaluations addition (Bowersox and Closs, 1996).

The analytic hierarchy process method (AHP) developed by (Saaty, 1994; Saaty 2015) involves consideration of the following hierarchic structure: target – criterion – alternatives.

In the work of (Kabashkin and Lučina, 2015) devoted to the model of decision support for alternative choice, the authors chose the pair wise comparison by the analytical hierarchy process because this method is based on qualitative evaluations. Therefore the results are transferred into a numerical form. The authors believe that the AHP (Analytic Hierarchy Process) is based on paired comparison and seems to be the best choice in this context since it allows structuring the choice procedure as a hierarchy of several levels.

In the work of (Kopytov, Urbach and Labendik, 2013) there is the analysis of the possibility of employing one of the most popular multiple-criteria decision analysis method 'the Analytic Hierarchy Process' to solve the problem of choosing the best method of nano-coatings. According to several authors, AHP method is the most efficient one for the choice of optimal freight transportation system. This provides a wider view of the picture to a decision maker and gives them possibilities for a more flexible process of decision making.

The AHP core lies in defining the relative indexes to evaluate alternative decisions. If we have n criterion or alternatives in the hierarchy background, there must be matrix A sized $n \times n$ created. This matrix is called the pair comparisons matrix and it reflects the decision maker's judgements.

Then, we have to verify the comparison matrix coordination according to the coordination index. In the work of (Taha, 2011) it is mentioned that the comparison matrixes are built according to the human judgements, so it is possible to expect some degree of incoordination and it is necessary to treat it with tolerance provided it stays within some definite 'possible' limitations.

According to (Kopytov and Abramov, 2013), the different groups of criteria have been evaluated by different experts. For instance, the economists have assessed the cost criteria; the transport technologists have evaluated the reliability and ecological criteria, while the managers have estimated the time criteria. The possibility of the pair-wise comparison of a smaller number of criteria in every group allows the experts to determine in a better way the weighted values according to these criteria. The authors have suggested that the number of criteria in each considered group should vary from 3 to 7. The evaluation of the significance of the criteria groups was determined by the experts with greater qualification.

According to the most experts' opinion, the AHP method enables us to control the experts' judgement solvency and allows increasing the evaluation reliability.

The general intermediaries choice algorithm (ICA) proposed in the work of (Lukinskiy et al., 2012) is, basically, the further development of point-rating assessment method. The ICA is based on the following positions: the criteria are subdivided into three groups: quantitative, qualitative and relay (or 'killer-evaluation'); the simplified pair-comparisons method (or AHP) is used to rank the criteria; quantitative data processing is carried out by the qualimetry methods, and to obtain quality criterion values we suggest to use Harrington desirability function. The calculation of the integral estimates is a sum of qualitative and quantitative criteria evaluation considering the criterion weight.

Unfortunately, among the accessible sources, except for (Lukinskiy and Katkova, 2014), the authors have not managed to find any work containing the comparative evaluation of the depicted methods. So, in spite of the fact that the examined work seems quite simple, in our opinion, there are several aspects of its solution that require additional researches to increase accuracy, transparency and unambiguity of the obtained results. Besides, analysis and systematization of different approaches will allow passing to the development of the combined model which is the synthesis of analytical and expert methods.

3. Comparative analysis of the logistics intermediaries choice method

This methodics approach is intended to clarify and unify the existent methods and intermediaries choice algorithm. And the essence of this approach is to carry out comparative calculations on the same empirical or experimental data. As a result of the analysis and structuring of obtained quantitative evaluations it will be possible to achieve the following objectives:1) to clarify the possibilities of every method; 2) to define the limits of their application; 3) to identify where it is advisable to use various methods altogether (to increase the decisions accuracy and reliability); 4) to classify approaches and methods for solving specific problems of choosing in supply chains in a view of the specifics of the executed logistic functions and operations.

Evidently, along with the relative calculations experience accumulation, there will be an opportunity to define some specific limitations of management decision making on the basis of one or multi-criteria assessments.

Let us examine these indicated intermediaries choice methods in a more detailed way to obtain the goal and to increase the reliability of relative calculations results.

Point-rating assessment method implies the implementation of the following stages.

1. One has to define the alternatives choice criteria and their specific measures a_{ij} for the goods intermediaries (suppliers) qualities and so on.
2. One has to choose the evaluation principles for each criterion and define their measurements scales.
3. One has to introduce measurement indexes w_i in the view of each criterion importance.
4. The points calculation is done by the formula

$$A_j = \sum_{i=1}^{n} w_i \cdot a_{ij} \, , \tag{1}$$

where A_j is the final point grade of the j-th alternative (intermediary); a_{ij} is the indicator (points) for the i-th criterion and the j-th alternative.

5. Decision making of the intermediaries choice A_{max} based on final point grades comparison A_j :

$A_{min} \leq A_1, ..., A_{n-1} \leq A_{max}$

The algorithms and integral evaluations calculations examples of logistic intermediaries given in these works differ from each other because the experts participating in the evaluations procedures have not been fully enough formalised and widely varies (for the criteria and alternatives we use points (ranks, weights, ratings) and specific indexes), wherein, their quantity evaluation is often very arbitrary.

On the one hand, this complicates obtaining of final results; on the other hand, this provokes choosing LI in various ways even for the same logistic system because some operations are arbitrary and subjective.

Analytic hierarchy process method. Analysis of the various sources has revealed that AHP covers more and more directions of human activity where it is required to make decision in the conditions of uncertainty or on the basis of the so-called "intangible (psychological, non-material) resources (signs)" (Saaty, 2015).

The calculation order of the weight indexes (criteria and alternatives) matrix according to AHP consists of the following stages.

Stage one. The pair-comparison matrix (PCM) is formed at the each chosen hierarchy level for the criteria and alternatives:

$$M = \begin{pmatrix} 1 & a_{12} & a_{13} \\ 1/a_{12} & 1 & a_{23} \\ 1/a_{13} & 1/a_{23} & 1 \end{pmatrix} \tag{2}$$

The experts choose components a_{ij} from the so-called fundamental scale: 1, 2, …9.

The second stage involves receiving the standardised matrix w_{ij} (each component is divided into the sum of table components, for example, 1 is divided into (1 + $1/a_{12}$ + $1/a_{13}$) and so on:

$$M_N = \begin{pmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{pmatrix} \quad (3)$$

Stage three. The average value of the matrix lines components sums give corresponding weight of every criterion or alternative w_n, for example, w_A, w_B, w_C. After being ranged the obtained values of the precedence matrix w_n are the solutions of the problem of resources distribution.

Stage four. At the fourth stage the matrix coordination is checked. To solve this task one has to calculate the proper matrix value n_{max} which was received when matrixes M and w_n had been multiplied. Then, the coordination relation C.R. is calculated by the formula:

$$C.R. = \frac{C.I.}{R.I.} = \frac{(n_{max} - n)}{(n-1) \cdot R.I.} \quad , \quad (4)$$

where C.I. is the coordination index of matrix M, and R.I. is the stochastic index of the matrix M coordination.

The values of R.I. for the various order matrixes n are shown in the form of a table (Saaty, 1994) or can be calculated by the formula (Taha, 2011)

$$R.I. = \frac{1{,}98 \cdot (n-2)}{n} \quad (5)$$

It is important to emphasise that R.I. is an empiric value which is the average meaning (expected value) of the coefficient C.I. for the large selection of randomly generated inversely proportional matrixes of the M kind.

The size of the 'admissible' limits of C.R. is set in the following way: if C.R.≤0,1, then the incoordination is acceptable, otherwise, the level is considered to be high and it is recommended to check pair-comparison components to obtain a more coordinated matrix. In the work of (Saaty, 2015) there is the following clarification: for the matrixes of n=3 order it is advisable to satisfy the condition C.R.≤0,05; for n=4 C.R.≤0,08; and finally, for all the other matrixes we can permit C.R.≤0,2, but not more than that.

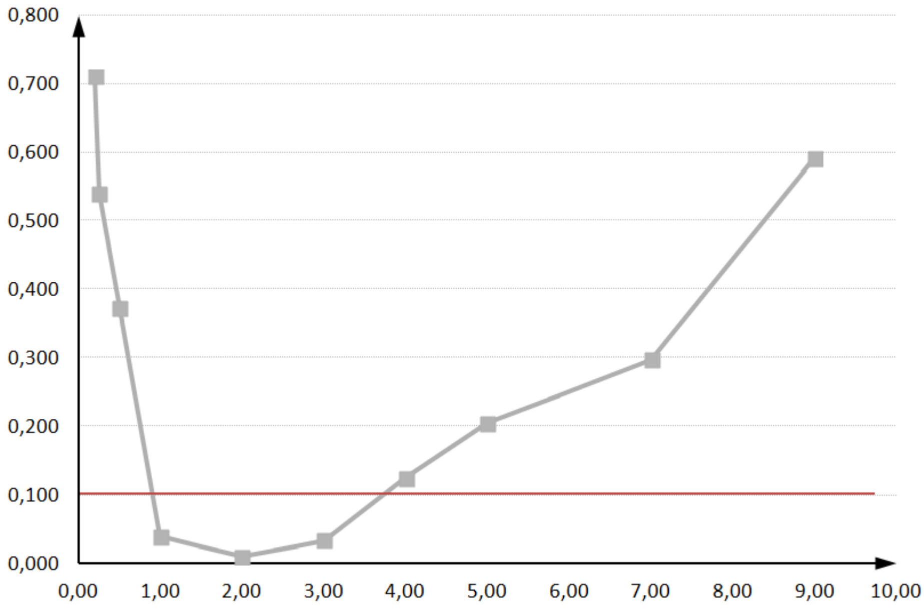
In spite of the increasing popularity of AHP there are still some discussible questions.

1. Why do we need to use the "fundamental scale" of Saaty (1, 2, ., 9) for alternatives and criteria having material nature (cost, weight, time etc.)?
2. Is it always necessary to use the fundamental scale for matrixes 3x3, 4x4, 5x5 or it is possible to use other scales (for example, Harrington's (1, 2, ., 7)?
3. Why is it thought that the coordination index of CI is the dispersion of an error the origin of which is conditioned by matrix components evaluation inaccuracy of a_{ij}? But what is the source of such an error: expert's opinion or other unknown (inexplicable) reasons?
4. What do we need to do if a matrix appears uncoordinated, i.e. C.R.>0,1? In this case, according to AHP, it is necessary to study the problem deeper and revise judgments. Attempts to use this recommendation have shown that with seeming simplicity, it is possible to "deform" the matrix of pair comparisons several times and obtain a necessary result, but then the expert practically renounces the authorship.
5. Why can we see the following contradiction: from the 40 matrixes sized of 3x3 which have been composed by the experts (Saaty, 1994) the coordination C.R.≤0,1 can be seen in 35 matrixes, i.e. in 88%; in the same work the coordination was 21% as a result of a statistic modelling of 100 matrixes?

Let us examine the matrix (C.R.=0,0391) to explain this effect:

$$M = \begin{pmatrix} 1 & 5 & 3 \\ 1/5 & 1 & 1/3 \\ 1/3 & 3 & 1 \end{pmatrix}$$

Let us do the calculations for the 16 variants and in each of them we will change only one component a_{13}, i.e., we will exchange the number 3 into 9, 8, …, 1,…, 1/9 (the meaning of a_{31} changes accordingly). In figure 1 there are calculation results that show only when a_{13}=1, 2 and 3 we can observe C.R.≤0,1, that is about 18%.



a_{13}	0,20	0,25	0,50	1,00	2,00	3,00	4,00	5,00	7,00	9,00
C.R.	0,711	0,540	0,373	0,040	0,010	0,034	0,125	0,205	0,298	0,592

Figure 1. The dependence of C.R. from the component meaning change of PCM

Thus, in spite of the obvious successes of the AHP use in several serious projects, we suppose that some aspects require further research.

The general intermediaries choice algorithm (ICA).

Taking into account the ambiguousness of some positions of AHP, in the work of (Lukinskiy et al., 2012) there was offered an alternative variant of the logistic intermediaries choice in supply chains. The fundamental difference between the ICA and AHP is that ICA provides for the reliable main intermediaries choice while AHP aims at forming the precedence matrix w_n which allows distributing of recourses among all the participants (alternatives).

Let us examine the intermediaries choice evaluation order using ICA which algorithm is shown in figure 2. The following modules in this algorithm are of the most interest.

1. The experts rank the indexes using the pair-comparisons; one of the possible variants is to calculate precedence matrix w_n according to AHP.

2. For the approximation of w_n the discrete distributions are used, e.g., the one of Poisson's or Fishburn's (Taha, 2011; Fishburn, 1972).

3. The qualimetry methods are used for the intermediaries (alternatives) quantitative indexes; the Harrington's desirability function is used for the qualitative ones.

At the same time the conducted calculations with the use of ICA have shown that some questions need further research, particularly, they need extra variants of applicable distribution laws and the use of the fuzzy sets to evaluate quality indexes, as well.

Summarizing the results of the analysis it is possible to state that each from the examined methods has some certain reliability degree, but it is possible to draw a conclusion about the possible areas of their use only after realization of comparative calculations.

4. Approbation

The comparative calculations have been executed for approbation of an offered methodical approach based on the data from the works of (Bowersox and Closs, 1996; Brodetskiy and Terentiev, 2005; Guy and Malakhov, 2011; Madera, 2010; Lukinskiy et al., 2012; Taha 2011). The calculation results are shown in tables 1-5. Let us examine them in a more detailed way.

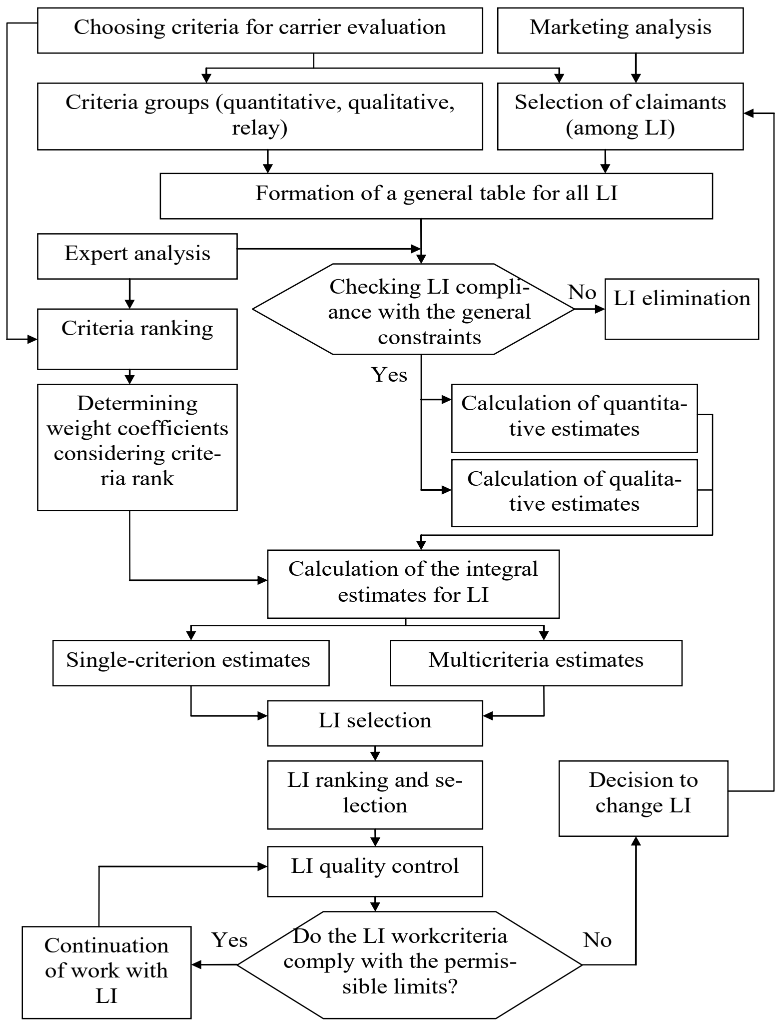


Figure 2. Algorithm for choosing logistic intermediaries

Example 1. In the work of (Lukinskiy et al., 2012) with the help of PRA the carriers choice is done (with 3 alternatives) using 5 criteria (table 1). In this table there are calculations based on ICA, wherein the Fishburn's distribution is chosen for the point indexes evaluation, and the minimum points have been chosen as a standard meaning during the alternative evaluation.

Table 1. Intermediaries choice results comparison

Method	Evaluation	The 1st carrier	The 2nd carrier	The 3rd carrier
PRA	Summary rating	20,99	14,94	21,02
	Place	2 (3)	1	2 (3)
ICA	Integral evaluation	0,697	0,698	0,554
	Place	2 (3)	2 (3)	1
Note: the best evaluation is a minimum rating				

Example 2. In the work of (Taha, 2011) the task of choosing the university (3 alternatives) is examined according to two criteria: place and reputation. The corresponding calculations are brought over in table 2, wherein the system analysis and AHP have been used to estimate the values of the criteria and the alternatives.

The calculations of PRA and two variants of ICA have been performed using the same data: in the first one the criteria evaluations were the same as the ones from the work of (Taha, 2011); in the second one the criteria evaluations were calculated by the Fishburn's formula (table 2).

Table 2. The results comparison of choosing among three universities

Method	Evaluation	University		
		A	B	C
PRA	Summary rating	31,7	18,5	18
	Place	1	2	3
AHP and system analysis	Combined weight	0,4743	0,2737	0,2520
	Place	1	2	3
ICA (the 1st variant)	Integral evaluation	0,867	0,487	0,440
	Place	1	2	3
ICA (the 2nd variant)	Integral evaluation	0,739	0,482	0,550
	Place	1	3	2

Example 3. In the work of (Brodetskiy and Terentiev, 2005) on the basis of AHP the choice of a city (4 alternatives) is done to optimise the location of the regional distribution centre using 6 criteria. All the values are obtained as a result of the expert survey, that is, without any real data. The calculations results are shown in table 3. In the same table there are ICA calculations results based on the point evaluations of the pair wise indexes and alternatives comparisons, that is, without the matrixes rationing procedure or coordination checking.

Table 3. The comparison results of choosing a location of the regional centre

Method	Evaluation	City (regional centre)			
		A	B	C	D
AHP	Summary rating	0,458	0,309	0,129	0,112
	Place	1	2	3	4
ICA (the 1st variant)	Integral evaluation	0,860	0,588	0,253	0,226
	Place	1	2	3	4
ICA (the 2nd variant)	Integral evaluation	0,827	0,619	0,291	0,265
	Place	1	2	3	4
Note: in the the 1st variant only the alternatives have been calculated; in the 2nd variant the alternatives and criteria have been calculated.					

In tables 4 and 5 there are the results of the comparative calculations of choosing a location for the supermarket (Madera, 2010) and the terminal (Guy and Malakhov, 2011) correspondingly. The main difference between these calculations and the previous ones is that instead of the points the quantitative and qualitative evaluations have been used for the alternatives. Accordingly, in the same tables there are the ICA.

Table 4. The comparison results of choosing a location of the supermarket construction

Method	Construction placement				
	A	B	C	D	E
AHP	3	1	5	2	4
ICA	2	1	5	3	4

Table 5. The comparison results of choosing a location of the terminal

Method	Container terminal location					
	A	B	C	D	E	F
AHP	1	6	2	4	5	3
ICA	1	6	2	3	5	4

5. Conclusion

On the basis of the analysis of the executed calculations it is possible to conclude the following.

1. The intermediaries choice results (of suppliers, carriers, locations, etc.) which have been calculated according to the different methods almost coincide, particularly those ones who got the best ratings (places 1 and 2).

2. The ICA method is more difficult that the PRA one, but its objectivity is higher because it allows not only to decrease point assessment variation, but to unite them by the certain patterns, as well. Apart from that, if the alternatives assessments have quantitative (qualitative) evaluations, there is no need for the points use.

3. We believe that the AHP method possesses substantial advantages without having any quantitative (tangible) information except for the experts' evaluations. At the same time, its laboriousness increases considerably comparing to PRA and ICA (especially within the criteria and alternatives increasing). Besides, it is important to remember about possible difficulties of coordinated precedence matrixes obtaining.

4. It is obvious that the ICA method produces almost the same evaluations as the AHP method does, and can be widely used taking into consideration the simplicity and larger unambiguity, and transparency of the experts' evaluations.

All in all, the development of the combined methodics must be the main direction of the further researches. This methodics consists of two approaches: the first one is analytical, for example, on the basis of total logistics costs (TLC), besides, TLC must include the maximum quantity of factors; the second approach is the expert one. It can include different variants, for example, in the case of an obvious situation it must include PRA; and in the case of moderate uncertainty and risk it must include ICA; under the conditions of total uncertainty it must include AHP.

References

1. Bowersox, D.J. and Closs, D.J. (1996) *Logistical Management. The Integrated Supply Chain Process.* New York: McGraw-Hill Companies, Inc.
2. Brodetskiy, G. and Terentiev, P. (2005) Application of an analytical heirarchy method for optimization of a local distribution centre disposition. *Logistics and supply chain management.* 1(6), 26-34. (In Russian)
3. Fishburn, P.C. (1972) *Utility theory for decision making*. New York: Wiley.
4. Guy, V. and Malakhov, D. (2011) Choosing a site for an off-dock terminal in the St. Petersburg transport hub using analytic hierarchy process. *Logistics and supply chain management.* 1(42), 55-59. (In Russian)
5. Kabashkin, I. and Lučina, J. (2015) Development of the model of decision support for alternative choice in the transportation transit system. *Transport and Telecommunication*, 16 (1), 61-72. DOI: 10.1515/ttj-2015-0007.
6. Kopytov, E., Abramov, D. (2013) Multiple-creteria choice of transportation alternatives in freight transport system for different types of cargo. In: *Proceedings of the 13th international conference: Reliability and statistics in transportation and communication (RelStat'13)*. October 16–19, Riga, Latvia, pp. 180–187.
7. Kopytov, E., Urbach, A., Labendik, V. (2013) Comparative multi-criteria assessment of nano-coating technologies. In: *Proceedings of the 13th international conference: Reliability and statistics in transportation and communication (RelStat'13)*. October 16–19, Riga, Latvia, pp. 207–216.
8. Lukinskiy, V.V. and Katkova H. (2014) Analysis of methods for choice of logistics intermediaries. *Logistics and supply chain management.* 2(61), 49-56. (In Russian)
9. Lukinskiy, V.S., Lukinskiy, V.V., Malevich, J. Plastuniak, I., Pletneva, N. (2012) *Models and methods of the logistics theory*. St.Petersburg: SPbSUEE.
10. Madera, A.G. (2010) *Modelling and decision-making in management.* Moscow: LKI. (In Russian)
11. Saaty, T.L. (1994) *Fundamentals of Decision Making*. Pittsburgh: RWS Publications.
12. Saaty, T.L. (2015) *Decision making with dependence and feedback. The Analytic Network Process.* Moscow: Lenand. (In Russian)
13. Taha, H. (2011) *Operations Research: an Introduction*. 9th ed. Upper Saddle River, New Jersey: Prentice Hall.

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OIL POLLUTION OF THE SOUTHEASTERN BALTIC SEA BY SATELLITE REMOTE SENSING DATA AND IN-SITU MEASUREMENTS

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Results of operational satellite monitoring of oil pollution of the sea surface together with in-situ measurements of the oil products concentration in the water column for the first time allowed to establish relation between the surface pollution originated from ships, and the general characteristics of spatial and temporal distribution of oil products in the water column in the Southeastern Baltic Sea. Areas with heightened concentrations of oil products in the surface and bottom layers were determined for the study area. The main directions of the contamination propagation are agreed with the main direction of annual mean transport of substances in the Gdansk Basin.

Keywords: the Southeastern Baltic Sea, oil pollution, satellite monitoring, field measurements, geochemical barriers, D-6 oil platform

1. Introduction

The main sources of oil pollution of the sea are ships, seepages from the seabed, rivers runoff, municipal and industrial discharges, and the atmosphere (Nelson-Smith, 1977; Burger, 1997; Patin, 2001, 2008; Nemirovskaya, 2004, 2012, 2013; Kostianoy and Lavrova, 2014). Oil pollution of the seas and oceans fall into chronic pollution (permanent pollution in small portions due to anthropogenic impact or natural causes) or accidental pollution (a rare but usually severe contamination as a result of catastrophic oil spills from ships, oil platforms, and offshore pipelines). The relative proportions of each of the sources (or causes) of oil pollution vary by 10 to 100 times, which is explained by different methods of estimations, the specifics of different regions of the oceans and inland seas, as well as by various decades taken for the analysis. The largest portion (20-50 %) of the total pollution of the oceans by oil products is associated with maritime transport (Burger, 1997; Patin, 2008; Nemirovskaya, 2013; Kostianoy and Lavrova, 2014).

During the last decade the intensity of shipping in the Baltic Sea is constantly growing. The number of vessels and their size is increasing, and this trend will continue in the nearest future. This leads to an increase in the chronic oil pollution, as well as to an increasing risk of a large oil spill in the Baltic Sea (HELCOM, 2013; Kostianoy and Lavrova, 2014; Kostianoy et al., 2015). Since 2004, in the Russian sector of the Southeastern Baltic Sea there is an oil extraction from the oil field Kravtsovskoye (D-6) operated by LUKOIL-KMN, Ltd. what involves certain risks of oil pollution.

The basic physical, physicochemical, and biological processes in the sea are associated with the location of contacting and interacting mediums and phases of the matter, the so-called, geochemical barriers (Emelyanov, 1986, 1998). It is known that the most important natural geochemical barrier zones for the Russian sector in the Southeastern Baltic Sea, in the absence of major rivers, are the following boundaries: "sea - atmosphere", "water - bottom" and "the sea - shore". The most subjected to the anthropogenic impact part of the marine environment is the sea surface. The main gas exchange with the atmosphere takes place through it. The bottom sediments, in turn, are a permanent source of secondary pollution of the sea (Nemirovskaya, 2012, 2013). Therefore we will consider the spatial and temporal characteristics of the oil products distribution on the basic physicochemical barriers.

The aim of this paper is to compare the oil pollution on the sea surface derived from satellite observations and in-situ measurements of the oil products concentration in the surface and near-bottom layers of the sea water in the Southeastern Baltic.

2. Data and Methods

2.1. Satellite observations

Satellite monitoring of the Southeastern Baltic Sea surface is carried out from the beginning of oil extraction at the D-6 - from June 2004 (Kostianoy et al., 2006, 2015; Bulycheva and Kostianoy, 2011, 2014; Lavrova et al., 2014). The main purpose of satellite observations is to detect oil slicks at the sea surface. From 12 June 2004 to 31 December 2014 for the purpose of satellite monitoring the images from several satellites were received and analyzed: ENVISAT (European Space Agency - ESA) - 1143 ASAR images, RADARSAT-1 (Canadian Space Agency - CSA) - 298 SAR images, RADARSAT-2 (MacDonald, Dettwiler and Associates, Ltd. – MDA, Canada) - 343 SAR images, as well as satellites of the Italian Space Agency (ASI) Cosmo-SkyMED-1, -2, -3, -4 - 61 SAR images (Fig. 1).

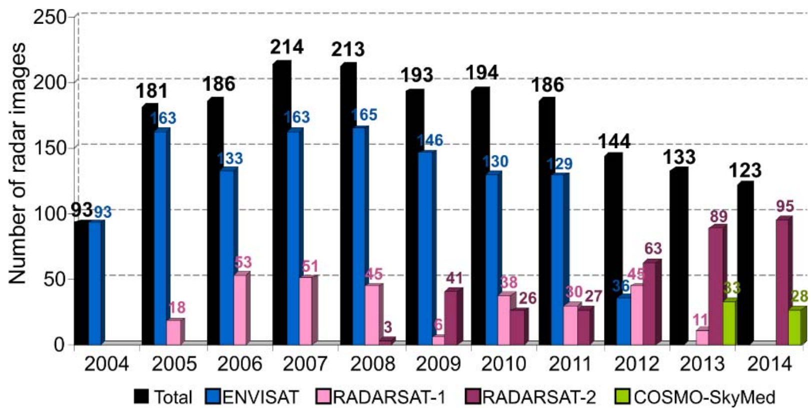

Figure 1. The number of SAR/ASAR images received from different satellites and analyzed (see Kostianoy et. al., 2015)

All these satellites are equipped with a synthetic aperture radar (SAR), which records the spatial variability of gravitational-capillary waves which are always present on the sea surface. The films of different origin, such as oil, biogenic, synthetic surfactants, as well as algal blooms, sea ice, and a number of hydrophysical and meteorological processes locally modify the surface roughness of the sea surface basically due to viscosity and form the smooth surface areas (slicks), which are captured by the SAR. The main advantages of the satellite SAR systems are the abilities to work in all weather conditions and independence on daylight. A limitation of the method is the condition that the near-water wind speed should be in the range of 2-10 m/s, otherwise radar images are not informative because of large areas of calm water in the sea (no roughness) at winds of 0-1 m/s or at winds >10 m/s when breaking wind waves dominate in the formation of the sea roughness. The processed radar images were received from the Norwegian satellite operator - the Kongsberg Satellite Services (KSAT, Tromsø). The interval between the successive SAR images ranged from 12 to 72 hours.

2.2. Field measurements

Concentrations of oil products in the sea water were obtained during the complex industrial environmental monitoring of the oil field Kravtsovskoye in 2003-2014 in the standard points of monitoring (Fig. 2). Sea water was sampled by plastic water sampler from the surface layer (0.5-1.0 m) and near-bottom layer (1.0 m from the bottom), as well as from the intermediate layers (10, 30, 50 and 70 m) depending on the depth at the point. Concentrations of oil products obtained during one survey at close points around the D-6 platform (the distance between points vary from 250 to 1000 m) were averaged to a single value. Concentrations of oil products in sea water were determined in the Federal State Unitary Enterprise Atlantic Research Institute for Fishery and Oceanography (Kaliningrad) by the fluorimetric method on the analyzer of liquids "Fluorat-02" (Document, 1998a, b).

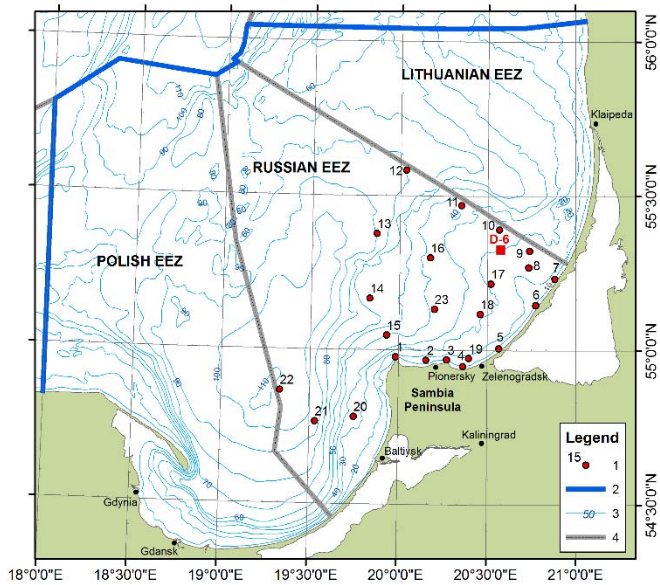

Figure 2. Study area.
Legend: 1 - points of sampling; 2 - area of satellite monitoring; 3 - isobaths, m; 4 – boundaries of Exclusive Economic Zones (EEZ)

3. Results of satellite observations

From 12 June 2004 to 31 December 2014 1845 satellite radar images were received and analyzed, and 1193 oil spills were detected. 616 oil slicks were located within the study area (Fig. 3). The most of the detected oil spills were observed in spring and summer (Fig. 4, Fig. 5) what could be explained by moderate near-water wind speed prevailed in these seasons, and oil slicks are well identified on the radar images. In autumn and winter time strong winds dominate in the region, and the SAR method does not work well (Bulycheva and Kostianoy, 2014). The study of seasonal variability of oil pollution was made in accordance with hydrological seasons specific for the Southeastern Baltic Sea. In particular, in the Gdansk Basin the period from January to March is taken as winter, April-June – is spring, July-September – is summer, and October-December – is autumn (Bernikova et al., 2007). About 80 % of all oil spills were detected from April to September, what corresponds to 86 % of the total area of oil spills detected in the area of satellite monitoring.

According to satellite radar imagery, the most polluted waters in the Southeastern Baltic Sea are the areas of shipping routes, anchorages to the west of the Sambia Peninsula, and the approaches to the port of Baltiysk. The sources of oil pollution northward of the port of Pionersky are small fishing ships (Bulycheva et al., 2014). The combined analysis of the shapes and concentration of oil spills with the location of the main navigation routes based on the Automatic Identification System (AIS) for the Baltic Sea (Fig. 6) led us to a conclusion that the main sources of oil pollution are different ships (Kostianoy and Lavrova, 2014; Bulycheva and Kostianoy, 2014; Kostianoy et al., 2015). The detailed examination of the Fig. 6 reveals that the oil spills are slightly displaced from the shipping routes - the places of their potential origin. This is explained by the peculiarities of hydrometeorological regime in the Southeastern Baltic Sea and general scheme of water circulation in the Gdansk Basin (Meier, 2007). Another reason is the pollution from small ships which are not equipped with the AIS (Bulycheva et al., 2014).

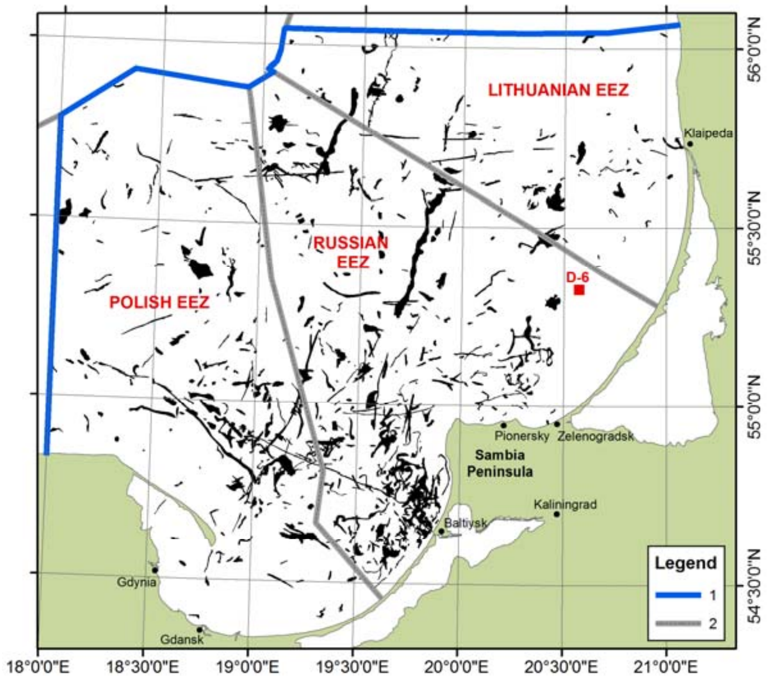

Figure. 3. Summary map of oil spill detected in the result of radar images analysis from 12.06.2004 to 31.12.2014
Legend: 1 – Area of satellite monitoring; 2 – boundaries of Exclusive Economic Zones (EEZ).
The real shapes of oil spills are presented

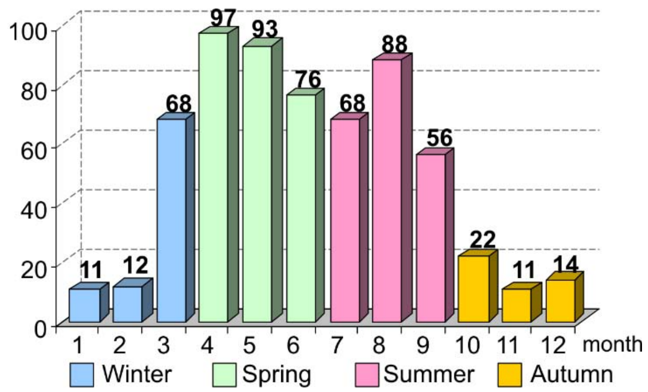

Figure 4. Seasonal variability of number of detected oil spills from 12.06.2004 to 31.12.2014

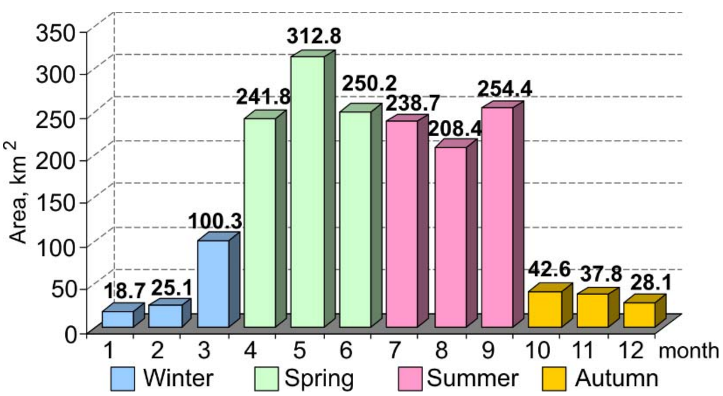

Figure 5. Seasonal variability of oil pollution area observed by satellite radar data from 12.06.2004 to 31.12.2014

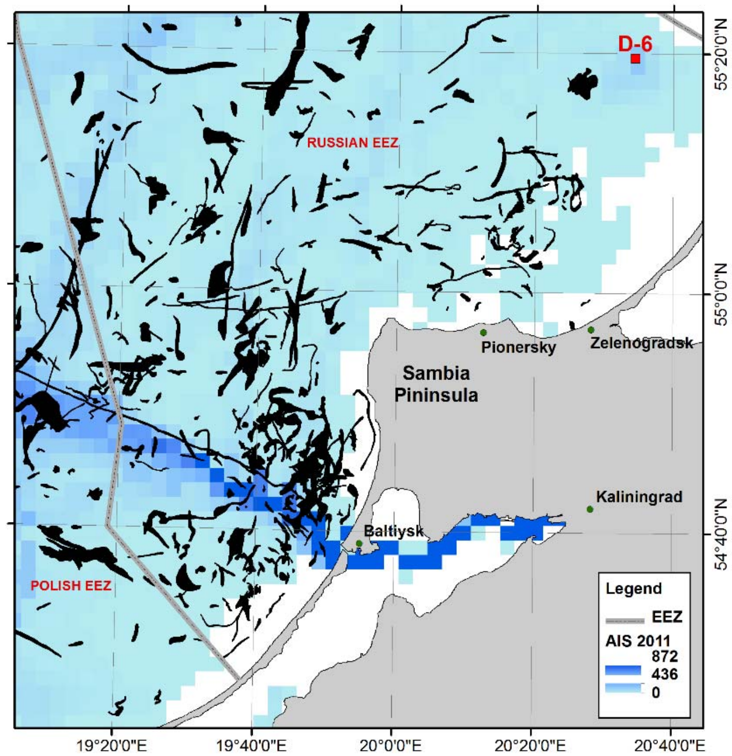

Figure 6. Density of the AIS signals according to (HELCOM, 2011) and oil spills detected from 12 June 2004 to 31 December 2014

The interannual tendency to reduction of oil pollution in the Southeastern Baltic Sea was observed from 2006 to 2011 (Fig. 7) (Bulycheva and Kostianoy, 2014). According to HELCOM, a similar trend was observed for the whole Baltic Sea in 1988-2011 (Kostianoy and Lavrova, 2014). In 2012, there was a sharp increase in the number of detected oil spills and as a result, the total area of oil pollution. In 2013, with a relatively small number of oil spills we observed a high total area of oil pollution what could be explained by a huge oil spill detected on 13 September 2013 (Bulycheva and Kostianoy, 2014).

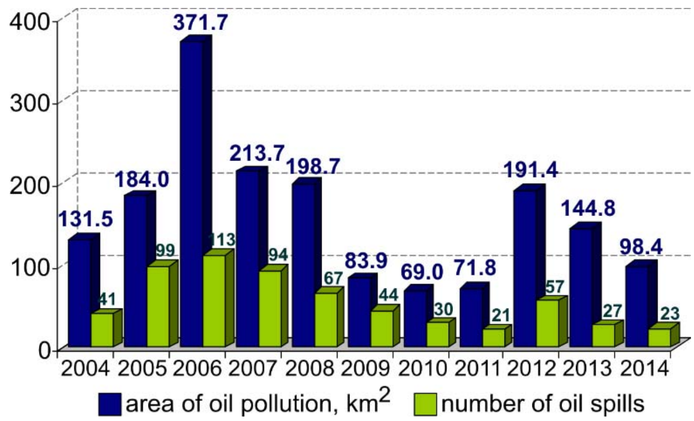

Figure 7. Interannual variability of area of oil pollution and the number of oil spills in the Southeastern Baltic Sea

4. Results of in-situ observations

In the interannual variability, the maximum concentrations of oil products in the surface and near-bottom layers were observed in 2003 (Fig. 8), what was associated with the accident of the Chinese tanker "Fu Shanghai" in the Southwestern part of the Baltic Sea, and the specific hydrometeorological conditions at that time (Nemirovskaya, 2012). Therefore, the data for 2003 were not taken into account for further analysis.

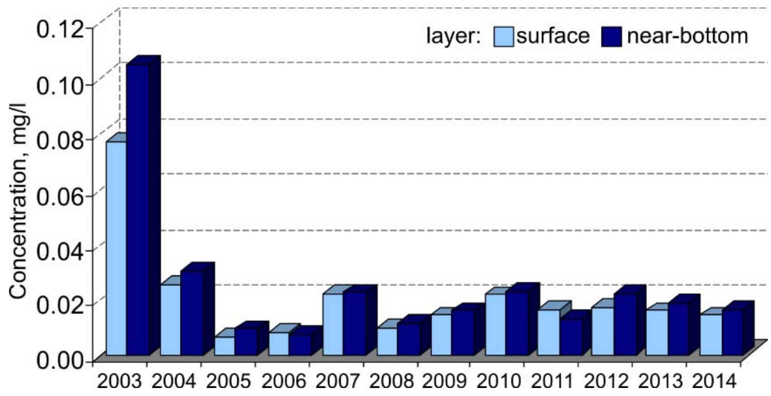

Figure 8. Interannual variability of the averaged concentration of oil products in the surface and near-bottom layers of the Southeastern Baltic Sea

Vertical distribution of the concentration of oil products and suspended matter in the water column were likely similar at different points. It is known that the gradient of density layer is the boundary separating the inflow of oil products from the sea surface, and the secondary pollution from the bottom sediments (Afanasyeva et al., 1990; Emelyanov, 1998). The highest values of oil products concentrations were observed at the sea surface, while the secondary maximum - above the main halocline at the depth of about 70 m. Therefore, at the deepwater points (>70 m deep) instead of oil concentration in the near-bottom layer, the concentration of oil products above halocline were used.

The average and maximum concentrations of oil products in the surface layer were slightly higher than similar concentrations in the near-bottom and intermediate layers (Table 1), what may indicate that the main source of oil products in the water column is the sea surface. A similar vertical distribution of the oil products concentration in different seasons was observed. Its maximum value was detected in spring and the minimum - in the autumn (Table 2). In all cases, the average concentration did not exceed the maximum permissible concentration = 0.05 mg/l (Order of the Federal Fisheries Agency, 2010).

Table 1. Concentrations of oil products in the Russian sector of the Southeastern Baltic Sea

Layer	Concentration, mg/l		
	min	**average**	**max**
Surface	0.001	0.018±0.021	0.208
Near-bottom	0.001	0.016±0.018	0.183
Water column	0.001	0.016±0.018	0.136

Table 2. Seasonal variability of concentrations of oil products in the surface and near-bottom layers in the Southeastern Baltic Sea

Season	Surface layer, mg/l	Near-bottom layer, mg/l
Winter	0.016±0.020	0.015±0.017
Spring	0.027±0.032	0.019±0.022
Summer	0.019±0.017	0.017±0.017
Autumn	0.014±0.011	0.012±0.009

In shallow coastal waters, near D-6 oil platform (monthly measurements in 2011-2014) the maximum average concentration of oil products were recorded in the surface layer (0.026 ± 0.014 mg/l) with the subsequent decrease of the concentration to the bottom (0.020 ± 0.011 mg/l – in the water column and 0.019 ± 0.009 mg/l - near the bottom). In general, areas of heightened concentrations of oil products in the surface and near-bottom layers are consistent with the main direction of transport of matter from the area of maximum accumulation of oil spills detected from satellite observations (Fig. 9, Fig. 10).

In the surface and near-bottom layers, areas with heightened and low concentrations of oil products were determined (Fig. 9, Fig. 10). At the sea surface, heightened concentrations were observed in waters adjacent to the Sambia Peninsula (Fig. 9). The maximum average concentrations of oil products were recorded at points 2 and 20 and amounted to 0.044 ± 0.046 mg/l and 0.035 ± 0.023 mg/l, respectively. A small exceeding of the concentration of oil products was noticed around the D-6 oil platform in the surface and near-bottom layers (Fig. 9, Fig. 10).

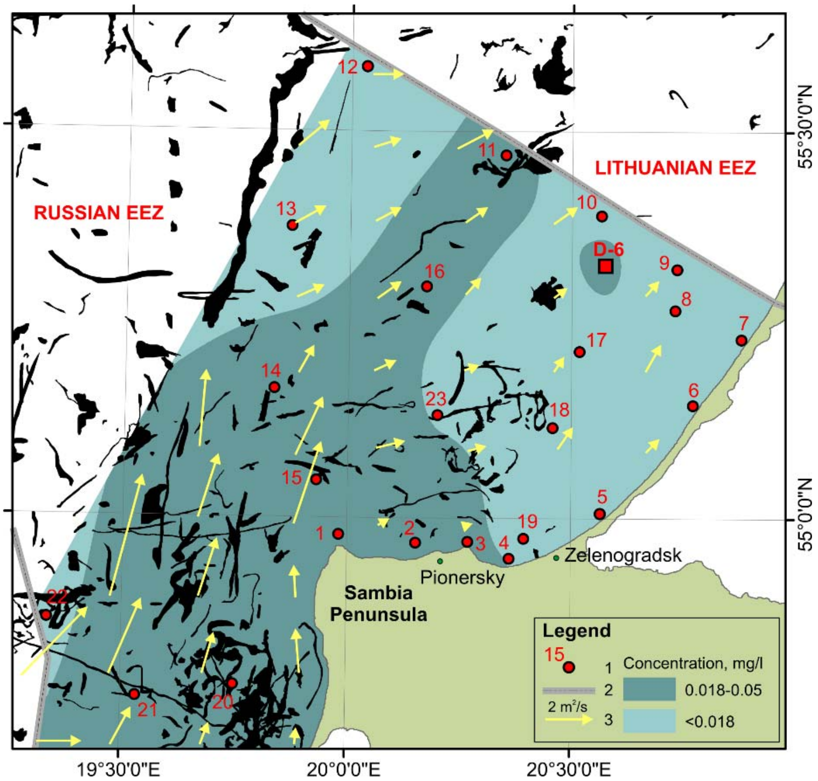

Figure 9. Spatial distribution of oil spills, mean annual concentration of oil products in the surface layer and the mean transport of matter in the surface layer of the Southeastern Baltic Sea.
Legend: 1 - points of water sampling; 2 - EEZ; 3 - transport of matter in the surface layer according to (Meier, 2007)

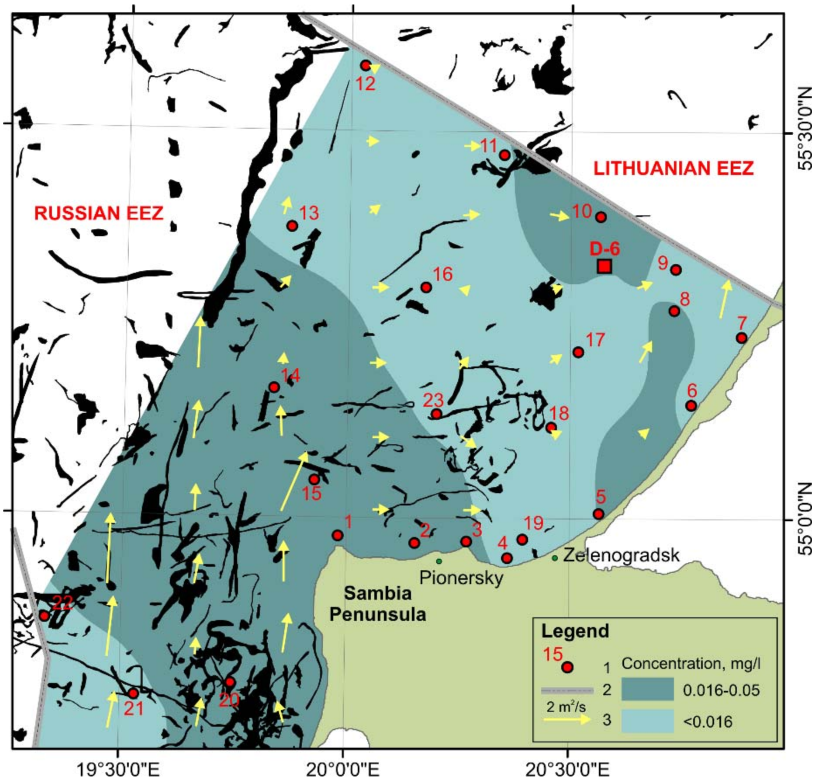

Figure 10. Spatial distribution of oil spills, mean annual concentration of oil products in the near-bottom layer and the mean transport of matter in the near-bottom layer of the Southeastern Baltic Sea.
Legend: 1 - points of water sampling; 2 - EEZ; 3 - transport of matter in the near-bottom layer according to (Meier, 2007)

Taking into account the system of currents in the Gdansk Basin (Meier, 2007) and the average direction of the near-water wind, directed to the North-East (Stont, 2014), there are favorable conditions for the transfer of matter from the main area of contamination to the North and North-East (see Fig. 9). In the particular cases, around the Taran Cape, there is a sufficiently complex system of currents enveloping the cape and propagating along the northern coast of the Kaliningrad Region (Meier, 2007).

In the near-bottom layer (or above the halocline), in general, the area of heightened concentrations of oil products coincides with the similar area on the sea surface layer (see Fig. 9, Fig. 10). The area around points D-6, 10, and 11 is stand out, what could be explained by the peculiarities of the circulation described above, as well as by activities on D-6 oil platform.

Elevation in concentration of oil products at points 5 and 8 (see Fig. 10) is likely a result of a transport of pollution from the area of the port of Pionersky.

5. Conclusions

For the first time, the comparison of the results of satellite monitoring of oil pollution at the sea surface in the Southeastern Baltic Sea and in-situ measurements of oil products concentration in the water column was carried out. Overlapping the results of satellite and field observations together with the peculiarities of the general water circulation allowed to trace the main transfer of oil contamination. The main source of oil pollution of the waters around the Sambia Peninsula is the main shipping routes westward from Sambia Peninsula. The main transport of oil pollution from the waters westward of the Sambia Peninsula occurs in the northern and north-eastern directions, both in the surface and the near-bottom layers.

Low concentrations of oil products in the seawater (below the maximum permissible concentration) suggest that the oil spills observed on the radar imagery are not catastrophic and do not affect the ecological situation in the Southeastern Baltic Sea. This is also supported by the fact that despite the change in the number of oil spills and the total surface of oil pollution in five times in the period between 2004 and 2014, the concentration of oil products in the seawater remains more or less stable and does not follow the interannual variability of the detected oil spills. This means that natural physical and biogeochemical processes in the sea are still capable to “consume” the observed incoming volume of the anthropogenic oil pollution.

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References

1. Afanasyeva, N.A., Geydarov, F.A., Zatuchnaya, B.M., and Ivanova T.A. (1990) The role of suspended matter in the redistribution of petroleum hydrocarbons in the marine environment (on the example of the North Atlantic). In: *Oceanographic aspects of the preservation of seas and oceans from chemical pollution*. Moscow, Gidrometeoizdat, 216–219 (in Russian).
2. Bernikova, T.A., Dubravin, V.F., Nagornova, N.N., and Stont, Zh.I. (2007) The climatic seasons of the Southern Baltic. Proc. V International scientific conference "Innovations in science and education - 2007". Kaliningrad, Kaliningrad State Technical University, Part 1, 53-55 (in Russian).
3. Bulycheva, E.V. and Kostianoy, A.G. (2011) Results of the satellite monitoring of oil pollution in the Southeastern Baltic Sea in 2006-2009. *Modern problems of remote sensing of the Earth from space*, V8, N 2, 74-83 (in Russian).
4. Bulycheva, E.V. and Kostianoy, A.G. (2014) Results of satellite monitoring of the sea surface oil pollution in the Southeastern Baltic Sea in 2004-2013. *Modern problems of remote sensing of the Earth from space*, V11, N 4, 111-126 (in Russian).
5. Bulycheva, E., Kuzmenko, I., and Sivkov, V. (2014) Annual sea surface oil pollution of the south-eastern part of the Baltic Sea by satellite data for 2006-2013. *Baltica,* V27, Special Issue, 9–14.
6. Burger, J. (1997) *Oil spills*. Rutgers University Press. New Brunswick. 262 pp.
7. Document (1998a) PND F 14.1:2:4.128-98 *Quantitative chemical analysis of water. Methods of measurement of the mass concentration of oil in the samples of natural, drinking, waste waters by the fluorimetric method on the analyzer of a liquid "Fluorat-02."* (in Russian).

8. Document (1998b) PND F 16.1:2.21-98 *Quantitative chemical analysis of soil. Methods of measurement of the mass fraction of oil in the samples of soil and ground by the fluorimetric method using the liquid analyzer "Fluorat-02."* (in Russian).
9. Emelyanov, E.M. (1998) *The barrier zones in the ocean. Sedimentation and mineralization, geo-ecology*. Kaliningrad, Yantarny skaz, 416 pp. (in Russian).
10. HELCOM (2013) *Illegal discharges observed during aerial surveillance 2013*. Source: http://www.helcom.fi/Lists/Publications/HELCOM/report/202013.pdf
11. Kostianoy, A.G., Bulycheva, E.V., Semenov, A.V., and Krainyukov, A.V. (2015) Satellite monitoring systems for shipping, and offshore oil and gas industry in the Baltic Sea. *Transport and Telecommunication*, V16, N2, 117-126.
12. Kostianoy, A.G. and Lavrova, O.Yu. (Eds.) (2014) *Oil pollution in the Baltic Sea*. Springer-Verlag, Berlin, Heidelberg, New York. V27. 268 pp.
13. Kostianoy, A.G., Litovchenko, K.Ts., Lavrova, O.Yu., Mityagina, M.I., Bocharova, T.Yu., Lebedev, S.A., Stanichny, S.V., Soloviev, D.M., Sirota, A.M., and Pichuzhkina, O.E. (2006) Operational satellite monitoring of oil spill pollution in the southeastern Baltic Sea: 18 months experience. *Environmental Research, Engineering and Management*, N4(38), 70-77.
14. Lavrova, O.Yu., Mityagina, M.I., Kostianoy, A.G., and Semenov, A.V. (2014) Oil pollution in the southeastern Baltic Sea in 2009-2011. *Transport and Telecommunication*, V15, N4, 322-331.
15. Lobkovsky, L.I., Levchenko D.G., Leonov A.V., and Ambrosimov A.K. (2005) *Geo-environmental monitoring of oil and gas marine areas*. Moscow, Nauka, 326 pp. (in Russian).
16. Meier, H.E.M. (2007) Modelling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea. *Estuarine, Coastal and Shelf Science*, N74, 610-627.
17. Nelson-Smith, A. (1977) *Oil and ecology of the sea*. Moscow, Progress, 298 pp. (in Russian).
18. Nemirovskaya, I.A. (2004) *The hydrocarbons in the ocean (the snow – ice – water - suspended matter - bottom sediments).* Moscow, Nauchny mir, 328 pp. (in Russian).
19. Nemirovskaya, I.A. (2012) Petroleum hydrocarbons. In: *Oil and the environment of the Kaliningrad Region*. V2: The Sea (Eds.) V.V. Sivkov, Yu.S. Kadzhoyan, O.E. Pichuzhkina, V.N. Feldman. Kaliningrad, Terra Baltica, 152-173 (in Russian).
20. Nemirovskaya, I.A. (2013) *Oil in the ocean. Pollution and natural flows*. Moscow, Nauchny mir, 428 pp. (in Russian).
21. Order of the Federal Fisheries Agency (2010) *"On approval of standards for water quality of fishery water bodies, including the maximum permissible concentrations of harmful substances in the waters of fishery water bodies» N20, 18.01.2010* (in Russian).
22. Patin, S.A. (2001) *Oil and ecology of continental shelf.* Moscow, VNIRO, 340 pp. (in Russian).
23. Patin, S.A. (2008) *Oil spills and their impact on the marine environment and aquatic resources*. Moscow, VNIRO, 507 pp. (in Russian).
24. Stont, Zh.I. (2014) Modern trends in variability of hydrometeorological parameters in the southeastern part of the Baltic Sea and their reflection in the coastal processes. Synopsis of the thesis on geography sciences. Kaliningrad, Atlantic Branch of P.P. Shirshov Institute of Oceanology, 23 pp. (in Russian).

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CONDITION MONITORING OF OPERATING PIPELINES WITH OPERATIONAL MODAL ANALYSIS APPLICATION

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In the petroleum, natural gas and petrochemical industries, great attention is being paid to safety, reliability and maintainability of equipment. There are a number of technologies to monitor, control, and maintain gas, oil, water, and sewer pipelines. The paper focuses on operational modal analysis (OMA) application for condition monitoring of operating pipelines. Special focus is on the topicality of OMA for definition of the dynamic features of the pipeline (frequencies and mode shapes) in operation. The research was conducted using two operating laboratory models imitated a part of the operating pipeline. The results of finite-element modeling, identification of pipe natural modes and its modification under the influence of virtual failure are discussed. The work considers the results of experimental research of dynamic behavior of the operating pipe models using one of OMA techniques and comparing dynamic properties with the modeled data. The study results demonstrate sensitivity of modal shape parameters to modification of operating pipeline technical state. Two strategies of pipeline repair – with continuously condition-based monitoring with proposed technology and without such monitoring, was discussed. Markov chain reliability models for each strategy were analyzed and reliability improvement factor for proposed technology of monitoring in compare with traditional one was evaluated. It is resumed about ability of operating pipeline condition monitoring by measuring dynamic deformations of the operating pipe and OMA techniques application for dynamic properties extraction.

Keywords: pipelines, reliability, damages detection, operational modal analysis, modelling of dynamic deformations

1. Introduction

Oil and gas operators face problems to keep pipeline safe and workable to avoid adverse effect on environment and to fulfil obligations of product delivery. In the petroleum, natural gas and petrochemical industries, great attention is being paid to safety, reliability and maintainability of equipment. In this respect, data on failures, failure mechanisms and maintenance related to these industrial facilities and its operations have become of increased importance.

There are a number of technologies to monitor, control, and maintain gas, oil, water, and sewer pipelines. Most of these technologies rely on some kind of communication networks to transfer data collected from inside and outside of the pipelines to the control stations. Different network architectures have been used to provide reliable communication in pipeline systems and attempted to support pipeline monitoring.

Nowadays, most of the pipeline monitoring systems are based on wired networks to connect and communicate with pipeline sensors. A number of problems can be noticed for the monitoring systems using wired networks (Jawhar, Mohamed, and Shuaib, 2007), (Mohamed and Jawhar, 2008).. Three major problems can be mentioned. Firstly, any damage in any part of the wires of the network may significantly degrade the performance of the pipeline monitoring system. Secondly, the physical security of such systems cannot be achieved when the pipeline expands on large areas. Lastly, since most of the pipelines that carry gas, oil, water, or sewer are located underground or in zones difficult to reach, it is hard to locate faults and repair them. This makes the process of maintaining a faulty network a very complex task.

Advancements in sensor technology have made possible the automated real-time monitoring of the health of the pipeline systems. A number of sensor network based technologies have been designed to monitor pipelines and to provide remote facilities to detect and report the positions of any leakage, damage, or corrosion (Murphy, Laffey, O'Flynn, Buckley and Barton, 2007), (Jin and Eydgahi, 2008), (Stoianov, Nachman, Madden and Tokmouline, (2007). One can notice, however, that these systems are passive in the way that they only report on incidents and do not contribute to their forecast.

On the other side, a number of robotic agent based technologies to monitor pipelines and maintain them from damage has also been developed in literature (Nassiraei, Kawamura, Ahrary, Mikuriya and Ishii, 2007), (Scholl, Kepplin, Berns and Dillmann, 2000). These technologies are designed to detect and locate any leakage, damage, or corrosion. While a huge number of robot based systems have been proposed that are manually controlled, a few number have considered semi-autonomous/autonomous solutions. In (Kim, Sharma, Boudriga and S. Iyengar, 2010) cost effective, scalable, customizable, and autonomous sensor-based system, called SPAMMS is proposed. It combines robot agent based technologies with sensing technologies for efficiently locating health related events and allows active and corrective monitoring and maintenance of the pipelines. SPAMMS integrates RFID systems with mobile sensors and autonomous robots. While the mobile sensor motion is based on the fluid transported by the pipeline, the fixed sensors provide event and mobile sensor location information and contribute efficiently to the study of health history of the pipeline.

The new approach was proposed for monitoring of most risky parts of operating pipeline, including those that are crossing the railroad or speedway or pass close to residential district. This approach is based on Operational Modal Analysis (OMA) of pipeline dynamic properties applying wide-band deformation sensors. Since the beginning of the 90's, OMA attracts attention of researchers for dynamic properties study of big civilian objects. OMA techniques allow determining the modal properties of a structure using the system output data only, that is, the dynamic signals of the stressed structure. The system responds to ambient excitation solely and there is no test excitation affecting the system. OMA use some key approaches for evaluation of modal properties, which are distinguished by the methods of data arrangement and processing. OMA application for pipeline condition monitoring is attractive for several reasons:

- the opportunity to receive the dynamic characteristics of the unlimited part of a pipeline;
- modal characteristics are linearized thanks to a wide range of accidental excitations;
- all or some parts of the measured degree of freedom can be used for reference purpose, which significantly increases method resolution and helps to segregate the paired and closely located modes;
- it is useful for the vibration-based health monitoring (Zhang, Brincker, Andersen, 2005);
- it can be used for the implementation of preventive/predictive maintenance for condition monitoring of operating pipelines oriented on increase reliability and optimization of the relationship between equipment ownership and operating profits by balancing cost of maintenance with cost of equipment failure, and associated production losses.

Widest OMA application was found for the approaches using conversion in the time domain: Natural Excitation Technique (NExT) (Chang and Pakzad, 2013), model of the general Auto-Regression Moving Average vector (ARMA V) (George and Jenkins, 1976), Stochastic Subspace-based methods (D'ohler, 2011), and approaches in frequency domain, like Frequency Domain Decomposition (FDD) (Brincker, Zhang and Andersen, 2001) or least-squares complex frequency-domain (LSCF) (Peetersa, Van der Auweraera, Guillaumeb and Leuridana, 2004). In this research, the authors considered use of one of OMA approaches - Enhanced Frequency Domain Distribution (EFDD) for evaluation of the condition of a section of an operating pipeline.

This article considers application of OMA technique for damage identification of the experimental model of a pipeline with the actuation by flow inside. Gas or flow streaming inside a pipe excites plenty of structural modes allowing determination of modal properties of surveyed pipeline part. Whereas accelerations typically characterize dynamic behavior of a structure, wall deformations of motionless pipe may be more effective for this purpose. Nowadays, most advanced pipelines already have fiber-optic systems for condition monitoring (Inaudi, Glisic, 2010) however, its frequency range is low and they are limited to detect small local damages as joint weld or corrosion spots that cause 50% of gas pipelines problems as well as other material damages. Being limited by low frequency range, they are not sensitive enough to many important ambient impacts as well. Unlike fiber optics, the film-type piezo-electric sensors distributed along a pipe provide measurement of pipe wall deformations in practically unlimited frequency range. The model of operating pipeline facilitated by above deformation measurement system was called *smart pipe*. The pipe equipped with sensitive deformation transducers works as an antenna that feels any wall deformations caused by streaming flow inside or soil distortion outside. By the way, *smart pipe* provides adequate dynamic data, required for modal analysis.

The task of discussed research study was to verify the applicability of OMA for damage identification of smart pipe under operating conditions similar to natural ones. Practical application of modal analysis methods requires identification of natural modes of a structure in determined frequency range, therefore an experimental phase was preceded by mathematical modelling using the finite-element technique (FET).

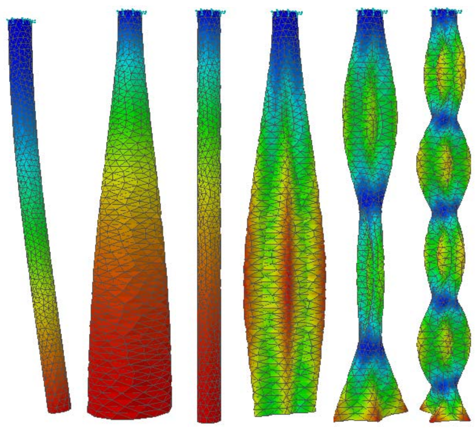
2. Modelling

For modelling a pipe, the triangular parabolic elements evenly spread over the whole surface of the model were used as finite elements (FE). Analysis of the normal modes shape and frequency of oscillation was done in respect to the first 20 natural modes, the displacement being used as a parameter.

Table 1 presents the calculated parameters of the natural modes of a pipeline model and Figure 1 demonstrates principal mode types.

Table 1. Modal frequencies of ideal and "faulty" pipes

Mode No	Mode id	Frequency		
		ideal pipe, Hz	fault pipe, Hz	Modify-cation, %
1a	1st bending	36.19	35.76	1%
1b		36.19	35.79	1%
2a	2nd bending	219.35	212.61	3%
2b		219.38	214.10	2%
3	1st torsion	487.61	478.06	2%
4a	3rd bending	585.56	562.30	4%
4b		585.67	567.75	3%
5	1st longit.	787.34	772.96	2%
6a	4th bending	1079.65	1063.49	1%
6b		1079.84	1064.07	1%
7a	1nd shell	1141.86	1128.12	1%
7b		1141.99	1128.60	1%
8a	2rd shell	1149.15	1134.48	1%
8b		1149.18	1134.59	1%
9a	3th shell	1172.39	1159.15	1%
9b		1172.45	1159.60	1%
10a	4th shell	1229.38	1215.44	1%
10b		1229.45	1215.55	1%
11a	5th shell	1338.21	1325.35	1%
11b		1338.34	1326.02	1%



a b c d e f

Figure 1. Calculated mode shapes

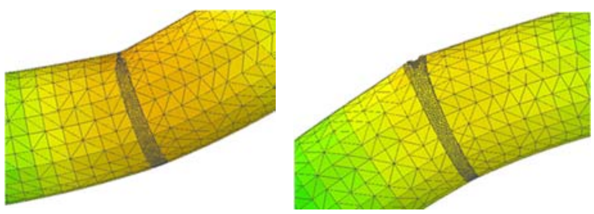


Figure 2. Mode modification after introducing a defect model

Column ideal pipe (Table 1) contains calculated frequencies of pipe model in ideal (non-faulted) state; column fault pipe includes frequencies of virtually damaged pipe. Analysis showed that the majority of the modes are paired, that is, they "sit" on the closely spaced frequencies and have similar modes with the 90^{o} phase shift. Paired modes have the same number but differ by letter *a* or *b*. Symmetry of the pipe model cross section is the reason of the pairing. Identification of the modes allowed determining of two major mode groups and two isolated modes. The first group includes four pairs of bending modes: *1ab* (Figure 1a)*, 2ab, 4ab, 6ab*, under which the pipe behavior is similar to bending oscillations of a beam. Such way of oscillation consider the cross sections of the hollow pipe deform in the same direction in which the longitudinal axis is bending. It means that at vertical bending mode the circular cross section of hollow pipe periodically compresses in vertical direction. Two isolated modes in low-frequency range are extremal cases of beam-like oscillation. The first one (No *3* in Table1, Figure 1b) is interpreted as the 1st mode of torsion oscillations, in which the cross-sections of the pipe swivel around the longitudinal axis. The second one (No *5* in Table1, Figure 1c) is the longitudinal mode, in which the free end of the pipe shifts along the longitudinal axis. In both cases cross sections do not change its round shape but vary diameter.

The second modes group includes five pairs of oscillation modes: *7ab* (Figure 1d), *8ab, 9ab* (Figure 1e)*, 10ab, 11ab* (Figure 1f), where the wall of the pipe behaves as a shell.

In each of the paired modes, the mode *b* is similar to mode *a*, yet turned by 90^{o}. Under shell oscillations the pipe model does not bend as a beam (the pipe axis is not deformed), however, the cross sections get deformed, being "flattened" and "stretched" in perpendicular directions.

To evaluate sensibility of natural modes to the local failure the computational experiment was done, where a defect of a real pipe was modelled as the pipe model wall saw-through (less than 10% of the circumference and 30% of the wall thickness).

Analysis of computed modes was limited by numeric evaluation of frequencies only, while evaluation of the mode shapes was done visually. However, since the frequency changing upon introduction of the defect is one of the modal parameters, it can be assumed that the mode is changing along with the change of frequency. Results of the computational experiment are shown in the column *faulty pipe* of Table 1. Different modes respond to the local fault in various ways. Thus, while the frequencies of the paired 1st bending mode, which depends on the global properties of the modelled pipe, decreased by 1% only, the 2nd and 3rd modes that depend more on the mass and rigidity distribution along the model length decreased up to 4%. For the shell modes, the modal frequencies decreased not more than 1%. Varying response of the modes to a local fault is illustrated by Figure 2 showing the behavior of faulted area along the 3rd bending mode (4ab Table 1) in the two opposite oscillation phases. As is evident, the defect coincides with the maximum deformation spot for this mode, therefore the parameters of that particular mode got distorted to the maximum extent.

Analysis of numerical pipe model identified two main groups of natural modes: bending and shell ones. Mode shapes of these groups have principal difference and their sensitivity to test fault differs.

3. Experimental study of operating pipeline model by OMA technique

The laboratory model of an operating pipeline was equipped with deformation sensors distributed along and circumferentially the pipe. The set of 21 deformation sensors provide data for experimental determination of the dynamic characteristics of a laboratory pipeline model. The laboratory pipeline model has the form of a straight section of a hollow pipe. Turbulent flow of water streaming through the pipe excites its walls. Controlled flow resistance in front of the pipe inlet allows adjusting of excitation level of the pipe walls by modulating the flow turbulence intensity.

Advanced piezoelectric film transducers (Figure 3) measure dynamic deformations of the oscillating pipe wall. Attached to the pipe surface the ultra-light sensors are exposed to stretching or compression together with the pipe wall almost without affecting the mechanical properties of the pipe. The preamplifier located next to the sensor on a flexible base transforms time-variant charge generated by the sensor under extension and compression of wall into the alternate electric voltage. Combination of the sensor and the preamplifier represents the deformation transducer.

Dynamic range of applied sensors is practically unlimited in terms of both the relative extension or compression and frequency. Tested segment of the experimental pipeline model has 21 transducers in the seven evenly distributed cross sections (Figure 4).

In each cross section, the transducers are located along the pipe axis on three lines that shifted at a 45^{o} angle from one to another. The transducers located on the top (blue line) and side (green line) generatrix are set by its length along the pipe axis (longitudinal transducers), and their task was to measure extension and compression of the "longitudinal" virtual fibers of the pipe. The transducers on the intermediary generatrix (red line) measured in circumferential direction that means deformation of pipe cross-section (lateral transducers).

Multichannel data acquisition unit collects signals from all 21 transducers simultaneously and then transfers it to the computer that saves the data and performs OMA. The result of data processing is an eigenvector based on geometrical model of the pipeline, which includes the normalized deformation values describing shapes frequencies and damping factors of determined modes.

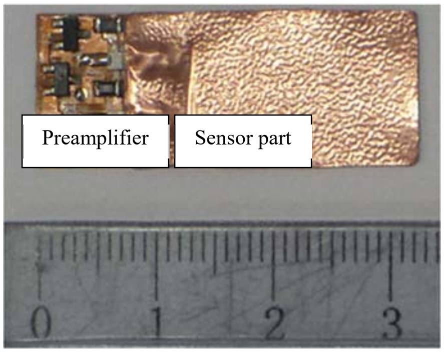


Figure 3. Deformation transducer

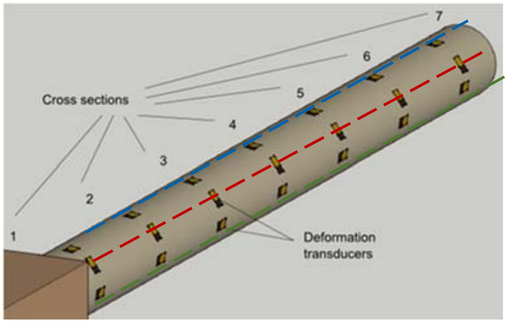
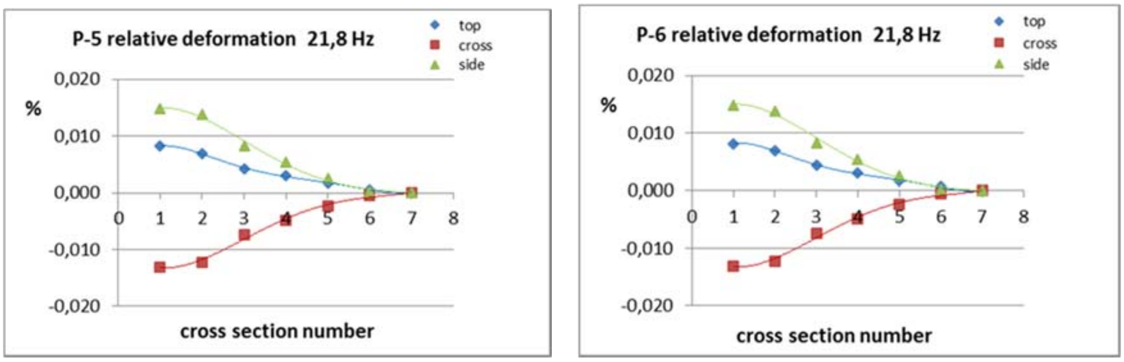


Figure 4. Distribution of transducers on the pipeline segment

3.1. Mode shape identification of one-sided fixed pipe model

The first version of operating pipeline model was built-up as one-sided fixed steel pipe with measurement set-up as on Figure 4. Diagrams, like presented on Figure 5, facilitate modes shape identification using experimental measured modal parameters. The normalized deformation magnitudes are related to the cross section number and plotted by taking into account the phase of oscillation (positive or negative). Depending on the location of the data points - the top and side of the pipe (longitudinal transducers) or between them (lateral transducers), the magnitude values on the diagram are connected by a blue, red or green line. Modes identification bases on the assumption that measured deformations of the pipeline model are linked through the second derivate with the displacements that were computed for numerical model of the pipeline. Figure 5a illustrates deformation of the pipe model oscillating at 1st bending mode (21, 8 Hz).



a) b)

Figure 5. Deformation diagrams of first bending mode: a) - initial condition, b) – faulted; top generatrix – blue rhombus; side - green cones; cross generatrix (lateral transducers) – red squads

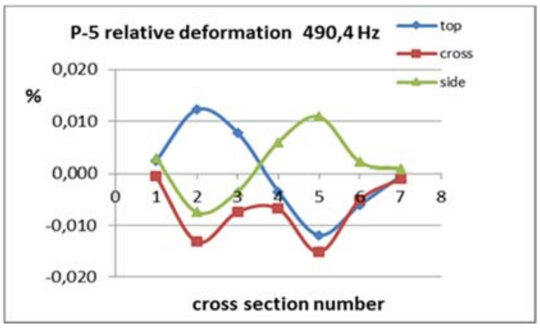
The maximum displacement of the free end of the cantilever fitted pipe under the first bending mode is approaching zero deformation that may be seen in the section *7* for all transducers. Conversely, the minimum displacement next to pipe fixity (1st section) computed by numerical model is correspondent to the maximum deformation of the pipe walls. Comparison of deformation magnitudes along the top and the side generatrix in the same cross section allows determining the oscillation phase in relation to the fixed coordination system of the laboratory facility. The magnitudes and phase ratio of both lateral sensor lines give an idea about wall deformations distribution along the pipe model. A positive value of the top and the side deformation magnitudes indicates location of oscillation plane between its generatrix. Asymmetrical fixity of the operating pipe model causes 62º slope of the oscillation plane (under the first bending mode) from the vertical that is why deformations at the side generatrix (green) dominate over the top generatrix (blue) deformations (Figure 5a). Bending of the pipe causes maximal "flattening" of cross sections near its fixity (cross section No 1), so side generatrix (red) appears to be located next to maximal compression line.

Analysis of the experimentally obtained modal shapes demonstrates their similarity to the numerically estimated data. At the same data numerically estimated modal frequencies appear to be lower than experimentally obtained due to simulation problems of experimental model boundary conditions. Thus, the first bending mode computed as 36Hz, in fact turned out 21.8Hz. Comparison of calculated and experimentally obtained mode shapes demonstrated their close resemblance, proving the model quality. In analyzing the properties of experimental model through the OMA technique no paired modes predicted by the digital model were revealed. That is because the fixity of the experimental pipe did not correspond to the numerical one.

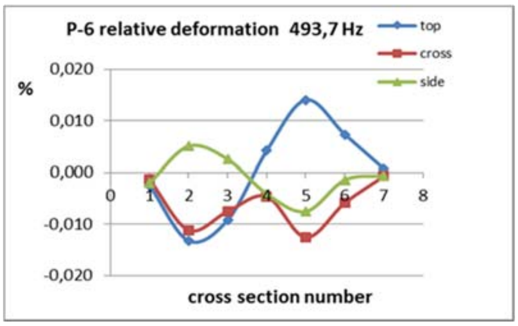
To estimate the lowest sensitivity limit to mechanical properties modification the local damage was introduced into the laboratory pipeline model. Geometry of the fault was similar to the numerical model (paragraph 2), the cut-through the wall of the natural pipe was less than 30% of the wall thickness. Analysis of the experimentally obtained modal parameters of the pipeline model demonstrated variable response of different modes to modification of the technical state (as the numerical analysis also). The deformation distribution diagrams (OMA obtained) reflecting shapes of the first bending mode in the healthy (Figure 5a) and defective conditions (Figure 5b) did not differ practically. Integrated difference of normalized magnitudes between two states of the pipe did not exceed 0.2%, while the frequencies differed by a mere 0.1%, which corresponded to the estimated data.

At the same time, the differences proved more significant in some other modes. For example, the difference of magnitudes for the third bending mode oriented in the inclined plane between the initial (Figure 6a) and defective (Figure 6b) states was: in terms of magnitudes – 12.5%, and in terms of frequency – 0.7%. Modification of the mode shape happened primarily due to the change of the slope angle of the oscillation plane (in relation to the vertical) from 42º to 25º because of the defect. As we may see, the third bending mode has higher response to fault than the first one conditioned on the fact that location of the defect practically coincided with position of the maximum deformation for this mode, which was obvious already at the modelling stage.

Considered above means that mode shapes of higher order are more effective for detection of local failures of operating pipeline.



a)

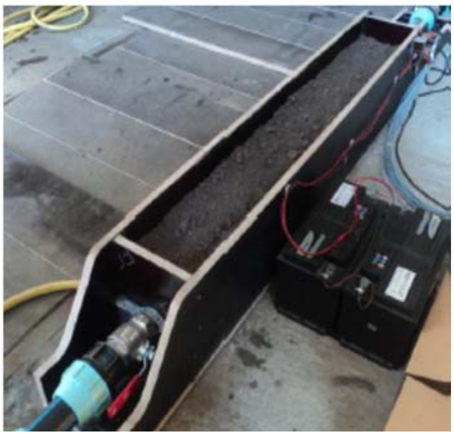


b)

*Figure 6***.** Deformation diagrams of 3rd bending mode: a) - initial condition, b) – faulted; top generatrix – blue rhombus; side - green cones; cross generatrix (lateral transducers) – red squads

3.2. Impact of different media and faults to both-sided fixed pipe model

Another operating pipeline model allowed to study its modal behavior in conditions similar to natural pipeline (Figure 7).



a) b)

Figure 7. Operating pipeline model: a) - testing box with pipe buried in the soil; b) – the pipe with transducers

Two opposite walls of the massive box (Figure 7a) are the pillars of the pipe with transducers (Figure 7b) fixing its ends in the transverse direction and limiting its movement in the axial direction. Both the box and the pipe model with the measurement system are waterproof. Ambient media in the box around the pipe model is variable: pipe can operate in open air, can be buried in a soil, and can be doused in a water. The copper-alloy pipe has the same measurement set-up as described in section 3.1.

As experimental data shows the properties of ambient media may seriously effect on modal parameters of the pipe model. Figure 8 illustrates how varying media modifies the shape of 3rd shell mode of the pipe model in healthy state (no defects). It is evident that more consistent media reduce modal magnitudes slightly (Figure 8a, b, c). Media impact to modal frequency is more effective. For instance, loose soil reduced frequency or 3rd bending mode for 0.2% only however, water dipping of the operating pipe reduced frequency of the same mode for almost 30%. On top of media impact intensity and composition of the streaming flow may affect modal parameters of pipe model.

In case if media outside and flow inside remain stable in a determined time period, the pipe condition monitoring becomes available. For this purpose the parameter of modal parameters variation to be calculated.

The ensemble of estimated modal parameters experimentally obtained using OMA in the state *S* of the pipeline model could be written as eigenvector matrix

$$M_S = [m_{i,j,k}]$$

where i – number of DOF in one section (3), j – number of sections (7), k – mode number, $m_{i,j,k}$ – eigenvalue measured at DOF(i,j) of kth mode.

For monitoring purpose current state *S* to be compared with initial state (etalon) *E* by calculation of its difference

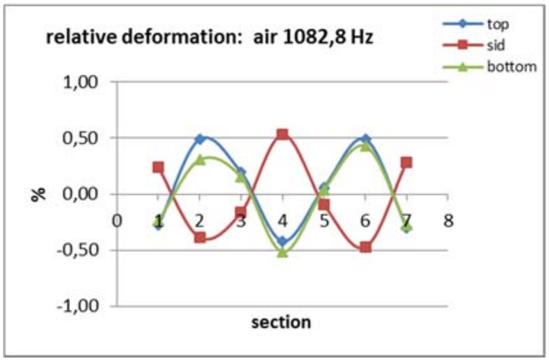
$$\Delta M_s = M_S - M_E$$

Modal parameters variation (MPV) estimates difference of modal parameters between current and initial state of the pipe model. Such differential eigenvector for current pipeline state estimates how far this current state of the pipe model is remote from its initial state (or etalon).

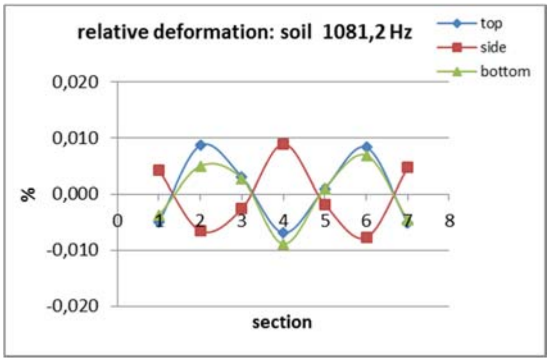
Experimental data obtained from testing of five technical states of the operating pipe model provided computation of MPV parameter for:

- healthy or initial state (three tests),
- local fault as thinning of the pipe wall (20% of wall thickness and about 0.5% of square) made by polisher,
- static deflection of the pipe model (maximal deflection – 0,8% of the pipe model length) simulating earth-slide of natural pipeline.

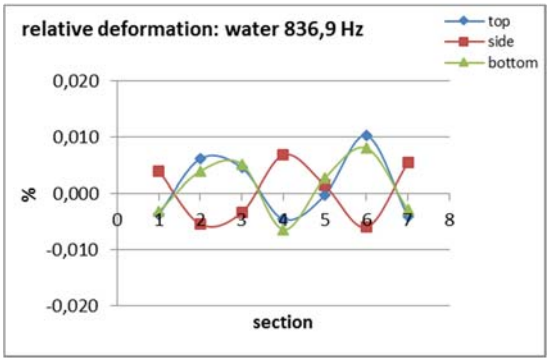
Figure 9 illustrates variation of mode shapes and frequencies of operating pipe model at the 1st bending mode in above mentioned states.



a)

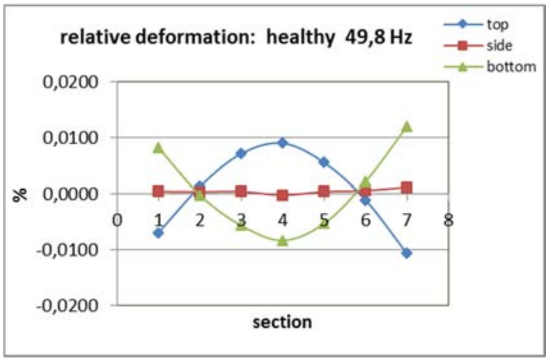


b)

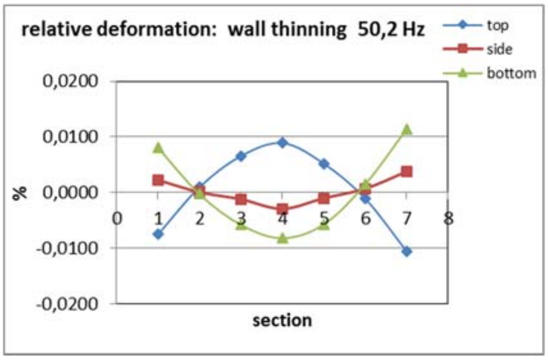


c)

Figure 8. Deformation diagrams of 3rd shell mode with different media: a) – air, b) – soil, c) - water



a)



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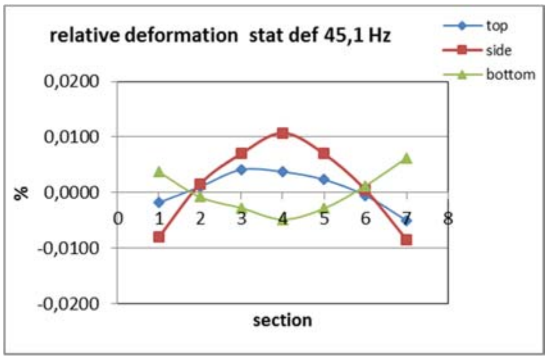


c)

Figure 9. Deformation diagrams of the 1st bending mode in: a) – healthy state, b) – wall thinning, c) – static deflection

Symmetry of diagram of healthy state (figure 9a) is broken by green line of side sensors line distortion (Figure 9b) when pipe wall was thinned locally. Maximal distortion of diagram red line locates close to the place, where the fault was implemented. Diagrams of Figure 9c dramatically change in comparison with healthy state (Figure 9a) as well as the frequency dropped for 10%. The reason is that even slightly deflected pipe has lost symmetry and as the result has greatly modified its mechanical properties. Analysis of found mode shapes of the pipe model shows that MPV parameters have various sensitivity of bending and shell mode shapes to different faults. For instance, MPV of bending modes is more sensitive to static curve of the pipe than shell ones. However, sensitivity of MPV to local faults depends mostly of fault types and mode orders. It means, there is no privilege for MPV of mode types for detection of local faults.

As illustration of MPV sensitivity in depend of mode type Figure 10 shows MPV histogram for three pipe technical states. For both types of modes the scatter of MPV does not exceed 2.2…2.4dB within "healthy" states of operating pipe. Also in case of local fault (thinning) MPV for both modes grows to 4dB and more. However, static curve of operating pipe increase MPV of only bending modes (to 6.6dB), whereas shell modes parameter raises less (up to 4.3dB).

Results of OMA trial application for condition assessment of the experimental pipeline demonstrates varying sensitivity of the modal parameters to defects. While the frequencies of the natural modes changed less, modification of the pipe deformation shapes was quite obvious. That happened because the frequency of every mode is a global parameter of an object, while the deformation distribution (mode shapes) is the function of the local mass and stiffness distribution of the structure. Hence, the diagnostic efficiency of the modal shape parameters is much higher in comparison to the mode frequency parameters. This explains the fact that changes in the shape of the higher order modes as a response to a defect are able to become a reliable indicator of the alterations - even a relatively smaller-scale local changes of the structural state.

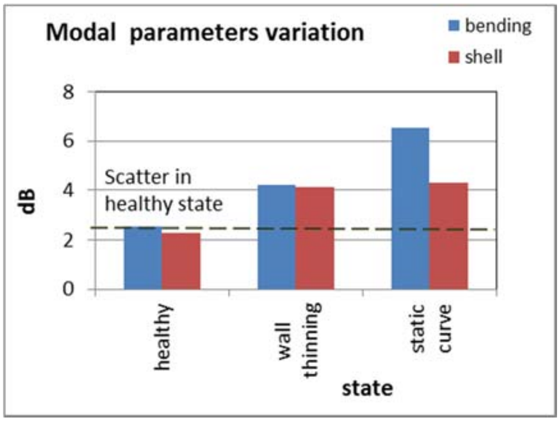


Figure 10. Modal parameters variation in depend of the pipe model technical state

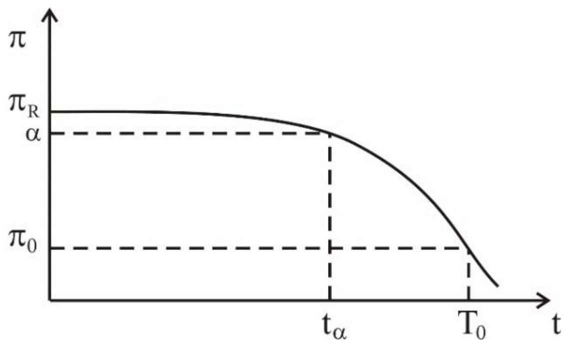


Figure 11. Deterioration of functional capabilities

3.3. Operation modal analysis technique application on the natural scale operating

To verify OMA applicability for monitoring purposes in actual environmental conditions the natural scale operating pipeline was built up (figure 12). The pipeline has total length more than 80m, 88mm diameter and pipe wall thickness 4mm. Pump station provides pressure of water up to 40Bar and flow stream velocity 1-5m/s.

The pipeline is welded using separated steel pipes of 6m length each. Above-ground pipeline part contains 5 pipes, under-ground one has two pipes. Pipelines are equipped by 168 deformation sensors (figure 3) allocated along seven tested pipes protected by cover layers. Tested pipes are connected by cables to measurement cabin where multichannel acquisition unit and PC are located. During the test the acquisition unit collects signals from transducers, provides its conditioning and transfers to PC that provides data collection and preliminary development. Operation modal analysis of collected data was applied at post processing stage.

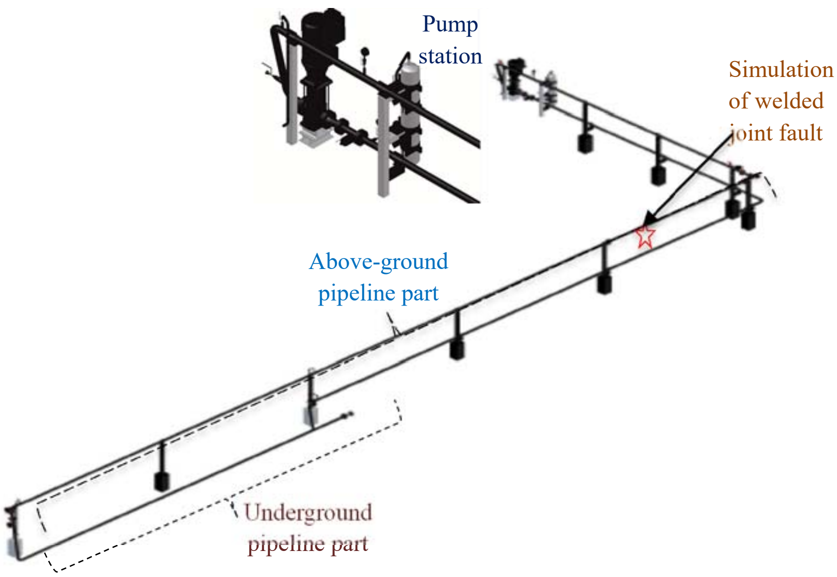
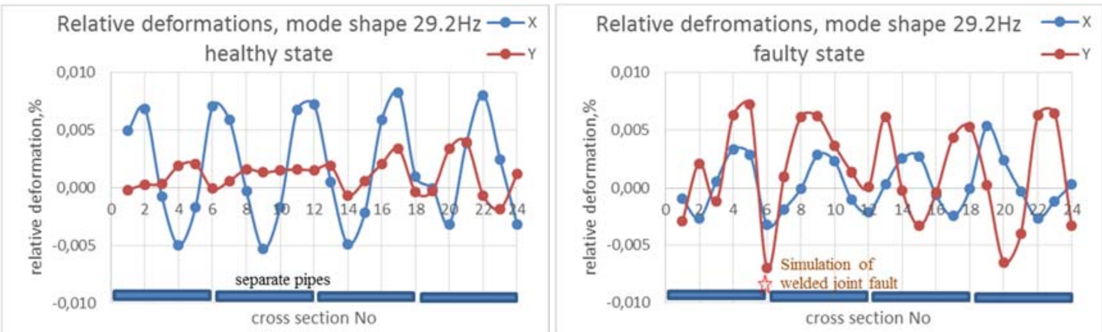


Figure 12. Natural scale operating pipeline model

The research study included test sessions when the pipeline operated at different modes (varied pressure and flow speed) at its healthy and faulty states. Test data development of healthy state pipeline confirmed as higher intensity of flow turbulence the better conditions for modal parameters identification using OMA technique. Simulation of welded joint fault (typical defect of operating pipelines) was implemented as the circumferential cut of one pipe wall. The cut was 1 mm depth and occupied 30% of pipe round. The fault was successfully identified using OMA that is illustrated by deformation diagrams on Figure 13.



a) b)

Figure 13. Deformation diagrams of the n^{th} bending mode of above-ground pipeline:
a) – healthy state, b) – simulated fault of welded joint

Results of experimental study (including laboratory and natural scale pipelines tests) demonstrates two important outputs. From one hand, the flow streaming along a pipeline is able to generate its natural modes that could be identified using OMA techniques. From other hand, dynamic properties of pipe walls are sensitive enough to any damage that provides opportunity to detect state modification of operating pipe. These bring convincing proofs of OMA techniques capability to identify different damages of operating pipelines that allows application of actual condition based or predictive maintenance.

4. Reliability of pipeline with OMA application for condition monitoring

Oil and gas pipelines are critical infrastructure for effective transportation and distribution of energy resources. Pipelines can unexpectedly fail for many reasons including, corrosions, cracking, process upsets, and external environment. One of the key elements of maintainability is implementation of Preventive/Predictive Maintenance (PPM) based on condition monitoring of operating pipelines. Properly developed PPM programs are engineered efforts, which optimize the relationship between equipment ownership and operating profits by balancing cost of maintenance with cost of equipment failure, and associated production losses. Through the utilization of various nondestructive testing and measuring techniques, predictive maintenance determines equipment status before a breakdown occurs.

Proposed in this paper OMA technology of structural properties and dynamic deformations of pipeline can be an effective instrument for PPM. Let us investigate the impact of the adoption of technical condition diagnostics with OMA technology on the reliability of pipeline operation.

The typical deterioration of functional capabilities of pipeline shown at the Figure 11 (Guo, Song, Ghalambor, Lin, 2013). Condition-based monitoring (CBM) of parameter π carry out with proposed technology with the sensitivity level α. The moment t_α is point of time when you first detect incipient failure depends on the condition monitoring technique. If maintenance actions are not executed, the system failure occurs at time T_0 due to the development of degradation processes.

The following assumptions were made in their mathematical formulation:

- The service life of pipeline is infinite.
- The pipeline monitoring and maintenance system should be able to find any defects in the unhealthy pipeline under monitoring before any failure happens.
- Degradation rate for different modes of failure is constant (ISO 14224) with parameter λ_i, where $i=1,..n$ is number of detected modes of failures.
- In the case of operation without CBM i-mode failure is hidden and continues to develop before the rise of system failure with the failure rate φ_i, $i=1,\dots n$.
- When a failure detected during condition-based monitoring, a preventive maintenance is carried out with repair rate μ_i, where $i=1,..n$ is number of detected modes of failures.
- A pipeline after maintenance actions becomes as good as new.
- The occurrence of critical failures and their repair have an exponential distribution with parameters λ_0 and μ_0 respectively.

Let us compare two strategies of pipeline repair – with continuously condition-based monitoring with proposed technology and without such monitoring. For this purpose, we use Markov chain model with discrete random process whose future states only rely on their current states and are independent of their past states.

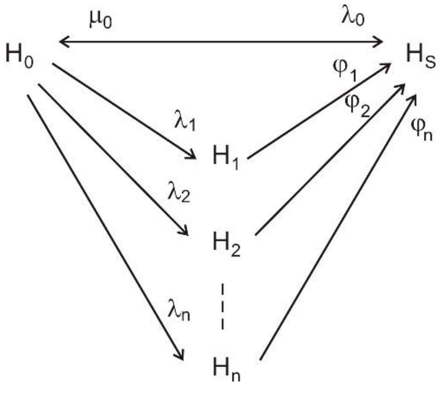


Figure 14. Markov's state transition diagram for system without condition-based monitoring

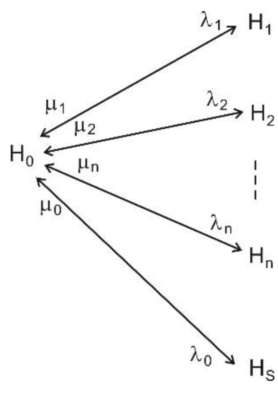


Figure 15. Markov's state transition diagram for system with continuously condition-based monitoring

Model 1. Strategy of pipeline repair without condition-based monitoring.

The behavior of the examined system is described by the state transitions (Figure 14): H_0 - state in which system is operating and available for use; H_i - the appearance of i-mode failure ($i=1,\dots n$); H_s - the appearance of system failure.

On the base of the state transition diagram for a Markov's process shown in Figure 14, we can write the system of Chapman–Kolmogorov's equations:

$$P_0'(t) = \mu_0 P_s(t) - \left(\lambda_s + \sum_{i=1}^{n} \lambda_i\right) P_0(t)$$
$$P_i'(t) = \lambda_i P_0(t) - \varphi_i P_s(t), \quad i = \overline{1,n}$$
$$P_s(t) = \lambda_s P_0(t) + \sum_{i=1}^{n} \varphi_i P_i(t) - \mu_0 P_s(t)$$

The normalizing condition is

$$P_s(t) + \sum_{i=0}^{n} P_i(t) = 1$$

After transformation of the above mentioned set of equations we can obtain the value for P_i (i = 1,…n, s) via P_0:

$$P_i = \frac{\lambda_i}{\varphi_i} P_0, \qquad i = \overline{1,n}$$
$$P_s = \left(\lambda_0 + \sum_{i=1}^{n} \varphi_i\right) \mu_0{}^{-1} P_0$$

Value of P_0 can be obtained by replacement P_i (i = 1 . . . n) in the normalizing equation:

$$P_0 = \left[1 + \left(\lambda_0 + \sum_{i=1}^{n} \varphi_i\right) \mu_0{}^{-1} + \sum_{i=1}^{n} \frac{\lambda_i}{\varphi_i}\right]^{-1}$$

Availability of system for this model is $A = P_0$.

Numerical values associated with the calculation of availability are often awkward for highly reliable systems. For this reason, it is more convenient to use the complement measure of availability, namely, unavailability U. Unavailability is the probability that an item will not operate correctly at a given time and under specified conditions (Dunn, William R, 2002). It opposes availability.

$$U = 1 - A = P_s + \sum_{i=1}^{n} P_i$$
$$U = \frac{a_1}{1 + a_1} \tag{1}$$
$$a_1 = \left(\lambda_0 + \sum_{i=1}^{n} \varphi_i\right) / \mu_0 + \sum_{i=1}^{n} \lambda_i / \varphi_i$$

Model 2. Strategy of pipeline repair with continuously condition-based monitoring.

The behavior of the examined system is described by the state transitions (Figure 15): H_0 - state in which system is operating and available for use; H_i - the appearance of i-mode failure (i=1,… n) which is detected during condition-based monitoring, a preventive maintenance is started; H_s - the appearance of system failure.

On the base of the state transition diagram for a Markov's process shown in Figure 14, we can write the system of Chapman–Kolmogorov's equations:

$$P_0'(t) = \sum_{i=1}^{n} \mu_i P_i(t) + \mu_0 P_s(t) - \lambda_0 P_0(t)$$
$$P_i'(t) = \lambda_i P_0(t) - \mu_i P_i(t), \quad i = \overline{1,n}$$
$$P_s'(t) = \lambda_0 P_0(t) - \mu_0 P_s(t)$$

The normalizing condition is

$$P_s(t) + \sum_{i=0}^{n} P_i(t) = 1$$

After transformation of the above mentioned set of equations we can obtain the value for P_i ($i = 0,\ldots n, s$):

$$P_i = \frac{\lambda_i}{\mu_i} P_0, \;\; i = \overline{1,n}$$

$$P_s = \frac{\lambda_0}{\mu_0} P_0$$

$$P_0 = \left(1 + \sum_{i=0}^{n} \frac{\lambda_i}{\mu_i}\right)^{-1}$$

Unavailability of system for this model is

$$U = 1 - A = P_s + \sum_{i=1}^{n} P_i$$

$$U = \frac{a_2}{1 + a_2} \tag{2}$$

$$a_2 = \sum_{i=0}^{n} \frac{\lambda_i}{\mu_i}$$

It is possible to evaluate the increasing of the reliability in the pipeline with continuously condition-based monitoring in comparison with pipeline without such diagnosis with the help of the reliability improvement factor $V = U_1/U_2$, where U_1 - unavailability of the system in the first model and U_2 - unavailability of the system in second one in accordance of equations (1) and (2).

Analysis of the coefficient V indicates that the under the conditions $\lambda=k\varphi$, $\lambda=d\lambda_0$, $\mu=b\mu_0$ and $\lambda_0<<\mu_0$, that is done for most highly reliable systems, its value can be described by the approximate expression $V=z\gamma_0$, where $\gamma=\mu_0/\lambda_0$, $z=nkb/(nd+b)$.

Numerical example. At the Figure 16 there are V(b) dependencies for various failure modes n and typical average meanings of the characteristics $k=1$, $MTBF=1/\lambda_0$=300 days, $MTBR=1/\mu_0$=3 days (Sahlqvist, 2014).

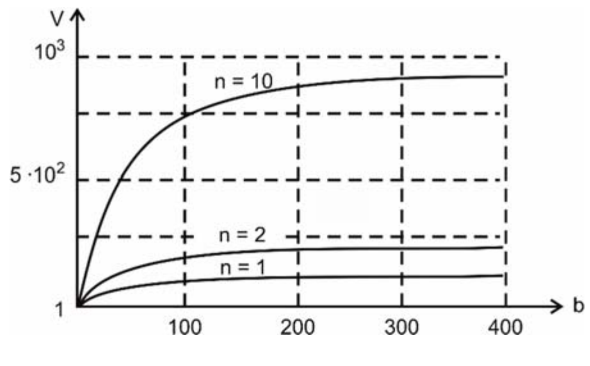


Figure 16. Variation of reliability deterioration coefficient

5. Conclusions

Finite-element modelling proved applicability of modal properties for condition monitoring of operating pipeline. Experimental model of operating pipeline of laboratory scale was built up for OMA techniques validation as the tool for pipe condition monitoring. Turbulent flow stream excited pipeline model walls provides ambient excitation required for OMA application. The measurement system including experimental piezo-electric deformation transducers and 21- channel acquisition unit characterized dynamic behavior of the pipeline functional model. The EFDD technique was applied to compute parameters of natural modes using experimentally obtained data. Numerically computed modes provide identification of experimentally obtained modes that ensures reliable estimation of the changes in the modal parameters. It was revealed that using the mode shape parameters as the diagnostic indicators is more advantageous compared to mode frequencies. It was proved that the modal parameters of the operating pipeline obtained using modal analysis technique are able to characterize its dynamic properties, so modification of these properties could be used as diagnostic indicators of pipeline model defects.

Two strategies of pipeline repair – with continuously condition-based monitoring with proposed technology and without such monitoring, was evaluated from reliability point of view. It is shown that reliability improvement factor for proposed method is by several orders of magnitude more effective in compare with traditional one. Thus, the research study of the pipeline model has proven ability of operating pipeline condition monitoring applying OMA techniques to dynamic deformations measured on the operating pipe.

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References

1. Jawhar, I.; Mohamed, N.; Shuaib, K. (2007) *A Framework for Pipeline Infrastructure Monitoring Using Wireless Sensor Networks*, in the *Proceedings of the Sixth Annual Wireless Telecommunications Symposium (WTS 2007)*, Pomona, CA, USA, 26–28 April 2007; pp. 1–7.
2. Mohamed, N. and Jawhar, I. (2008) A Fault Tolerant Wired/Wireless Sensor Network Architecture for Monitoring Pipeline Infrastructures," in *SENSOR-COMM '08: Proceedings of the 2008 Second International Conference on Sensor Technologies and Applications*. Washington, DC, USA: IEEE Computer Society, pp. 179-184.
3. Murphy, F.; Laffey, D.; O’Flynn, B.; Buckley, J. and Barton, J. (2007) Development of a Wireless Sensor Network for Collaborative Agents to Treat Scale Formation in Oil Pipes, in *EWSN*, pp. 179–194.
4. Jin, Y. and Eydgahi, A. (2008) Monitoring of Distributed Pipeline Systems by Wireless Sensor Networks, in the *Proceedings of the 2008 IJAC-IJME International Conference*, Nashville, TN, USA.
5. Stoianov, I.; Nachman, L.; Madden, S. and Tokmouline, T. (2007) PIPENET: A Wireless Sensor Network for Pipeline Monitoring, in the *Proceedings of the 6th international conference on Information processing in sensor networks*. New York, NY, USA: ACM, pp. 264–273.
6. Nassiraei, A.; Kawamura, Y.; Ahrary, A.; Mikuriya, Y. and Ishii, K. (2007) Concept and Design of a Fully Autonomous Sewer Pipe Inspection Mobile Robot Kantaro, in the *Proceedings IEEE International Conference of Robotics and Automation*, April 2007, pp. 136–143.
7. Scholl, K.-U.; Kepplin, V.; Berns, K. and Dillmann, R. (2000) Controlling a Multi-Joint Robot for Autonomous Sewer Inspection, in the *Proccedings of the IEEE International Conference on Robotics and Automation ICRA ’00*, vol. 2, pp. 1701–1706.
8. Kim, J.-H.; Sharma, G.; Boudriga, N. and Iyengar, S. (2010) SPAMMS: A Sensor-Based Pipeline Autonomous Monitoring and Maintenance System, in the *Proceedings of the Second International Conference on Communication Systems and Networks (COMSNETS)*, 5-9 Jan. 2010, pp.1-10.
9. Minwoo Chang and Shamim N. Pakzad. (2013) Modified Natural Excitation Technique for Stochastic Modal Identification. *Journal of Structural Engineering*, ASCE, October, pp. 1753-1762.
10. George, E. P. Box, Gwilym M. Jenkins. (1976) *Time series analysis: forecasting and control*. San Francisco. Holden-Day.
11. D’ohler, M. (2011) *Subspace-Based System Identification and Fault Detection: Algorithms for Large Systems and Application to Structural Vibration Analysis*. Dynamical Systems. Universit´e Rennes Nr.1.
12. Brincker, R.; Zhang, L. and Andersen, P. (2001) *Modal Identification of Output-Only Systems Using Frequency Domain Decomposition*. Smart Materials and Structures, 10 (2001) 441–445.

13. Bart Peetersa, Herman Van der Auweraera, Patrick Guillaumeb and Jan Leuridana. (2004) The PolyMAX Frequency-Domain Method: A New Standard for Modal Parameter Estimation? *Shock and Vibration*. T. 11. – №. 3-4. – C. 395-409.
14. Zhang, L.; Brincker, R. and Andersen, P. (2005) An Overview of Operational Modal Analysis: Major Development and Issues, in the *Proceedings of the 1st International Operational Modal Analysis Conference*, Copenhagen, Denmark.
15. Inaudi, D.; Glisic, B. (2010) *Long-Range Pipeline Monitorin,* 400 p.

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PROPOSAL OF LANDFILL SITE MODEL IN THE PARTICULAR TERRITORY

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Nowadays, waste logistics is a relevant element within the worldwide logistics system. This paper is focused on the proposal of the appropriate model of landfill site for disposal of municipal waste. This issue refers to waste logistics in urban areas. In this regard, three different alternative models of landfill sites are considered. Landfill site model can significantly influence the waste management productivity and effectiveness of the enterprise. In the paper, one of the decision-making problem methods is utilized. This particular method enables to assess each model of landfill site in relation to each of the specified criterion and order the models according to the achieved results.

Keywords: Landfill site, waste logistics, municipal waste, decision-making problem, urban area

1. Introduction

Waste is according to § 3 of Act No. 185/2001 Coll., On waste, as amended (hereinafter referred to as the "Act"); any movable thing that the owner disposes of or intends or has duty to dispose of and belongs to a group of wastes listed in Annex 1 to this "Act".

The disposal of waste in accordance with the "Act" always takes place when a person passes the chattel, belonging to the groups of waste, for recovery or disposal under the "Act", or when a person passes it to another person authorized to collect or purchase the waste in accordance with the "Act", regardless of whether the transfer is without charge or paid. The disposal of wastes also occurs when the person alone removes the chattel belonging to a group of wastes.

The legal person whose activities produce waste or natural person authorized to do business whose business activities produce waste are the waste producers within the meaning of the "Act". The municipality is considered to be the originator of the waste for municipal waste (hereinafter referred to as MW), arising from the territory of the municipality, which has its origin in the activities of natural persons, which are not subject to the obligations of the originator. The municipality becomes the originator of the municipal waste when a natural person puts the waste at a designated location; the municipality will become the owner of this waste simultaneously.

2. Waste Logistics in Urban Areas

According to the "Act", municipal waste is all the waste generated within the municipality by the activity of natural persons and which is listed as a municipal waste (MW) in the implementing the regulation - Decree no. 381/2001 Coll., Waste Catalogue, with the exception of waste produced by legal entities or natural persons authorized to do business.

According to Decree no. 381/2001 Coll. (Eko-Kom, 2011), Waste catalog, each waste has its own catalog number. Municipal waste has No. 20 in this Decree and is divided into three groups and further into several subgroups.

2.1. Municipal Waste and Its Production

Production of municipal waste (Eko-Kom, 2011; Míka and Kučerková, 2014) in the Czech Republic is about 4 mil. tons/year. The main type of waste is mixed municipal waste and bulky waste, ie types of waste remaining after the sorting the usable components in systems of separate collection of waste. In improving the waste recovery and reducing the waste storage, it is an obvious potential for change in requirements for gathering and thereby the collection and transportation (distribution) of waste. To increase the utilization and reduce the storage of waste, it is necessary to extend the separate collection systems and build the new devices for a central treatment of Sorted residual municipal waste.

Overall, demands to increase the transportation performance for waste and its streamlining can be anticipated.

Table 1 contains the data on NO production in the Czech Republic in 2012 (tons/year).

Table 1. NO production in the Czech Republic in 2012 (tons/year) (Waste Management, 2012)

Waste code	**Waste name**	**Waste production (A00) (t/year)**
20 01 01	Paper and paperboard	259018,928
20 01 02	Glass	77859,541
20 01 08	Biodegradable waste from kitchen and canteen	14417,669
20 01 10	Clothing	948,051
20 01 11	Textile materials	5247,702
20 01 25	Edible oil and fat	2780,307
20 01 38	Wood	12139,742
20 01 39	Plastics	68931,391
20 01 40	Metals	97459,822
20 02 01	Biodegradable waste	130354,35
20 03 01	Mixed municipal waste	2812243,041
20 03 02	Wastes from marketplaces	14676,842
20 03 07	Bulky waste	383709,589
20 01 33, 20 01 34	Batteries and accumulators	1251,047
20 01 35, 20 01 36, 20 01 23, 20 01 21	Products which are subject to recollection classified under those codes	14127,61
-	Other NO categorized in No. 20	5585,807
Total		**3900751,439**

2.2. Sources of Waste

Main sources of waste are (Míka and Kučerková, 2014):

- Households (waste from citizens) - These wastes are collected in the municipality, which must ensure the collection, transport, disposal of municipal waste collection, transport, gathering and temporary storage of separated components of municipal waste. In addition to MW, municipalities pick over another waste as well - construction waste, tires, etc. According to Decree 3/2001, On the management of municipal and construction waste within the city area, natural persons are obliged to gather, sort and transmit the MW, separately, to recovery (utilization) and disposal.
- Municipality or cities (waste generated within the municipality or city area) - Many services in the city or municipality area are provided by authorized person under the contract with the city or municipality. Mostly, these are technical services or other services dealing with the waste management.
- Organizations (other than municipalities and cities) – All the services such as banks, schools, medical facilities, shops, as well as offices, trades, etc. are included in this type of waste sources. All of the above mentioned organizations produce waste similar to municipal waste and therefore it is often classified in the same category.

In these areas, a lot of different kinds of waste are produced. Some of them are usually further processed (recycled), some of them are subject to recollection (this is mainly related to hazardous waste) and other can no longer be utilized. This last kind of waste is to be put to a landfill or burned in incinerators.

2.3. Transportation of Municipal Waste

Transportation of municipal waste includes both waste transportation from the place of its origin (eg.: household) to the place of its concentration (eg.: station of containers) as well as the transportation of waste from the place of its concentration to the disposal area.

Generally (Míka and Kučerková, 2014), transportation of municipal solid waste can be divided according to various criteria. The most common division is according to:

- Transport distance
- Used transport means

3. The Technique Used for the Collection and Transportation of Municipal Waste

The selection of transport means for waste collection and transportation is adjusted to a wide range of waste containers. In the Czech Republic, there are universal superstructures, allowing the emptying all the basic types of containers - 110, 120, 240 and 1100 l.

For the transportation of waste (Míka and Kučerková, 2014; Kampf, Gašparík, Kudláčková, 2012), various, for this purpose especially designed cars, are used. They can be divided into three groups:

- Collecting garbage trucks – for the garbage removal gathered in the standardized trash containers
- Carriers of the containers – for the garbage collected (gathered) in the garbage carriages
- Transport garbage trucks - for the long haul of garbage from transshipment stations

4. Decision-making Problems

Selecting the suitable landfill site model for disposal and dumping the municipal waste can be viewed as a decision-making problem in which the final decision is affected by a group of external factors. For the purpose of solving the decision-making problems (Klein, et al., 1993) the methods of multi-criteria analysis can be used. The decision means in a given situation choosing one option from a list of potentially viable variants against several criteria. Next to the list of criteria indirectly forming the objective of the decision analysis (Brožova, Houška, Šubrt, 2003), it is necessary to have a list of variants from which to choose.

Generally (Zavadskas, Turskis, 2011), the basic procedure for the multi-criteria analysis (evaluation of alternatives) includes six steps: (1) Identification of variants, (2) Establishment of a set of criteria, (3) Determination of criteria weightings, (4) Determination of criterion examples, (5) Partial evaluation of variants and (6) Selecting the most suitable variant.

A detailed description of methods (Fotr, et al., 2006; Zavadskas, Turskis, 2011) of decision-making can be found in literature dealing with this issue. There are a number of methods that are used for solving multi-criteria analysis issues. The simple ones (Klein, et al., 1993) do not take into account the weight of each criterion and therefore are not appropriate for this paper because in the group of criteria which influence the layout of handling space, significant differences in the importance of criteria exist.

4.1. Determining the Criteria Weightings

Determining the criteria weightings (Fotr, et al., 2006; Saaty, Vargas, Wendell, 1983) is closely related to the completeness of a set of criteria reflecting the essential characteristics of the alternative. This is usually a key step in the analysis of the model of multi-criteria analysis. The information obtained in any way is used to determine the preferential relations between alernatives depending on the objectives of the entire analysis.

Methods (Saaty, Vargas, Wendell, 1983; Zavadskas, Turskis, 2011) for the weightings determining can be divided according to the information we have on the preference of criteria.

4.2. Selecting the Appropriate Alternative

Methods (Brožova, Houška, Šubrt, 2003) for the alternative selecting are divided according to what information about the preference among the criteria they require for their work and methods in terms of weights and about the alternative in the form of a criteria matrix with cardinal values as well: (1) maximizing the benefits, (2) minimizing the distance from the ideal variant and (3) preferential relationship.

Specific methods (Brožova, Houška, Šubrt, 2003; Fotr, et al., 2006; Saaty, 1983) for the most appropriate alternative selecting: Lexicographical method, Permutation method, ORESTE method, TOPSIS method, Weighted Sum Analysis – WSA, AHP method, Ardolana method and other.

5. Data and Methods

5.1. Identification of Alternatives

In phase one, it is necessary to identify a set of alternatives from which the final solution will be selected. The following different types of landfill site models were identified.

5.1.1. Landfill Site Model A

In this model, municipal waste is dumped horizontally, that is parallel to the main road infrastructure and ancillary roads as shown in Figure 1.

Figure 1. Landfill site model A

All garbage trucks serve only in the horizontal direction (parallel to the main road infrastructure). Generally, each section of landfill site is served by one garbage truck and one bulldozer. All horizontal ancillary roads are unidirectional and are used both for unloading of garbage trucks and the transit.

5.1.2. Landfill Site Model B

In this model of landfill site, municipal waste is dumped vertically, that is perpendicularly to the main road infrastructure and main railway track as shown in Figure 2.

Figure 2. Landfill site model B

There are ancillary horizontal roads which are bidirectional and are used only for unloading of garbage tracks (not for transit of vehicles). Roads in this landfill site model provide a faster access to individual sections. The same garbage truck and bulldozer can serve in various sections of landfill site (due to bidirectional ancillary roads).

5.1.3. Landfill Site Model C

Fourth model presents a combined form of previous two models (Figure 3). Municipal waste is dumped vertically to the main road infrastructure and horizontally to another main road infrastructure, ancillary roads and main railway track.

Figure 3. Landfill site model C

In this model, ancillary horizontal roads are bidirectional and are used both for unloading of garbage tracks and for the transit as well. Roads in this landfill site model provide the fastest access to individual sections (compared to the other landfill site models). The same garbage truck and bulldozer can serve in various sections of landfill site.

Garbage trucks travel a shorter distance, bulldozers are utilized more but the traffic is more because of the connection to two types of main road infrastructure.

5.2. Identification of Criteria

Phase two (Fotr, et al., 2006; Kampf, Gašparík, Kudláčková, 2012) of the decision-making problem process includes an identification of the set of criteria which affects whole process in the context of selecting the alternatives. The rational creation of evaluation criteria significantly depends on a thorough knowledge of the object of evaluation and on a systemic understanding of its structure and its functions. The set of criteria (Fotr, et al., 2006; Saaty, Vargas, Wendell, 1983) must be comprehensive i.e. it must reflect the essential characteristics of the objects (alternatives). If the latter is not the case, a big distortion in the results may occur.

It is necessary to differentiate the criteria according to the type of preference: increasing preference (maximization, profit), decreasing preference (minimization, loss) and alternating preference - preference changes when a certain value is achieved.

Decision-making for a typical landfill site model requires taking more than one criterion into account. After determining the objectives of the available knowledge analysis, relevant to this paper, four criteria primarily from transport-economic fields were identified: (a) investment costs of the landfill site building (costs), (b) minimum unloading time of garbage trucks and movement speed of bulldozers (U&M - unloading time and movement speed), (c) minimization of ancillary road infrastructure to create greater dump capacity and better accessibility of dump sections (D&A - dump capacity and accessibility), and (d) amount of traffic and extend of space needed to build a whole landfill site in a particular territory (T&S - traffic and extend of space).

5.2.1. Investment Costs of the Landfill Site Building (Costs)

Considering the assumptions in alternative C, ancillary horizontal roads are connected to two types of main road infrastructure (vertical and horizontal) and there can be more bulldozers. Apparently, that is the reason why this landfill site model has the highest cost compared to the other ones.

However, this model needs the least number of garbage trucks as the distance for trucks travel is less and more bulldozers are there to serve.

Based on the above mentioned assumptions, alternative A is next and alternative B is the least cost.

5.2.2. Unloading Time of Garbage Trucks and Movement Speed of Bulldozers (U&M)

Alternative C has the minimum unloading time with a fastest access to individual landfill site sections, compared to the other alternatives. Model B is the second in the order and the highest unloading time and the slowest access to individual sections belongs to alternative A - due to unidirectional ancillary roads.

5.2.3. Dump Capacity and Accessibility of Dump Sections (D&A)

Alternative B is the most capacious (since the smallest number of horizontal ancillary roads) followed by alternative A and C. In model B, ancillary roads only for unloading of garbage tracks are used and the connection to the horizontal main road infrastructure is omitted so the dump capacity is increased. Also the capacity of the model A is higher than model C because of the less road infrastructure used for transit or unloading.

In terms of using the bulldozers and garbage trucks in both import and export area (accessibility) of the landfill site, alternative C is the best. Considering the existence of bidirectional ancillary roads, alternative B is suitable in terms of accessibility as well. On the other hand, transit ancillary roads are omitted in this model. Due to the existence only the unidirectional ancillary roads, alternative A is the worst accessible.

5.2.4. Traffic and Space Needed to Build a Whole Landfill Site (T&S)

As mentioned above, because of the connection to two types of main road infrastructure, alternative C has the greatest amount of traffic. Alternative A is the second worst and due to the omitted transit ancillary roads, alternative B has the least traffic.

In terms of size of the space needed to build the particular model of landfill site, models A and B are the same good. These models of landfill site have a connection to either horizontal or vertical main road infrastructure. Construction of the model C takes the most space due to the largest number of connecting infrastructure.

5.3. Determining the Key Methods

Selecting the suitable method (Klein, et al., 1993; Saaty, 1983) depends on the perspective of the investigator interested in the subject. There are many different methods of decision-making problems which can help in the selecting the landfill site model. In practice, however, many methods cannot be used because they do not allow for the processing of all the intricacies intended in this matter and the fact that we do not know the details of the users of landfill sites, which we could have analyzed.

On this basis (Saaty, 1986), it was decided to use the *Analytic Hierarchy Process (AHP) method*, which appears to be relatively easy to handle and apply to so complex and difficult task of selecting the landfill site model.

In its calculation, the AHP method uses criteria with set weightings. Again, there are several methods to determine the criteria weightings. For the purposes of this paper basis (Saaty, 1986), the *Saaty pairwise comparison method* was chosen. A number of criteria have lesser or greater effect on the model selection. It was therefore necessary to choose such a method which allows human judgment to determine the relationship preference between two criteria being compared. Furthermore (Klein, et al., 1993; Saaty, Vargas, Wendell, 1983), the Saaty method allows for the detailed division of these preferences.

5.3.1. Saaty Pairwise Comparison Method

This is a method (Saaty, 1983) of quantitative pairwise comparison of criteria. For the evaluation of paired comparison of criteria, a 9 (1,3,5,7,9) point scale is used. It is also possible to use intermediate values - 2,4,6,8. Matrix elements (Bonissone, 1998; Saaty, Vargas, Wendell, 1983; Zavadskas, Turskis, 2011) $S = (s_{ij})$ are interpreted as estimates of the proportion of the weights of the *i*-th and *j*-th criteria.

The researcher (Bonissone, 1998; Saaty, Vargas, Wendell, 1983) compares each pair of criteria and enters the sizes of preferences of *i*-th in relation to the *j*-th criterion in the Saaty matrix $S = (s_{ij})$. In case *j*-th criterion is preferred above that of the *i*-th criterion, inverse values are entered into the Saaty matrix (s_{ij} = 1/3 for low preference, s_{ij} = 1/5 for strong preference, etc.).

This already indicates the basic characteristics of the Saaty matrix. Saaty (1983) designed several numerically very simple ways by which the weights can be estimated. Vector of their values is denoted as $v = (v_1, v_2, \ldots, v_k)$. The most commonly used method of calculating weights is the normalized geometric mean of a row in a Saaty matrix (Saaty, Vargas, Wendell, 1983), the procedure is sometimes called "*logarithmic least squares method*".

The "*priority vector*" i.e. the normalized weight is calculated for each criterion using the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria.

Calculating the geometric mean of each row of the matrix S (Formula 1):

$$g_i = \sqrt[k]{\prod_{j=1}^{k} s_{ij}}\,,\ for\ i,j = 1,2,\ldots,k \tag{1}$$

where: g_i - geometric mean; s_{ij} - elements of Saaty matrix; $\prod$ - product of values of Saaty matrix elements.

Normalization of the geometric mean (Formula 2):

$$v_i = \frac{g_i}{\sum_{i=1}^{k} g_i},\ for\ i = 1,2,\ldots,k \tag{2}$$

where: v_i - normalized geometric mean; g_i - geometric mean; $\sum$ - sum of geometric means´ values.

5.3.2. Analytic Hierarchy Process Method

The Analytic Hierarchy Process (AHP) method, first suggested by Saaty (1983) more than three decades ago, is one of the widely used multi-criteria decision-making methods. AHP (Saaty, 1986; Saaty, 1990; Saaty, 2008) can effectively handle both qualitative and quantitative data to decompose the problem hierarchically where the problem is broken down thoroughly and its related sub-elements with regards to the hierarchical level are listed in relation from the overall objective to the sub-objectives. General AHP procedure is composed of four main phases (Figure 4):

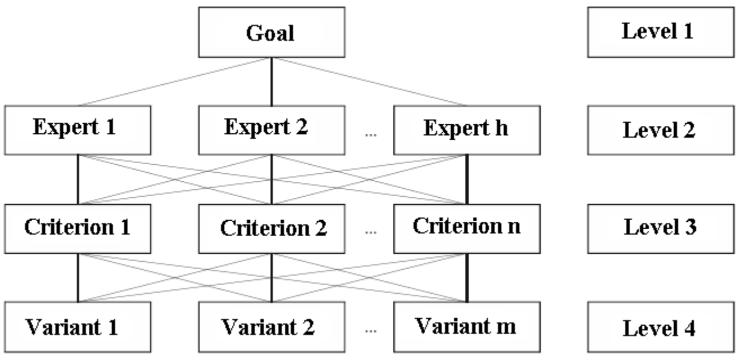

Figure 4. The Analytic Hierarchy Process structure (Saaty, 1990)

- Hierarchical problem decomposition: Identifying the decision problem and overall goal/objective – the problem is decomposed into sub-elements hierarchically (which are structured at different levels in the form of a hierarchy, from the top through the intermediate to the lower-level, which usually contains a finite number of decision elements),
- Evaluation phase: the relative importance of each element at a particular level is measured by a procedure of pair-wise comparison. Decision makers provide numerical values for the priority of each element using a rating scale,
- Synthesis of alternatives (ranking): the priority weights of elements at each level are computed using an eigenvector or least square analysis.
- Result: the above process is repeated for each level of the hierarchy until a decision is finally reached by overall composite weights.

The goal (Saaty, 1990) is to select the alternatives that results in the greatest value of the objective function. This is a compensatory optimization approach.

6. Calculations and Results

6.1. Determining the Criteria Weightings

As mentioned above, the determining the criteria weightings is realized using the Saaty pairwise comparison method. The first step of the Saaty method (Saaty, 1983; Saaty, Vargas, Wendell, 1983) is to determine the relationship between each pair of criteria when the level of preference is determined in a spot range between 1-9. This is determined as follows:

- To ensure the greatest possible objectivity in the selecting the appropriate landfill site model, 10 experts from the field of waste logistics were asked to determine preferences between individual criteria. Each of the ten experts set a level of significance for each pair of criteria.
- For each element of the matrix, a product of the sub-matrices of all experts was established and then the average was calculated.

Subsequently, elements of the Saaty method were used for further calculations. The individual values obtained from a procedure of the criteria weightings determining and the values obtained for the individual criterion in the intermediate calculations and the final values of the vector of weights of individual criterion are given in Table 2.

Table 2. Values obtained using the Saaty method

	Criterion	**1**	**2**	**3**	**4**
1	Costs	1	3	3	5
2	U&M	1/3	1	1/2	3
3	D&A	1/3	2	1	4
4	T&S	1/5	1/3	1/4	1
Product of values		45	1/2	8/3	1/60
Geometric mean		2.590	0.841	1.278	0.359
Normalized geometric mean		0.511	0.166	0.252	0.071

Explanatory notes:
U&M - unloading time and movement speed,
D&A - dump capacity and accessibility,
T&S - amount of traffic and extend of space.

The final product of a consistent Saaty pairwise comparison method is the overall priority vector (normalized geometric mean) of the criteria as illustrated in the last row of Table 2.

6.2. Selecting the Appropriate Alternative

It was decided that for the purpose of this paper, one of the decision-making problem methods, known as Analytical Hierarchy Process, is applied. In our case, it enables to evaluate the suitability of three identified alternatives of landfill site models. The outcome of this method (Kampf, Lizbetin, Lizbetinova, 2012; Saaty, 1990) is an order of three landfill site models based on the overall preferences expressed by the experts' evaluation.

Assigning the judgment of decision makers (experts) to each of the criteria was the first step of this method. Subsequently (Kampf, Lizbetin, Lizbetinova, 2012; Saaty, 2008), according to the AHP process, a comparison of individual models between them by each determined criterion was performed. And again, ten experts were asked to determine preferences between individual alternatives by each criterion. Each of the ten experts set a level of significance for each pair of alternatives by the corresponding criterion. And for each element of the matrixes assessment (Saaty, 1990), a product of the sub-matrices of all experts was established and then the average was calculated.

All comparisons of the models for each criterion (cost, U&M, D&A, T&S) are presented in the following tables (Table 3 - 6).

Table 3. The comparison matrix of the models for cost

Cost	**Model A**	**Model B**	**Model C**
Model A	1	1/3	2
Model B	3	1	5
Model C	1/2	1/5	1
Geometric mean	0.874	2.466	0.464
Normalized geometric mean	0.230	0.648	0.122

Table 4. The comparison matrix of the models for unloading time and movement speed

U&M	Model A	Model B	Model C
Model A	1	1/2	1/4
Model B	2	1	1/2
Model C	4	2	1
Geometric mean	0.5	1	2
Normalized geometric mean	0.143	0.286	0.571

Table 5. The comparison matrix of the models for dump capacity and accessibility

D&A	Model A	Model B	Model C
Model A	1	1/5	1/2
Model B	5	1	4
Model C	2	1/4	1
Geometric mean	0.464	2.714	0.794
Normalized geometric mean	0.117	0.683	0.200

Table 6. The comparison matrix of the models for amount of traffic and extend of space

T&S	Model A	Model B	Model C
Model A	1	1/4	3
Model B	4	1	7
Model C	1/3	1/7	1
Geometric mean	0.909	3.037	0.362
Normalized geometric mean	0.211	0.705	0.084

In total, four criteria were determined and for each one its weight was calculated. This weight must be subdivided among the alternatives. Weight of each criterion and also alternatives´ weights according to these criteria were calculated (see Table 2 - 6).

7. Conclusions

In order to determine the overall order of alternatives, sum of values of each alternative by the individual criterion multiplied by the weight of the corresponding criterion was counted. Subsequently, models were placed in descending order whereby the order of alternatives was identified (Table 7).

The AHP method of the decision-making problem has convinced to be useful tool in this matter on the most appropriate scenario in landfill site model among four proposed alternatives.

The horizontal type as the first layout, then the modified form of previous one would be the second layout, the third layout is a vertical type and the fourth layout is a combined form of previous layouts.

Resulting weightings of each layout according to each criterion and the order of layouts are in the following Table 7.

Table 7. Resulting weightings and the order of alternatives

Criterion / Model	Cost	U&M	D&A	T&S
Model A	0.230	0.143	0.117	0.211
Model B	0.648	0.286	0.683	0.705
Model C	0.122	0.571	0.200	0.084
Criteria weightings	0.511	0.166	0.252	0.071
Sum of values for models (A,B,C)	0.186	0.601	0.213	
Order of models	**3.**	**1.**	**2.**	

In this regard, the following performance criteria have been considered in the decision making process: (a) costs, (b) unloading time and movement speed, (c) dump capacity and accessibility, and (d) traffic and extend of space.

Ultimately, having considered the above results of the calculations, in the overall order of alternatives, *model B* appears to be the most appropriate landfill site model in the particular territory followed by model C and model A. The used method allows for the reducing and adding in the number of criteria that are taken into account in search of solutions.

Preferences differ from one decision maker to another (Kampf, Gašparík, Kudláčková, 2012); therefore, the outcome depends on who is making the decision and what their goals and preferences are.

Furthermore, in future, the managers and operators of landfill site should be more involved with non-monetary issues and decision criteria such as environmental issues like air and noise pollution etc.

References

1. Brožova, H., Houška, M., Šubrt, T. (2003) *Modely pro vícekriteriální rozhodování*. Česká zemědělská univerzita v Praze, Prague: CREDIT, ISBN 80-213-1019-7, 178 p.
2. Bonissone, P. P. (1998) *Determination of Weight Vector (cardinal ratio scale) from Pairwise Comparisons.* [online].
3. Eko-Kom. (2011) *Municipal waste*. [online]. Prague. Available at: http://www.ekokom.cz.
4. Fotr, J. et al. (2006) *Manažerské rozhodování,* Vyd. 1. Praha: Ekopress, ISBN 80-86929-15-9. 409 p.
5. Kampf, R., Gašparík, J., Kudláčková, N. (2012) Application of different forms of transport in relation to the process of transport user value creation. *Periodica Polytechnica Transportation Engineering*, 40(2), pp. 71 – 75.
6. Kampf, R., Lizbetin, J., Lizbetinova, L. (2012) Requirements of a transport system user. *Communications*, 14(4), pp. 106-108.
7. Klein, G. A. et al. (1993) *Decision making in action: Models and methods*. Westport, CT, US: Ablex Publishing, 480 p.
8. Míka, J., Kučerková, M. (2014) Logistics of the Disposal of Municipal Waste. In: *LOGI – Scientific Journal on Transport and Logistics*, Institut Jana Pernera, o.p.s., and Institute of Technology and Business in České Budějovice, Czech Republic, 1/2014, ISSN 1804-3216, pp. 88-92.
9. Saaty, T. L. (1983) Priority Setting in Complex Problems, in Hansen, P. (Hrg.), Essays and Surveys on Multiple Criteria Decision Making. In: *Proceedings of the Fifth International Conference on Multiple Criteria Decision Making*, Berlin/Heidelberg/NewYork: Springer-Verlag, pp. 140-155.
10. Saaty, T. L. (1986) Axiomatic Foundation of the Analytic Hierarchy Process. *Management Science*, 32(7), pp. 841-847.
11. Saaty, T. L. (1990) *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*, RWS Publications, Pittsburgh, Pennsylvania, 292 p.
12. Saaty, T. L. (2008) Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), pp. 83-98.
13. Saaty, T. L., Vargas, L. G., Wendell, R. E. (1983) Assessing Attribute Weights by Ratios. *Omega - The International Journal of Management Science,* 2(1), pp. 9-13.
14. Waste Management. (2012) Waste Management Information System. [online]. Available at: http://www1.cenia.cz/www/odpady/isoh.
15. Zavadskas, E. K., Turskis, Z. (2011) Multiple criteria decision making (MCDM) methods in economics: an overview. *Technological and Economic Development of Economy*, 17(2), ISSN 2029-4913, pp. 397-427.

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ANALYSIS OF PACKETS DELAY IN WIRELESS DATA NETWORKS

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The networks with wireless links for automation control applications traffic transmission when packets have small size and application payload is predictable are under consideration. Analytical model for packets delay on their propagation path through the network is proposed. Estimations for network architectures based on WiFi and Bluetooth wireless technologies are made. The specifications for physical layer 802.11 a/b/g/n and 802.15.1 are under consideration. Analytical and experimental results for delivered network bandwidth for different network architecture, traffic structure and wireless technologies were compared to validate that basic mechanisms are correctly taken into account in the model. It is shown that basic effects are taken into account and further accuracy "improvement" of the model will give not more than 5%. As a result that is important for automation control applications we have reliably received the lowest possible level for packets delay in one wireless link. For 802.11 it is of order of 0.2 ms, for 802.15.1 it is 1.25 ms and is true when application packet can be transferred by one data frame.

Keywords: WLAN, WiFi, Bluetooth, 802.11, 802.15.1, packet delay

1. Introduction

Wireless Local Area Networks based on 802.11technology (WiFi) and 802.15.1 (Bluetooth) have become quite popular and widespread. The nature of links based on the radio channel and the access to the shared resource of this channel cause variable available bandwidth, variable packet delay and loss rate. If changes in these parameters are not taken into account it may prevent to the correct operation of the networked time-sensitive applications, such as multimedia or control applications.

In the automation area, there is a clear trend promoting the use of wireless control channels in the factory floor. Automation control applications bring forward the demands to wireless links structure. It is obviously that delay in the delivery of packets introduced by the network links may degrade control applications performance or just makes such control quite impossible. Therefore, a good estimation of the network latency together with network bandwidth will facilitate robust system designs.

In this paper the analytical model for the estimation of possible delay of packets in links and provided network bandwidth with "acceptable" performances for several WiFi technologies (802.11 a/b/g/n) and Bluetooth technology (802.15.1) is considered. The approach in the model follows the one in (Krivchenkov and Saltanovs, 2014) but essentially includes the calculations for technology 802.15.1. The differences between the contention mechanism (competition) for radio recourse in the links for 802.11 and resource reservation mechanism for 802.15.1 are taken into account.

The experimental data for different Access points (AP) and wireless host's adapters were collected in set of experiments. Analytical and practical results for delivered network bandwidth for different network architecture, traffic structure and wireless technologies were compared to validate that basic mechanisms are correctly taken into account in the model, and it may be recommended as a useful tool for network designers.

2. Model of data transfer network

2.1. Common characteristics of the model

In our model we are taken into account the network architecture and traffic structure, we consider that there are the streams of packets with data between communicating nodes:

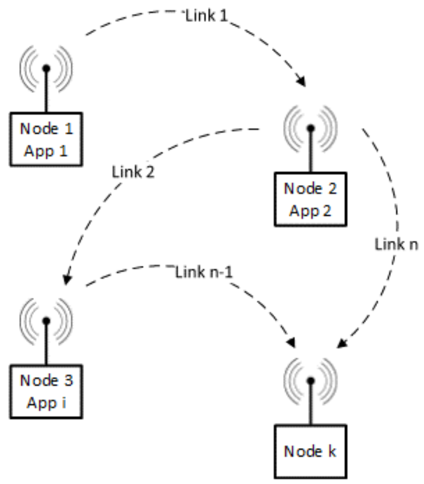

Figure 1. The architecture of network and structure of traffic

The sources of packets (see Figure 1) are Applications working in the nodes. There are links between nodes and paths of packets between different nodes. For the general definition we introduce the next entities: $\hat{R}_{App}$ - the traffic structure (or payload) on the level of applications; $\hat{S}$ -the architecture of network, is defined by applications demands and wireless technologies possibilities; $\hat{P}$ -wireless technologies parameters; $\hat{I}$ - parameters of noise in wireless channels; $T_{Frame}(\hat{P},l)$ - frame (packet on Data Link layer) transfer time through a link, where l – packet size on application layer; $PER(\hat{I},\hat{P},l)$ -probability of error in a packet when it is transmitted through a link; $D_{App}(\hat{S},\hat{R}_{App},T_{Frame}) = D_{App}(\hat{S},\hat{R}_{App},\hat{P},\hat{I},l)$ - the application packets delay on a path.

In these notations the task of "effective" network design for real time applications formally will be as follows. For the given range of $\hat{R}_{App}$, l and $\hat{I}$ the network with $\hat{S}$ and $\hat{P}$ to be provided in what for the delays of packets it is guaranteed that $\hat{D}_{App}(\hat{S},\hat{R}_{App},\hat{P},\hat{I},l) \le \hat{D}_0$ or the delays will be not greater than some given delays.

2.2. Analytical model for estimations

Payload characteristics

Payload in the model is characterized by several obvious parameters:
R_{AppP} - number of packets generated by application per unit time (packet per second); l - applications packet size (byte). So, the bit rate generated on application level will be:

$$R_{App} = R_{AppP} \cdot 8l \tag{1}$$

It is measured in bits per second (bps) or Kbps, Mbps.

The next "enhancement of payload" on data transfer channel is defined by protocols used on Transport and Network layers. For every network technology Data Link layer also adds some bytes. For: $\Delta l_{Transport}$ - additional bytes of transport protocol; $\Delta l_{Network}$ - additional bytes of network protocol; Δl_{Frame} - additional bytes of data link protocol. The bit rate on Physical level will be:

$$R_{App}^{Phy} = R_{AppP} \cdot 8(l + \Delta l_{Transport} + \Delta l_{Network} + \Delta l_{Frame}) \tag{2}$$

Late we will take into account later that for UDP protocol $\Delta l_{Transport}$ =8, for IP protocol $\Delta l_{Network}$ =20 and for an example for 802.11 frames Δl_{Frame} =36.

To characterize the process of packets transfer we introduce two more parameters:
T_{Frame} - the time of frame transfer through the link and R_{Frame} - the number of frames transmitted per unit time. It is important that if one application packet is transferred exactly by one frame (for an example well-known fragmentation mechanism for transmission technology is not used) we have:

$$R_{App} = R_{AppP} \cdot 8l = R_{Frame} \cdot 8l \tag{3}$$

We define also dimensionless parameter that characterizes "busyness" of channel. Often it is also called "payload" or "utilization":

$$\rho = R_{Frame} T_{Frame} \tag{4}$$

This quantity is in the range $0 \le \rho \le 1$. When ρ=0 no frames are transmitted, when ρ=1 the channel is busy in every moment of time (100% utilized).

Packet delay

For packets transfer process some model of service can be introduced. In such model application packets are just requests for service and the intensities of requests are λ_i (index i enumerates applications). Service is provided in links and intensities of services are μ_{ni} (index n enumerates links). So, the set of links on the path give us a set of service nodes:

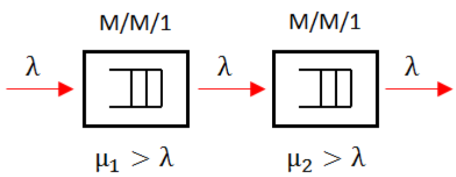

Figure 2. Service model for the path of 2 links

According to the Queueing Theory, when requests with intensity λ are coming on sequence of serving nodes where service is made with intensity μ and when time intervals between requests and time of request's service are exponentially distributed (so called M/M/1model) the average service time in one node will be:

$$\bar{t} = \frac{1}{\mu} + \frac{1}{\mu} \cdot \frac{\rho}{1-\rho}, \text{ where } \rho=\lambda/\mu \text{ and } 0 \le \rho < 1 . \tag{5}$$

Simplification of real world processes in this model for packets delay is obvious, but it is accepted in many cases for the estimations in computer networks design. This model can be "easy improved". For an example we may use M/G/1 instead M/M/1 approximation, when service tame has an arbitrary distribution and the average service time instead (5) will be:

$$\bar{t} = \frac{1}{\mu} + \frac{1}{\mu} \cdot \frac{\rho(1+c^2)}{2(1-\rho)}, \text{ where } c = \frac{\sqrt{D(t_s)}}{\bar{t}_s} \tag{6}$$

$D(t_s)$- the variance of service time (for exponential distribution of service time c=1).

Now let us define what "payload" or "utilization" will be in (5) and (6). If some link has its own serving recourse and it not shares this recourse with other links due to definition (4) utilization of link will be:

$$\rho_n = \sum_{\{i\}_n} R_{Frame_{ni}} T_{Frame_{ni}} \tag{7}$$

$\{i\}_n$ -means that summing to be done taking into account those applications witch packets will be transferred through link n. If serving recourse is shared with other links in (7) will be additional term:

$$\rho_n = \sum_{\{i\}_n} R_{Frame_{ni}} T_{Frame_{ni}} + \sum_{\{i\}_{n'}, \{n'\}_n} R_{Frame_{n'i}} T_{Frame_{n'i}} \quad (8)$$

$\{n'\}_n$ - denotes summing for all those links witch use the same serving recourse as link n has.

For packets delay on some path $\{n\}_i$ using (6) and (8) we have:

$$D_{App_i} = \sum_{\{n\}_i} D_{App_{ni}} = \sum_{\{n\}_i} T_{Frame_{ni}} (1 + \frac{\rho_n (1+c^2)}{2(1-\rho_n)}) \quad (9)$$

In our model (9) gives the relationship between packets delays D_{App} and network and traffic structure. There is some average time for frames transfer T_{Frame}. And payloads that applications generate R_{App} denote payloads calculated for frames per unit time R_{Frame}. Relationship between R_{App}, R_{AppP}, R_{Frame} are given in (1),(3).

For the simplification of understanding (9) let us consider the examples.

Example 1. Node1 is connected through WiFi channel to AP, transmits to Node2. Node2 is connected to AP with wired network. If we neglect with the delay in wired network, (9) and c=1(exponential distribution of T_{Frame}) gives:

$$D_{App} = T_{Frame} \cdot \frac{1}{1 - R_{AppP} \cdot T_{Frame}}$$

Example 2. Node1 and Node2 are in the same BSS (Basic Service Set for 802.11) and Node2 transmits to Node1:

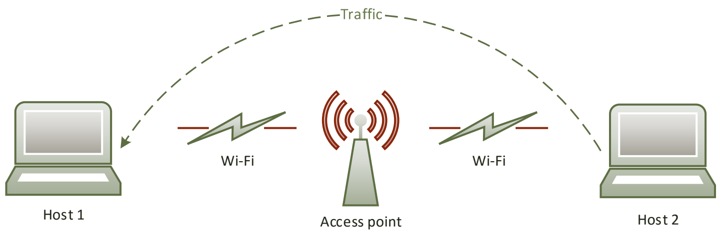

Figure 3. Structures of network and traffic for Example 2

We have 2 wireless links for this case and (9) gives:

$$D_{App} = 2 \cdot T_{Frame} \cdot \frac{1 + (c^2 - 1) \cdot R_{AppP} \cdot T_{Frame}}{1 - 2 \cdot R_{AppP} \cdot T_{Frame}}$$

Example 3. Node1 and Node2 are in the same BSS. Node 1 transmits to Node2 and Node2 transmits to Node1. If characteristics of application traffic for Node1 and Node2 are the same, the delay of packets in both directions from (9) will be:

$$D_{App} = 2 \cdot T_{Frame} \cdot \frac{1 + 2 \cdot (c^2 - 1) \cdot R_{AppP} \cdot T_{Frame}}{1 - 4 \cdot R_{AppP} \cdot T_{Frame}}$$

On Figure 4 we have presented calculated values for different examples (Ex2, Ex3) and models (M/M/1, M/G/1, and simulation model “802.11g model Ex2”).

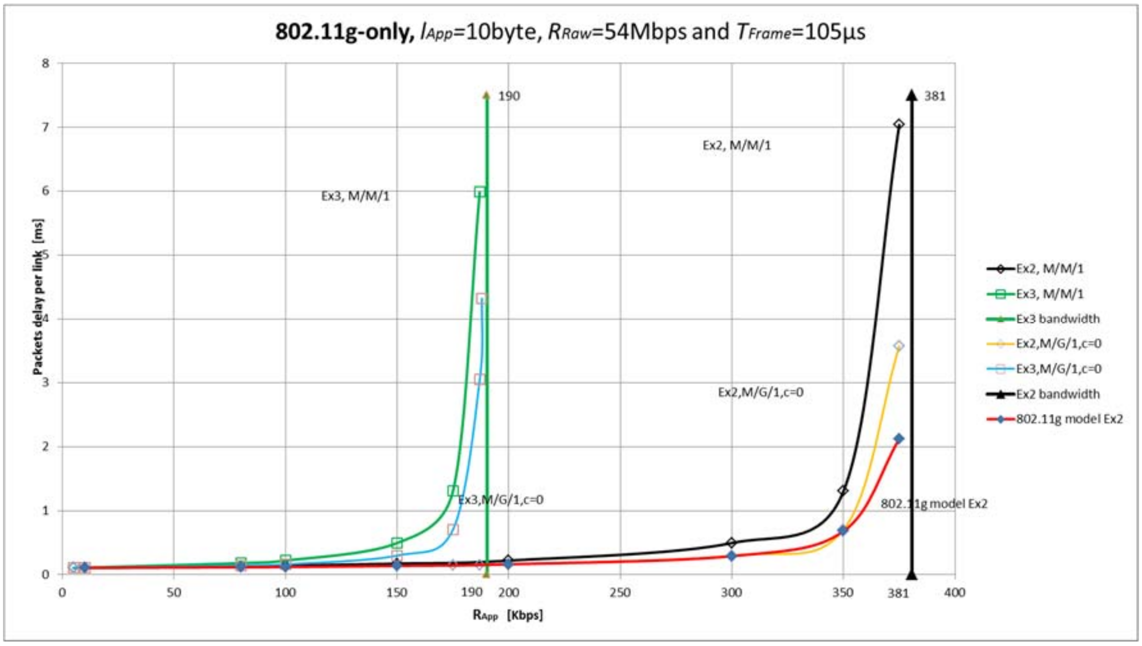

Figure 4. Calculated values for packets delays and different architectures

Thus, for different architectures there are common features. There is a limit of bit rate for applications and near this limit the delays of packets are sharply enhanced; so wireless channel has a bandwidth; minimal possible delay is defined by average frame time T_{Frame} . Bandwidth of channel is definitely related with "payload" (or utilization) given for the model in equation (8). Models give the significantly different values when utilization grater then 0.9. So, simplest model (M/M/1) is applicable for the estimations in the range for ρ~ 0 – 0.9. For the practice (packet delay needs to be of order T_{Frame}) the range ρ~0÷0.5 is recommended and "practical" bandwidth may be calculated when ρ=0.5.

2.3. Frame transfer time

In previous pats of this paper we have discussed a simple model for the packets delay (and hence maximum throughput) for wireless networks. It was emphasized that for successful estimations we need to have reliable knowledge about T_{Frame} for the technology that will be used in the network. In this section we discuss this parameter.

Frame transfer time for 802.11

In recent paper (Krivchenkov and Saltanovs, 2014) it was shown that for 802.11 networks a comparison of frame transfer time can move beyond a simple comparison of nominal bit rates R_{raw} for different PHY (physical layer) specifications 802.11 a/b/g/n. Following to the to 802.11 specifications (Gast, 2002), clarifying article (Gast, 2003) and publication (Qiang Ni, 2005) we try to take into account the transmission of small UDP packets and differences for MAC layer. We tried to consider the frame transfer mechanism. It was shown the importance of concurrent principle for the access to the radio channel and transactional nature of frame transfer. For the 802.11 T_{Frame} estimations are summarized in next table.

Table 1. Relationships for T_{Frame} estimations for different 802.11 specifications. UDP packets, application packet size *l* [bytes], R_{raw} - bit rate on PHY layer [Mbps]

	802.11b	802.11a	802.11g-only BSS	802.11g Protection RTS/CTS	802.11n
T_{Frame} [µs]	$444+\frac{8(l+78)}{R_{raw}}$	$94+\frac{8(l+64)+6}{R_{raw}}$	$94+\frac{8(l+64)+6}{R_{raw}}$	$520+\frac{8(l+234)+6}{R_{raw}}$	$100+\frac{8(l+64)+6}{R_{raw}}$

In Table 1 the delays in wireless links frames transfer are considered for 802.11 MAC layer specifications. Only DCF (Distributed Coordination Function) access method was under consideration. Implementation of DCF is mandatory for every WiFi device. On transport layer of the network UDP protocol is assumed and it carries application packets of small size (no packetization is performed as for Voice over IP, no fragmentation is supposed) and this is often a demand of automation control applications. The estimations give us minimal possible T_{Frame} (no mechanism of contention window CW changes is taken into account; also no mechanism ARF (Auto Rate Fallback) is supposed).

In wireless channel no pass loss, fading and interference was supposed but those effects may be taken into account in analytical model by reducing maximal possible raw bit rate given by specifications of PHY layer to some lover bit rate (ARF mechanism). As one can conclude from figures in Table 1 frame transfer time is primarily determined by the structure of the frame and R_{raw} is not so sufficient if packets are small.

Frame transfer time and bandwidth for 802.15.1

Analysing the characteristics of 802.15.1 or Bluetooth (BT) network that are important for the frame time transfer estimations we fallow to fundamental book (Tanenbaum and Wetherall, 2011). The architecture of BT is based on "piconet" structure:

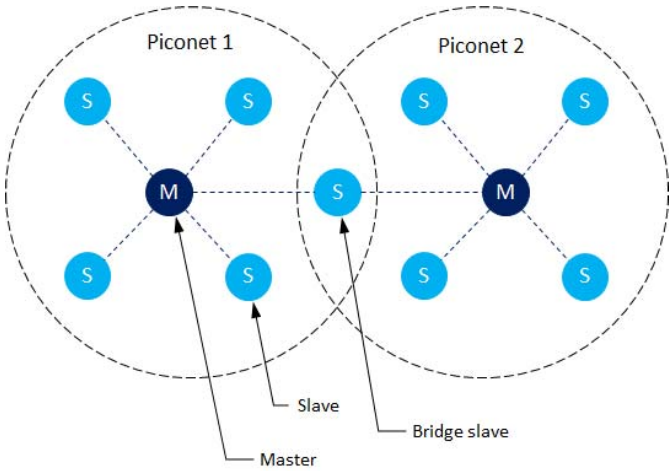

Figure 5. Architecture of Bluetooth network

In one piconet there is one Master and till 7 active Slave nodes. The data can be transferred only between Master and Slave, so data are transferred between Slaves only through Master. Due to the protocols stack two types of connections may be realized: SCO - Synchronous Connection Oriented and ACL - Asynchronous Connectionless Link. For control application traffic transfer only ACL type is of interest.

On PHY level the shared radio resource is pseudo random sequence of channels (there are 79 frequency channels width of each is 1MHz). TDM (Time Division Multiplexing) method is used for data transfer in piconet. As frequency hopping is used (FHSS – Frequency Hopping Spread Spectrum method) there is a slot time (frequency channel is changed every slot time). The slot time for 802.15.1 is 625μs or frequency is changed 1600 times per second. Master synchronizes the process for all nodes in piconet. For duplex data transfer in the connection between Master and Slave always pares exist – slots Master – Slave and slots Slave – Master. There are several bit rates (in our terms "raw") for data transfer on PHY level (Pahlavan and Krishnamurthy, 2009): 1 Mbps (modulation BFSK for Bluetooth 1.0); 2 Mbps (modulation PSK); 3 Mbps. On MAC (data link) layer the frames with appropriate structure exist. To transmit a frame 1, 3 or 5 time slots may be used (Figure 6) and the structure of frame is different for that cases (Figure 7).

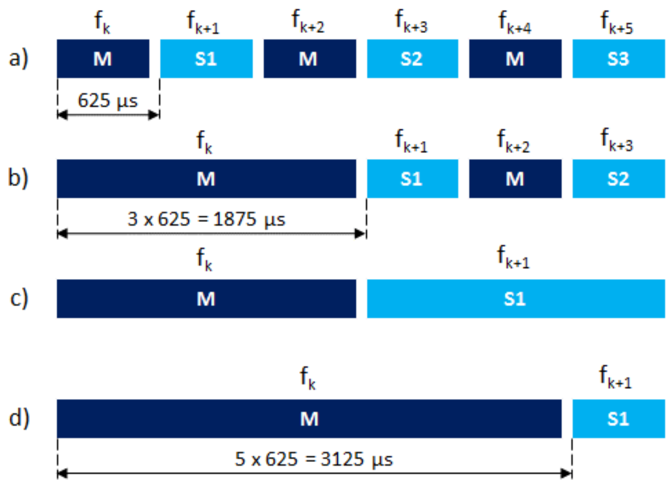

Figure 6. Transmission frames of different length: a) one-slot frame; b) asymmetric three-slot; c) symmetric three-slot; d) asymmetric five-slot

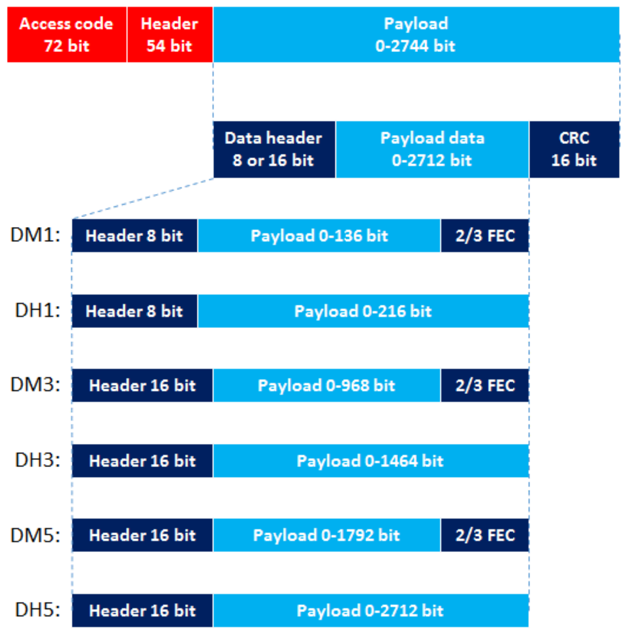

Figure 7. The frame structure for ACL (DM – Data Medium; DH – Data High; 1, 3, 5 – slots)

The maximum field size for data of packets coming on MAC level (payload on Figure 7) is defined by raw bit rate. On Figure 7 the payload length is shown for the raw bitrate 1Mbps. In (Tanenbaum and Wetherall, 2011) it is emphasized that only "payload" field is transmitted with speed 2 or 3 Mbps but the fields "Access code" and "Header" are always transmitted on speed 1Mbps. Table 2 demonstrates the ranges of "payload" length L for different frame structures (k – the number of slots for frame transfer) and raw speeds:

Table 2. Correspondence of payload length, R_{raw} and number of slots for ACL frames without correction of errors (DH type)

	k=1	**k=3**	**k=5**
R_{raw}=1 Mbps	L=0-27 byte	L=28-183 byte	L=184-339 byte
R_{raw}=2 Mbps	L=0-47 byte	L=48-360 byte	L=361-672 byte
R_{raw}=3 Mbps	L=0-76 byte	L=77-545 byte	L=546-1014 byte

Thus, 802.15.1 technology is characterized by some mechanism of slot time reservation to transfer the stream of data packets using frames of different structure. This mechanism is in strong dependence on packets size. Moreover it depends on number of active nodes in piconet and possibilities of network adapters to work on higher speeds (for an example due to signal to noise ratio in radio channel).

Let us estimate the frame transfer time for the case when for packet streams in radio channel in piconet with one Master (it is always so) and n Slave (according to the specifications n≤7) reservation mechanism gives time slot sequence as follows (see Figure 8):

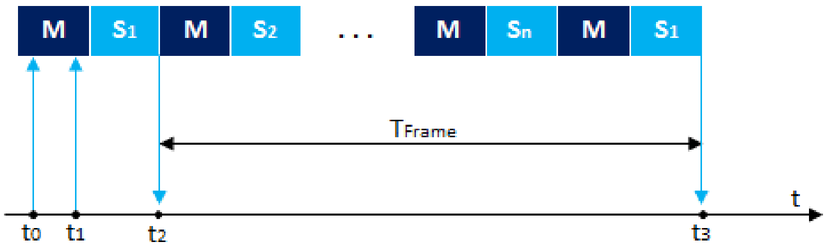

Figure 8. Time slot sequence for Master and n Slaves frames transfer. Here Master's and Slave's frames occupies the same number of slots

We have emphasize that for 802.15.1 the one slot time is 625µs and frame can occupy 1, 3 or 5 time slots. It is obvious that:

$$T_{Frame} = 625 \cdot \sum_{i=1}^{n}(k_{Mi} + k_i) = 625 \cdot (k_M \cdot n + \sum_{i=1}^{n} k_i) \ [\mu s] \quad (10)$$

Here k_i – number of slots for frames from Slave i to Master, and k_{Mi} – number of slots for frames from Master to Slave i. The equation (10) is an analog for T_{Frame} estimations for 802.15.1 as equations in Table 1 for 802.11 technologies.

It is not so easy to know what k will be in (10) due to lack of opacity for reservation mechanism. But we will suppose (and experiments confirm it) that reservation mechanism picks out minimal amount of slots for frames taking into account the packet size that comes on MAC layer. The ranges for packet sizes we have given in Table 2.

For the demonstration haw our model of estimations works for 802.15.1 wireless data channel and "small" application packets (*l*=10 byte, transport protocol UDP-IP with 28 additional bytes for MAC layer) we will consider two examples:

There are 2 nodes, - Master and Slave, so 2 streams of traffic are possible: Slave-Master and Master-Slave simultaneously; from Table 2 we have that it is possible to transmit such packets with frames of 1 slot on speed 2Mbps and the frame transfer time from (10) will be:

$$T_{Frame} = 625 \cdot (k_M \cdot n + \sum_{i=1}^{n} k_i) = 625 \cdot (1 \cdot 1 + 1) = 1250 \ [\mu s]$$

This estimation of T_{Frame} is true for both directions. For the bandwidth B (maximal possible throughput) for both directions from (9) we receive:

$$B = \frac{8 \cdot l}{T_{Frame}} = \frac{8 \cdot 10}{1250} = 64 \ [Kbps]$$

There are 3 nodes, - Master and two Slaves, so the traffics Slave1-Master, Slave2-Master are possible and in the revers directions: Master-Slave1, Master-Slave2; also traffics Slave1-Master-Slave2 and Slave2-Master-Slave1. The T_{Frame} for one link from (10) will be:

$$T_{Frame} = 625 \cdot (k_M \cdot n + \sum_{i=1}^{n} k_i) = 625 \cdot (1 \cdot 2 + 1 + 1) = 2500 \ [\mu s]$$

For the traffics that not share the same link (for an example those traffics are Slave1-Master-Slave2 and Slave2-Master-Slave1) it is true:

$$B = \frac{8 \cdot l}{T_{Frame}} = \frac{8 \cdot 10}{2500} = 32 \ [Kbps]$$

3. Experiments on data transfer network

To verify estimations that can be received from model described and frame transfer time calculations for 802.11 and 802.15.1 the set of experiments was performed. In experimental cases the architecture of network and structure of traffic were changed. In all cases the application payload was provided as a stream of "small" packets of size *l*=12 byte generated by utility Jperf. As a transport protocol UDP protocol was used. In all cases throughput and bandwidth (maximal throughput) were measured for data channels (paths) between Hosts. Wireless and wired links were composing channels.

3.1. Experiments for 802.11

In Table 3 the parameters of experiments are presented. As wireless technology 802.11g specifications for wireless links were used. For column "Architecture" in Table 3 symbol "/" denotes wired link and symbol "-" denotes wireless link. In all experiments we have tried to maximize the ratios "signal to noise" (SNR) as far as possible, so it can be supposed that wireless adapters of Hosts worked on higher possible "raw" speed.

Table 3. Comparison of experimental and model results for WiFi experiments. Bandwidth for different network architectures and structures of traffic was compared

Experiments			Wireless concurrent links in network	Wireless links on path	Experimental bandwidth [Kbps]	Model bandwidth [Kbps]	Deviation Experiment from Model bandwidth [%]	Calculated T_{Frame} [ms]
Name	Architecture	Traffic Bearer/BiDirectional						
WiFi 1.1	Host2-AP/Host1	B	1	1	848	911	-6,9	0,105
WiFi 1.2	Host2-AP/Host1	B	1	1	428	432	-0,9	0,222
WiFi 2.1	Host2-AP/Host1	BD	2	1	280	311	-10,0	0,154
WiFi 2.2.1	Host2-AP/Host1	BD	2	1	232	255	-9,0	0,188
WiFi 2.2.2	Host2-AP/Host1	BD	2	1	285	311	-8,4	0,154
WiFi 3.1	Host2-AP-Host1	B	2	2	252	255	-1,2	0,188
WiFi 3.2	Host2-AP-Host1	B	2	2	300	311	-3,5	0,154
WiFi 4	Host2-AP-Host1	BD	4	2	139	140	-0,7	0,171
WiFi 5	Host1,Host2-AP/Host3	B	2	1	249	255	-2,4	0,188
WiFi 6	Host1,Host2-AP-Host3	B	4	2	130	140	-7,1	0,171
						Average	-5,0	0,2

The main conclusions from experiments are as follows. Our model is adequate to present the real process of packets transfer in the network with WiFi links; the predicted bandwidth of the channel is higher (approximately 5%) than experimental one and this fact can be taking into account by more precisely the contention window (CW) changing mechanism. Frame transfer time (and application packet transfer time for "small packets") for the specification 802.11g (and also for 802.11a,n) is about 0.2 ms per wireless link; this fact may be important for the real time applications packets streams.

3.2. Experiments for 802.15.1

In Table 4 the parameters of experiments are presented. 802.15.1 specifications for wireless links were used. In all experiments we have tried to maximize the ratios "signal to noise" (SNR) as far as possible, so it can be supposed that wireless adapters of Hosts worked on higher possible "raw" speed.

Table 4. Comparison of experimental and model results for Bluetooth experiments. Bandwidth for different network architectures and structures of traffic was compared

Experiments			Wireless concurrent links in network	Wireless links on path	Experimental bandwidth [Kbps]	Model bandwidth [Kbps]	Deviation Experiment from Model bandwidth [%]	Calculated T_{Frame} [ms]
Name	Architecture	Traffic Bearer/ BiDirectional						
BT 1.1	Master-Slave	B	2	1	72	77	-6,6	1,25
BT 1.2	Slave-Master	B	2	1	68	77	-12,0	1,25
BT 2.1	Master-Slave	BD	2	1	70	77	-9,5	1,25
BT 2.2	Slave-Master	BD	2	1	69	77	-10,5	1,25
BT 3.1	Master-Slave; Slave	B	2	1	67	77	-12,4	1,25
BT 3.2	Slave-Master; Slave	B	2	1	63	77	-18,4	1,25
BT 4.1	Master-Slave; Slave	BD	2	1	65	77	-15,2	1,25
BT 4.2	Slave-Master; Slave	BD	2	1	65	77	-14,8	1,25
BT 5.1	Slave1,Slave2-Master	B	4	1	36	38	-5,5	2,5
BT 5.2	Slave1,Slave2-Master	B	4	1	32	38	-16,4	2,5
BT 6.1	Slave1-Master-Slave2	B	4	2	34	38	-12,2	2,5
BT 6.2	Slave2-Master-Slave1	B	4	2	31	38	-18,2	2,5
BT 7.1	Slave1-Master-Slave2	BD	4	2	33	38	-14,3	2,5
BT 7.2	Slave2-Master-Slave1	BD	4	2	32	38	-16,4	2,5
Average							-13,0	

The main conclusions from experiments are as follows. Our model is adequate to present the real process of packets transfer in the network with Bluetooth links; the predicted bandwidth of the channel is higher (approximately 13%) than experimental one and this fact can be corrected taking into account more precisely the time slot reservation rescheduling mechanism. Smallest frame time (and application packet transfer time for "small packets") for 802.15.1 is about 1.25 ms per wireless link (and is proportional to the number of active Slaves in piconet); this fact may be important for the real time applications packets streams.

4. Conclusions

In the matter of fact we have proposed analytical model for the estimations of application packets delay on their propagation paths through the network in what wireless links are present. It is done on the basis of Queueing Theory on network level and calculations of frames transfer time (Data Link or MAC layer) for wireless technologies 802.11 and 802.15.1. Analytical model gives the relationships between delays and bit rate on application level for different network architecture and traffic structures.

The delays for frames transfer are considered for 802.11 MAC layer specifications, only DCF (Distributed Coordination Function) access method was under consideration and PHY layer specifications 802.11 a/b/g/n were analyzed. For 802.15.1 specifications ACL (Asynchronous Connectionless Link) frame structure were taken into account. On transport layer of the network UDP protocol was used which carry application packets of small size (no packetization is performed) and this is often a demand of automation control applications. We have not considered here influence of pass loss, fading and interference in wireless channel.

The set of experiments were performed on WiFi and Bluetooth networks to validate the model and some of them are presented. It is shown that basic effects are taken into account and further accuracy "improvement" of the model will give not more than 5%. As a result that is important for automation control applications we have reliably received the lowest possible level for packets delay, for 802.11 it is 0.2 ms and for 802.15.1 it is 1.25 ms (for one wireless link).

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References

1. Krivchenkov, A. and Saltanovs, R. (2014) The performance analysis of WiFi data networks used in automation systems. In: *Proceedings of the 14th International Conference "RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION" (RelStat'14),* pp. 356-366.
2. Gast, M. (2002) *802.11 Wireless Networks: The Definitive Guide.* O'Reilly, 464 pp.
3. Gast. M. (2003) When Is 54 Not Equal to 54? A Look at 802.11a, b, and g Throughput, *published on Wireless DevCenter*, http://www.oreillynet.com/wireless/.
4. Qiang Ni. (2005) Design and Analysis of MAC Protocol for IEEE 802.11n, *published of Hamilton Institute,* www.hamilton.ie/ncnrc/, 23 pp.
5. Tanenbaum, A.S. and Wetherall, D.J. (2011) *Computer networks*. 5th ed. Pearson Education, Inc., publishing as Prentice Hall.
6. Pahlavan, K. and Krishnamurthy, P. (2009) *Networking Fundamentals: Wide, Local and Personal Area Communications*, John Wiley & Sons, Ltd., ISBN: 978-0-470-99289-0.

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RESEARCH OF THE EFFICIENCY OF THE WIRELESS POWER TRANSFER WITH THE EMPLOYMENT OF DD INDUCTANCE COILS

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The paper is devoted to using of DD inductance coils for the wireless power transfer. The aim of the given research is to determine influence of the parameters of resonance transformer on the efficiency of the wireless power transfer with the use of the DD inductance coils. Experimental installation of the wireless power transfer by a resonance inductive method was constructed. Experiments were performed with it help. Research results show influence of the distance between the coils of inductance, of the resonance transformer frequency, of the storage source voltage and of the temperature conditions on the efficiency of the wireless power transfer.

Keywords: DD inductance coil, wireless power transfer, resonance transformers, resonance inductive power transfer

1. Introduction

Currently, the technologies wireless power transmission for charging the automobile accumulators are given sufficient attention (Wu and other, 2011; Miller and other, 2012; Covic and other, 2013; Li and other, 2015). Charging the accumulating batteries on the move seems very perspective which is confirmed by the standards of the leading world countries (Pereirinha, 2013). But the technology of wireless power transmission for moving transport means is yet at the stage of the prototypes research and development. To charge the accumulating batteries with the wireless electro power transmission there is employed the method of electromagnetic induction.

To increase the efficiency of the systems of wireless power transmission with the electromagnetic inductance and the distance between the transmitting and receiving windings of the transformer, there is employed the technology of the resonance inductive power transfer (Kurs and other, 2007; Grajski and other, 2012). Its essence lies in using two circuits adjusted at one resonance frequency and forming a single resonance transformer. To excitate the oscillating contour of the transmitting winding of the transformer there are used the non-sinusoidal impulses. For developing resonance transformers there are used flat one-side coils of inductance: inductance coils – DD inductance coils and ring inductance coils (Budhia and other, 2013).

The main characteristic of the efficiency of the wireless system of power transmission is the efficiency which characterizes the part of power coming from the power source to the system load (power storage). The values of the wireless power transmission efficiency must be close to 1 (Li and other, 2015). From the analysis of the principle of work of the wireless power transmission system, based on the resonance inter-induction of the transformer circuits, we can conclude that the efficiency of such system will be greatly dependent on the following factors:

- construction of the inductance coils of the resonance circuits of the transformer;
- distance between the inductance coils of the receiving and the transmitting circuits of the resonance transformer;
- methods of their excitation.

The advantage of using the DD coils of inductance is determined by their construction, size, and the configuration of the magnetic field which they form. There are some publications dedicated to the modelling of the wireless power transmission with the use of the DD inductance coils and to the research of the characteristics of the resonance transformers with the DD inductance coils (Li and other, 2015; Covic and other, 2013). Though, the existing evaluations of the efficiency of employing the DD coils of inductance have been received without the account of the following factors:

- Value of clearance of the existing auto transport means;
- Influence of change of distance between the DD inductance coils on the efficiency of the wireless power transfer;
- Influence of the capacity source on the efficiency of wireless power transmission;
- Temperature conditions of work of the wireless power transmission system.

The aim of the given research is to determine influence of the distance between the inductance coils, of the resonance transformer frequency, of the storage source voltage and of the temperature conditions on the efficiency of the wireless power transmission with the use of the DD inductance coils.

2. Experimental installation of the wireless power transfer by a resonance inductive method

To conduct research of the peculiarities of the resonance induction method of wireless transmission there has been developed a structural scheme of an experimental installation of wireless power transmission. The structural scheme of the experimental installation is given in fig. 1. To develop the structural scheme of the experimental installation of wireless power transmission there has been chosen the impulse way of stimulating oscillations in the transmitting circuit of the resonance transformer.

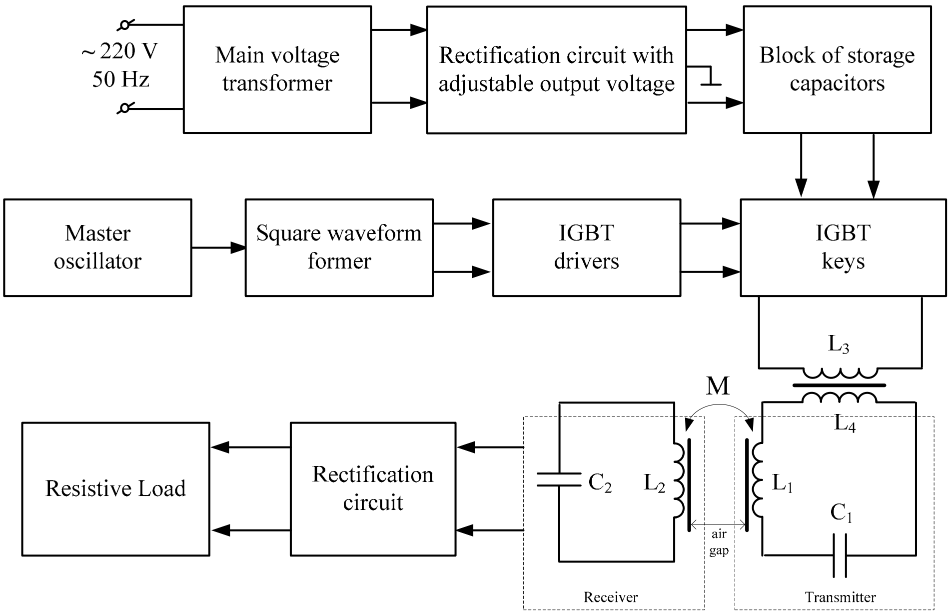


Figure 1. Block- diagram of the experimental installation of wireless power transfer

The experimental installation contains a transmitting circuit consisting of condenser C_1 and coil of inductance L_1, and a receiving circuit consisting of coil of inductance L_2 and condenser C_2. Stimulation of the transmitting circuit is performed by the method of consecutive stimulation with the help of the stimulation transformer formed by the primary winding L_3 and the secondary winding L_4.

The master oscillator forms right angle impulses which frequency may be regulated. Right angle impulses enter the generator of meander signals. The frequency of the meander signal is determined by the frequency of the right angle impulses. The meander signal enters the drivers of the IGBT transistors. The IGBT transistors' drivers are used to control the work of the IGBT transistors which perform the function of the electronic force keys. Usage of the IGBT transistors' drivers provides maximum coefficient of the IGBT transistors and their defense from the overloading. Performing the function of electronic keys, the IGBT transistors provide the discharge of accumulating condensers through the primary coil L_3 of the stimulating transformer.

The rectifier of the net voltage is the source of the transmitted power. Constant voltage from the rectifier output charges the accumulating condensers. In the scheme of the net voltage rectifier there is provided adjustment of the amplitude of the rectified net voltage. It allows adjustment of the constant voltage at the rectifier output and, therefore, the condenser voltage. The voltage of the alternating current produced at the condenser $\boldsymbol{C_2}$, goes to the rectifying device of the receiving circuit. The output voltage of this rectifying device is the output voltage of the experimental installation of the wireless power transmission by the resonance induction method. The view of the developed experimental installation of the wireless power transmission is given in Fig. 2.

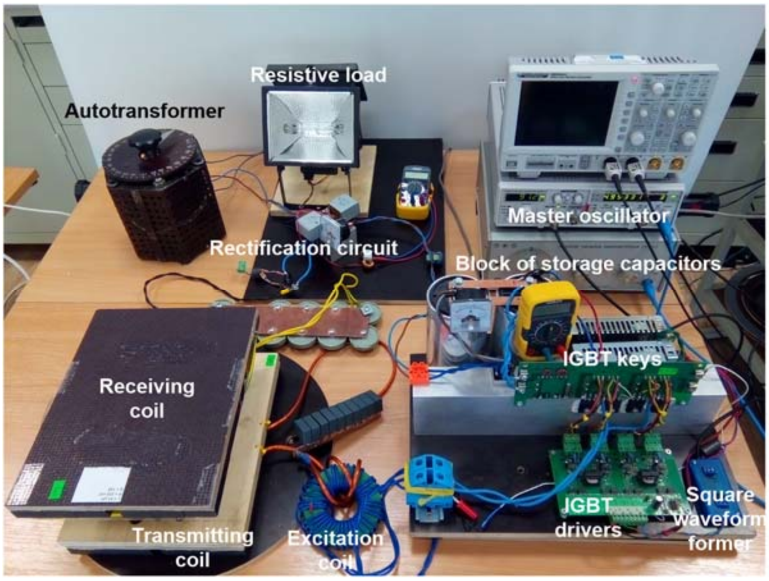
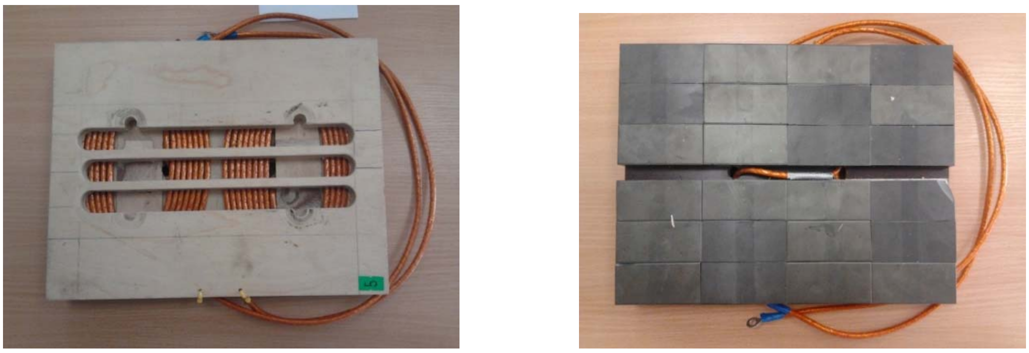


Figure 2. Experimental installation of the wireless power transfer

The auto transformer was used for adjusting the level of voltage produced at the bridge scheme of rectifying the net voltage. It provided adjustment of the constant voltage at the accumulating condensers (Fig.2.). As an active load of the rectification scheme at the receiving side there were used electric lighting lamps of different capacity. In the transmitting and receiving circuits there were used the rectangular DD coils of inductance.

The layout of the flat DD coil of inductance is given in Fig. 3. Fig. 3 shows the transmitting coil from the windings' side and Fig. 3.b shows it from the opposite side – from the side of the ferrite screen.



a b

Figure 3. DD inductance coil (a – from the windings' side, b и d – from ferrite shield side)

Every spiral winding of the transmitting DD coil contains 8 windings of litz wire of the 45 mm diameter. Every spiral winding of the receiving DD coil contains 10 windings of the W-200-2L wire. The ferrite screen was made in the form a plate of ferrite magnet bars with the penetrability of μ=60 and geometric sizes of 74x35x15 mm. The squares of the transmitting and receiving DD coils were of the similar sizes: 290x230 mm.

3. Impact of the distance between the dd coils on the parameters of the resonance inductive system of the wireless power transfer

With the wireless power transmission on the basis of the resonance mutual conduction of the circuits for the objects on move (in a dynamic mode), the distance between geometric centers of the transmitting and receiving coils may change. It changes because of the vertical and transversal shift of the receiving coil (moving object) regarding the center of the transmitting coil of the resonance transformer.

Change of the distance between the transmitting and receiving coils results in the change of the coefficient of mutual induction (mutual inductance) $\boldsymbol{M}$ and the coefficient of the kсв coils connection as well as in the change of the inductances of $\boldsymbol{L_1}$ and $\boldsymbol{L_2}$ coils of the transformer circuit. Change of the coefficient of the $\boldsymbol{k_c}$ connection changes the reactive and active resistances in the oscillating circuits which brings about change of the quality, of the oscillating circuits' resonance frequency, of the AFC circuits and of the whole resonance transformer. As the result, there changes the transmitted capacity and the efficiency of the whole system of the wireless power transmission.

Affect of the distance between the DD coils inductance $\boldsymbol{d}$ on the parameters of transmitting coil of inductance was researched at different mutual dispositions of the DD inductance coils. For this, the geometric center of the receiving coil was shifted at a certain distance regarding the center of the transmitting coil in parallel to one of the sides of the transmitting coil or the receiving coil shifted regarding the transmitting coil at a certain angle. Table 1 shows the variants of the mutual disposition of the DD inductance coils. The figures show in green the overlapping parts of the mutually disposed DD inductance coils.

Table 1. Variants of the mutual disposition of the DD inductance coils

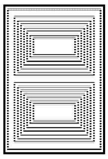
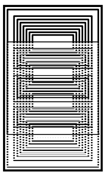
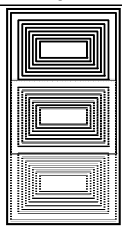
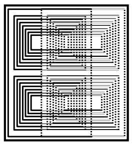
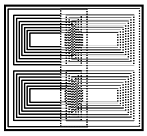
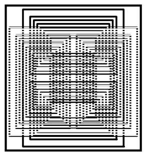
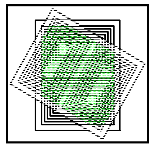
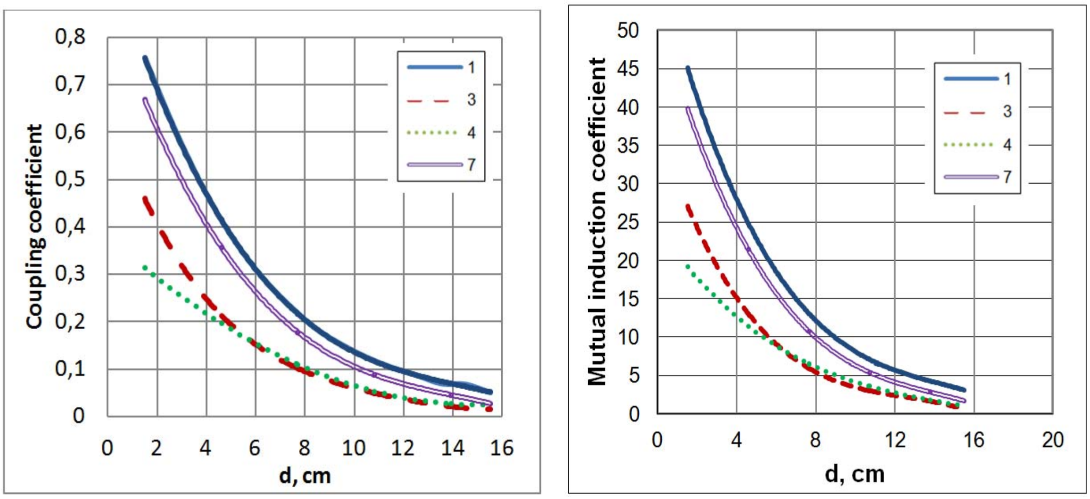
№	1	2	3	4	5	6	7
Kind							

Fig. 4 shows the received dependencies of the connection coefficients between the kсви coils and the coefficients of the mutual inductance $\boldsymbol{M}$ for those variants of the mutual disposition of the DD coils at which comes into force mutual dependence of the transmitting and receiving coils.



a b

Figure 4. Influence of distance the DD inductance coil on on coupling coefficient different variants of f the mutual disposition of the DD inductance coils

The values of the coefficient of connection and the coefficient of mutual induction are at maximum at any distance the DD inductance coils under the variant of the mutual DD coils disposition №1. In this variant of the DD coils disposition, the stream connection between the coils will be at maximum. The magnetic streams covering every winding of the DD coils will be turned one way [22]. Increase of the distance between the coils decreases the level of the magnetic field in the plane of the receiving coil. It brings about the decrease of the connection coefficient and the mutual induction coefficient.

If the DD coils of inductance are disposed in conformity with the variants 3, 4 or 7 (table 1) the stream cohesion will be deceased but the one way direction of magnetic streams will remain. The disposition of the DD inductance coils, in conformity with the variants 2, 5, 6 (Table 1) is characterized by the absence of the mutual connection: the coefficients of connection and the coefficients of mutual induction are close to zero. In such variants stream cohesion is decreased (variant №5), or the magnetic streams covering every DD coil winding will have different directions (variants 2 and 6).

The measurement scheme which block-diagram is shown in Fig.5 has been used for the study the power parameters of the resonant transformer. In this scheme series - parallel topology of the resonan transformer was used. The transmitting contour is a serial contour formed by the inductance L_1 and capacitor C_1. The receiving contour is a parallel contour formed by the inductance L_2 and capacitor C_2.

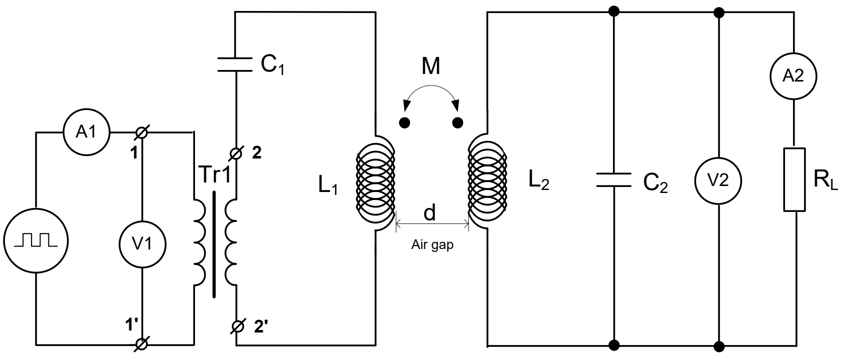
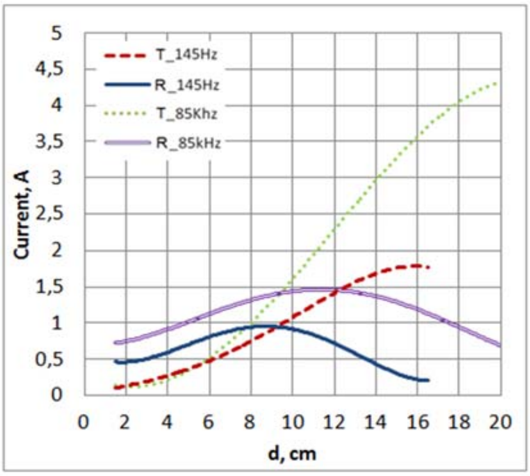


Figure 5. Measurement scheme for the study the power parameters of the resonant transformer

To excite oscillations in the transmitter contour transformer Tr1 has been used. Its secondary winding is included in the transmitting contour in series with L_1 and C_1. It provides a consistent inclusion of the exciting source of oscillations in the transmitting oscillatory contour. Transformer Tr1 has been made with toroidal core, its primary winding consisted of 18 turns and the secondary winding of the two turns. Load resistance RL is the input resistance of the rectification circuit (Fig. 2). Ammeters A1 and A2 were used to measure the input and output currents of the resonant transformer. Voltmeters V1 and V2 used to measure the voltage on the storage capacitor and on the load of resonant transformer.

The impact of air gap between DD coils has been investigated on parameters of the resonant transformer system of wireless power transfer. Investigations have been performed at two resonant frequencies: f_{res} = 145 kHz и f_{res} = 85 kHz. The variant of the mutual arrangement of DD coils №1 (Table 1) was used. The distance between the DD coils d was incremented by 3 cm. The square wave signal frequency of the master oscillator (Fig. 1) was set equal to the resonant frequency of the resonant transformer.

Fig.6. shows the impact of the distance d on the electrical parameters of the resonant transformer at a fixed voltage U_c on the storage capacitor U_c = 50 V (Fig.1. and Fig.2.). We can see that the output current is maximal at distances dmax between DD coil of resonant contour. At these distances, the coupling coefficient between the coils is less than 0.1 (Fig.4.a): d_{max} = 9 cm when resonant frequency equals 145 kHz and d_{max} = 12 cm when resonant frequency equals 85 kHz. Further increase in distance d leads to decrease the output current, because it decreases the level of the magnetic field near the receiver coil, and decrease the coupling coefficient between the coils (Fig.4.a). Therefore the transmitting contour current are linearly depends on d, except on the edge areas. The current value is small in the initial areas, due to the large coupling coefficient (the coefficient of mutual induction (Fig.4.a and Fig.4.b). The transmitting contour current reaches its maximum value with increasing the distance d, because the coupling is practically nonexistent between the contour coil (k_c <0.05 at Fig.4.a).The output current decrease when the distance in the initial area due to decrease of transmitting contour current.



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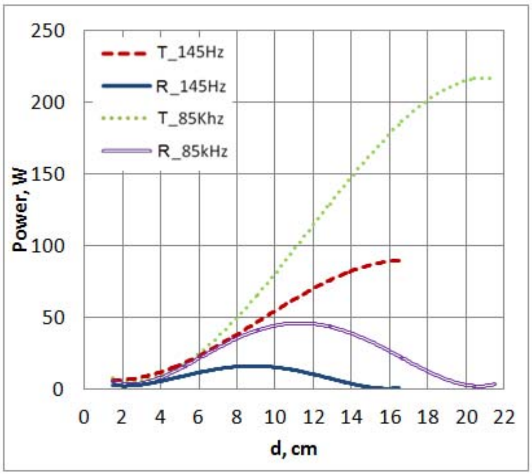

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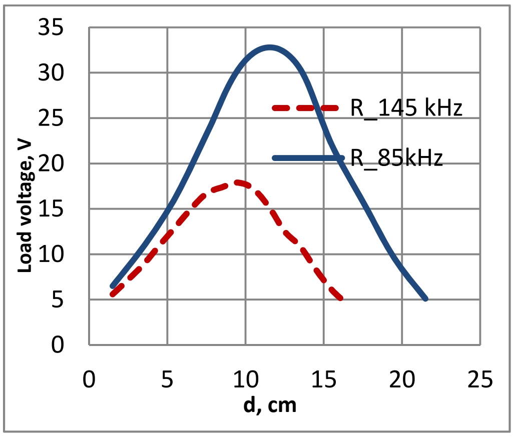

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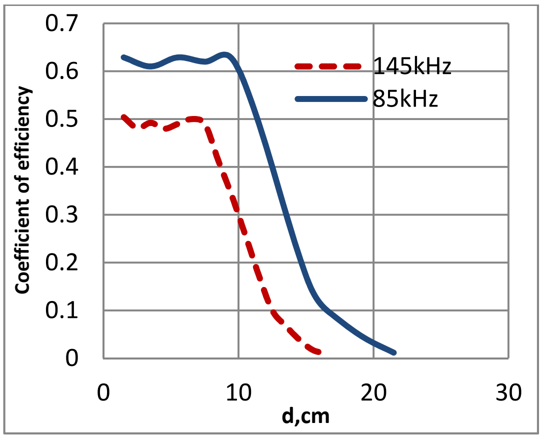


d

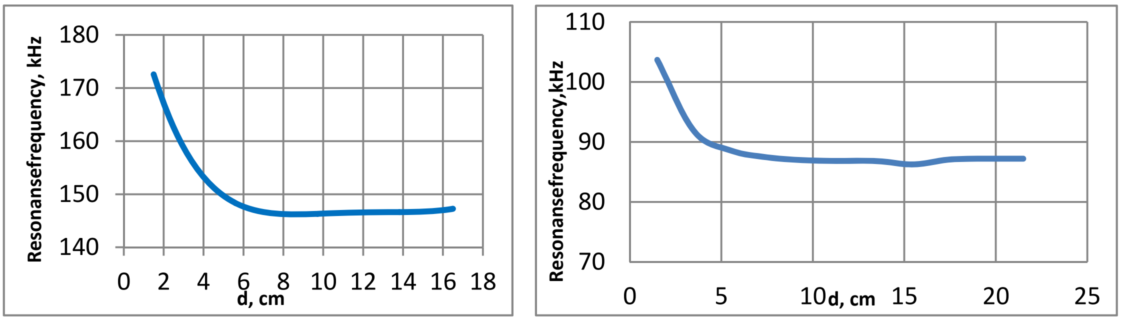
Figure 6. The impact of the distance d on the electrical parameters of the resonant transformer with Uc=50 V and two resonant frequencies (a- on the input and output currents; b - on the input and output powers; c- on voltage at the load receiving circuit; d- on power transmission coefficient; T-input parameters; R- output parameters)

The load resistance RL is equal 18 ohms, and it determines the f voltage at the load of the receiving contour (Fig.6.c). The kind of these dependences corresponds of output current changes. The kind of the output power dependences (Fig.6.b) is determined by the dependence of the transformer output current. All three output dependences have extremes but when resonant frequency equals 85 kHz dependences have maximums at greater distance between the coils. Input power (Fig.6.b) varies as well as the input current by increasing the distance ***d*** (Fig.6.a).

Fig. 6.d demonstrates the dependences of power transfer coefficient (рис.10.b) from the distance ***d***. When $\boldsymbol{d} > \boldsymbol{d_{max}}$ power transfer coefficients diminish rapidly, as at such distances there is a simultaneous increase input power, because increasing the input current with decreasing output power due to the reduction of the output current. Dependences of the power transfer coefficient do not change at the beginning of interval, since the speed of increase output and input power is the same with increasing distance ***d***.

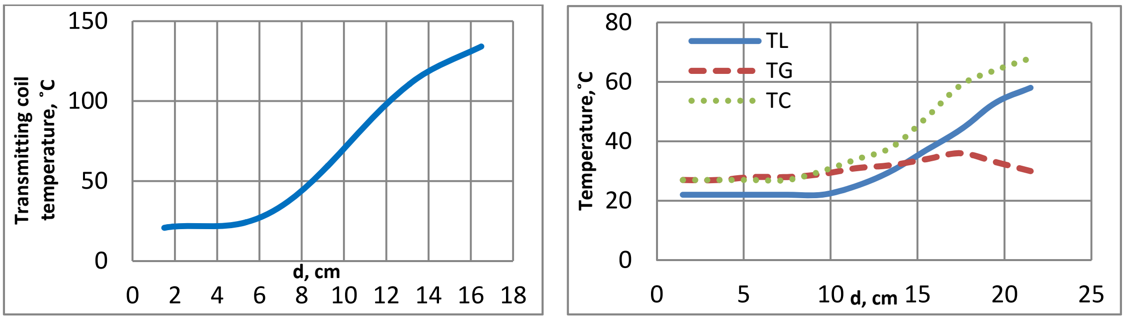
The resonant frequency of coupled contours decreases at changing the distance ***d***. Therefore, during research of dependencies which are shown in Fig. 6, values of the resonant transformer resonant frequency were fixed at each distance ***d***. The resonance frequency was determinated by sweeping the frequency of the master oscillator (Fig.1) to obtain the maximum load voltage in the receiving contour. Fig.7. shows the impact of the distance ***d*** on the resonant frequency of the resonant transformer at a fixed voltage on the storage capacitor U_c = 50 V.

It is seen that the resonant frequency of the resonant transformer decreases with increasing distance ***d***. It's value becomes equal to the resonance frequency of the transmitting contour, if the distance ***d*** is equal dmax. However, further increase in ***d*** (decrease k_c) causes a slight increase in the resonant frequency to several hundred Hz. For large distances, the current in the transmitting contour increases to several amperes (Fig.6.a) that leads to increasing the temperature of the winding of the transmitting coil. Fig.8. shows the change of transmitting coil temperature when the distance between coils changes with U_c = 50. When $d > d_{max}$ the transmitting coil temperature increases linearly. In result the inductance of the resonance transformer transmitting coil decrease, and the resonant frequency of the resonant transformer increase (Fig.7).



a b

Figure 7. Impact of the distance between the coils on the resonant frequency of the transformer with U_c = 50 V



a b

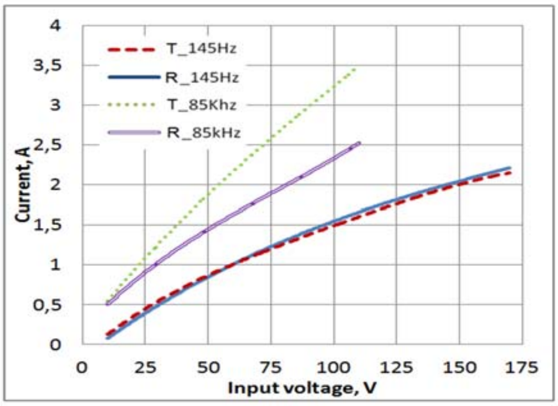
Figure 8. Temperature changes of transmitting coil (a - f_{rez} = *145 kHz*) and of transmitting part structural elements of resonant transformer (b - f_{rez} = *85 kHz*) when the distance between the inductance coils is changed with U_c = 50 V

Fig. 8.b show temperature changes of structural elements that impact on the resonant frequency: transmitting contour DD coil (TL), the transmitting contour capacitor (TC) and IGBT transistors (TG). These curves were obtained by air-cooling of those components. The temperature TG has changed slightly when the distance between the coils increases. It's clear that temperature of the transmitter coil and the temperature pf capacitor is linearly increased if d > 10 cm. Capacitors used in these experiments had a high thermal stability, therefore their capacitance changed slightly. Increasing the temperature of the transmitting DD coil give a decrease of its inductance and increase the resonant frequency of the resonant transformer when d > 12cm, even with air cooling.

4. Impact impact of voltage of storage capacitor on the eficiency of the wireless power transfer with the employment resonant inductive method

To transmit the required power to the load of resonant inductive transformer, the input voltage of the resonant transformer must be adjusted. The impact of the storage capacitor voltage Uc has been investigated on the frequency and energy parameters of the resonant transformer system of wireless power transfer. Investigations have been performed at two resonant frequencies: f_{res} = 145 kHz и f_{res} = 85 kHz. Distances between DD coils of the transformer are equal to dmax: d_{max}= 9 cm when f_{res} = 145 kHz and d_{max}= 12 when f_{res} = 85 kHz. Fig. 9 and Fig.10 demonstrates the results of investigations.

The storage capacitor voltage Uc was varied from 10 V to 170 V. Voltage boost of the storage capacitor Uc increases the transmitting oscillation circuit current (input current - T) and load current (output current - R). These dependencies have a small non-linearity (Fig.9.a).



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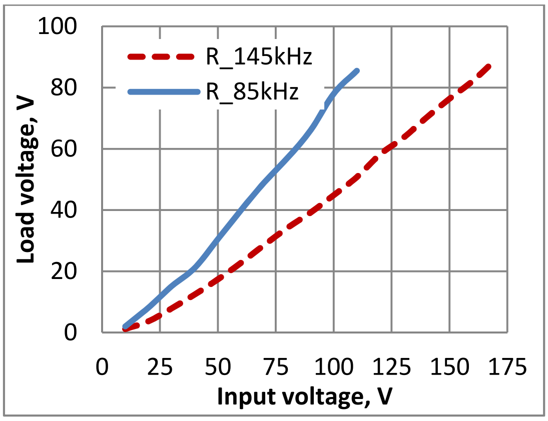

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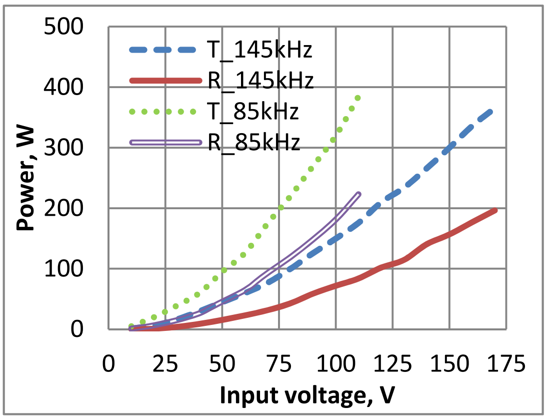
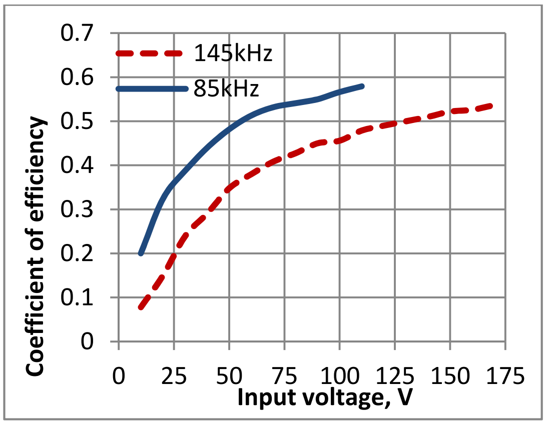
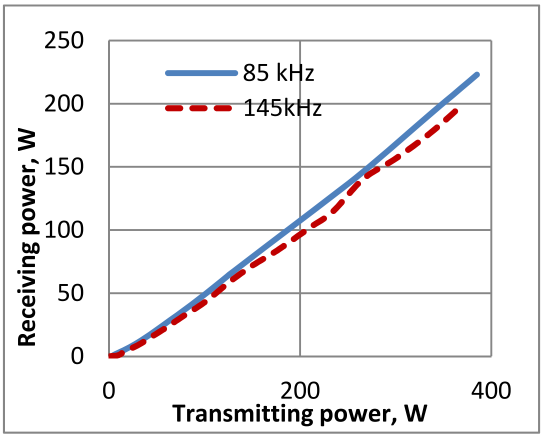


c



d

Figure 9. Impact of voltage U_c on the characteristics of the resonant system for f_{rez} = 145 kHz and f_{rez} = 85 kHz when $d = d_{max}$ (a – on currents in contours; b – on load voltage; c – on input and output power; d – on power transmission efficiency; T – transmitting contour; R - receiving contour)



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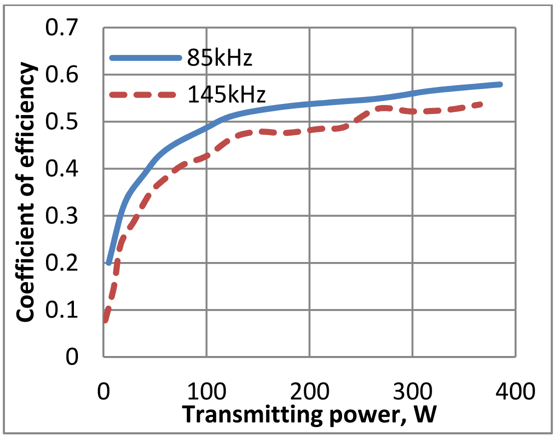


b

Figure 10. Eficiency of the wireless power transfer with the employment of DD inductance coils on resonanse frequencies f_{res} = 145 kHz and f_{rez} = 85 kHz when $d = d_{max}$ (a - the dependences receiving power of transmitting power; b – the dependences power efficiency of transmitting power)

The voltage at the load of receiving oscillation circuit depends on the voltage Uc weak nonlinear (Fig.9.b). This non-linearity is due to increased impedance of lighting lamps, which are load of circuit rectification (Fig.1). When the voltage U_c increases, the output current growth slows and lighting lamps impedance continues to increase. This leads to a linearization of the output voltage dependence. The input power and the output power depend quadratically on the voltage $\boldsymbol{U_c}$ (Fig.9.c). Power transfer coefficient is defined as the ratio of output power to transmit power. When the voltage $\boldsymbol{U_c}$ increases power transfer coefficient increases as well. However, its growth is slowing at a voltage of $\boldsymbol{U_c}$, exceeding 50 V (Fig.9.d).

Figure 10 demonstrates the dependences of output power of resonant transformer (Fig.10.a) and dependences of power transfer coefficient (рис.10.b) from power transfer. These dependences characterize the power transfer efficiency of resonant inductive method with the employment of DD induction coils. It is seen that when distances between DD coils is equal to optimal the output power depends on the transmitted power almost linearly (рис.10.a). However, the power transfer efficiency is small, if the input power is less than 50 W, though its changes are essential. If the input power exceeds 100 W, power transfer coefficients increases slightly, and they tend to the value 0.6. These results show that the power transfer by a resonance method with the employment of DD induction coils is more effective when the resonant frequency is 85 kHz. (Fig.9.d and Fig.10).

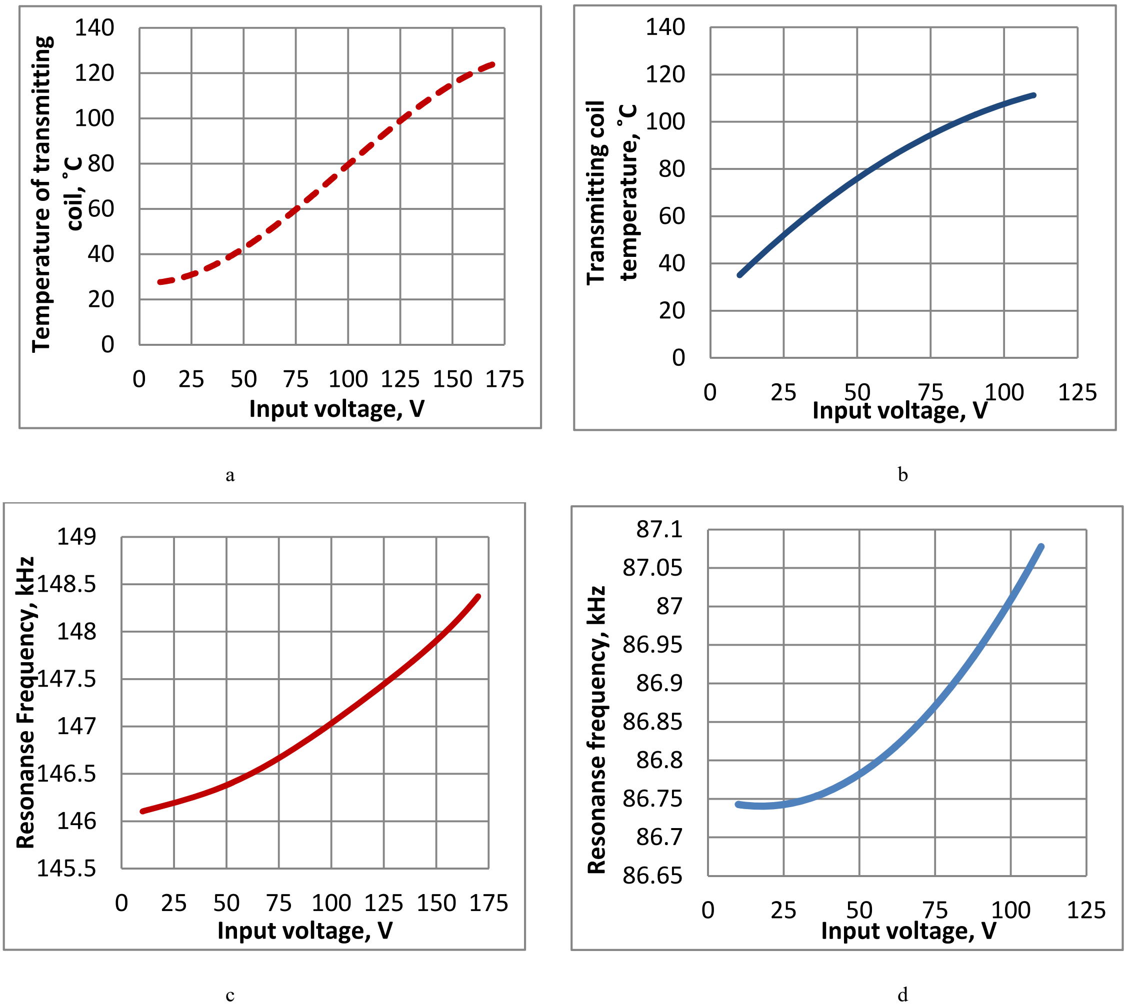


Figure 11. Impact of voltage U_c on temparature of tranmiting coil (a and b) and on resonant frerquency of resonant transformer (c and d) with $d = d_{max}$ for resonanse frequencies f_{res} = 145 kHz (a and c), f_{res} = 85 kHz (b and d)

High current in the transmitting contour (Figure 9) causes the heating of DD transmitting coil to temperatures close to the maximum allowable temperature of litz wire (130^0), which was used for the windings of the transmitter coil (Fig.11.a and Fig.11.b .). The transmitting DD coil inductance decreases at such high temperatures. So when storage capacitor voltage Uc was increased the resonant frequency of resonant transformer also increased (Fig.11.c и Fig.11.d). The resonant frequency of resonant transformer depends quadratically on the storage capacitor voltage $\boldsymbol{U_c}$ (Fig.11.c), and it changes significantly, especially when $\boldsymbol{f_{res}}$ = 145 kHz.

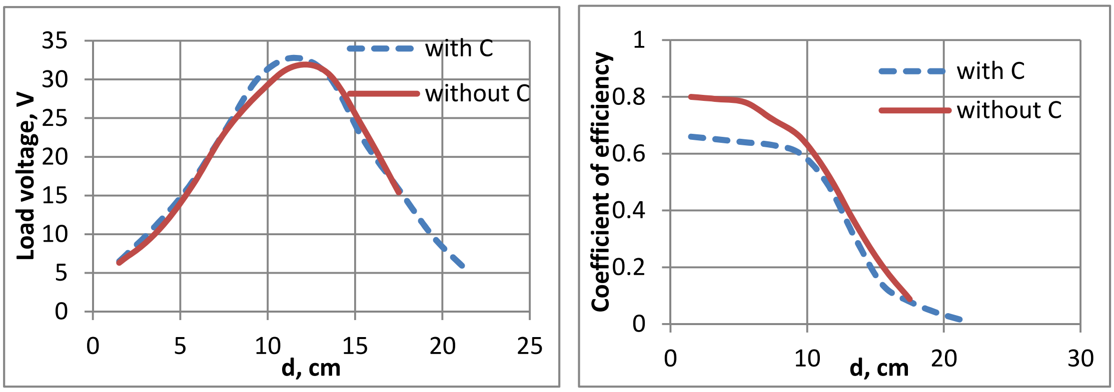
Analysis of the dependences on figure 6, figure 9 and figure 10 reveals that power transfer coefficients do not exceed 0.6, ie the use of DD coils do not provide high efficiency of wireless power transfer. To increase the transmitted power in the load and the power transfer coefficient to values close to 1 can increase the factor of transformation (increasing the number of windings in the secondary winding) excitation transformer Tr1 (Fig. 5.). This provides an increase the current in the transmitting coil of resonant transformer and an increase of transmitted power. At the same time the transmitting DD coil $\boldsymbol{L_1}$ temperature will be higher. The temperature stability of this coil was unable to provide during our research, unfortunately.

5. Research efficiency of wireless power transfer without resonance properties on the receiving side

An important condition for high efficiency of resonant inductive method of wireless power transfer is equal resonance frequencies at the transmitting and receiving oscillatory contours of resonant transformer. However, the investigation results show that the resonant frequency of the transmitting resonant contour of the transformer depends on the distance d (the distance between the DD coils), and the heating temperature of transmitter coil (Fig.7, Fig.8, Fig.11). Therefore, it is necessary to eliminate or to decrease an impact of above factors to provide high efficiency of power transfer with the employment of DD induction coils. The following methods can be used for this:

- the thermostabilization of the electronic components of resonant transformer;
- an automatic adjustment of the resonant frequency of the transmitting contour of resonant transformer at a fixed frequency master generator;
- an automatic tuning of master generator at the resonant frequency of the transmitting contour of the resonant transformer.

The third method allows simplifying the requirements for thermal stability and thermostabilization of the electronic components of resonant of the transformer and the resonant circuit is not used at the receiving side of resonant transformer. For example, be used on the receiving side receiving DD inductance $\boldsymbol{L_2}$ as the secondary winding of the transformer only by removing the contour capacitor $\boldsymbol{C_2}$. Fig. 12, Fig.13 and Fig.14 demonstrate the investigation results of inductive resonant method of wireless power transfer with the employment of a transformer circuit at the receiving side. Investigations have been performed at the transmitting contour resonant frequency $\boldsymbol{f_{res}}$ = 85 kHz.

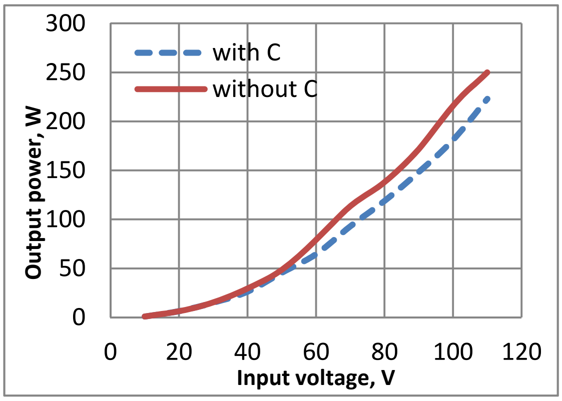


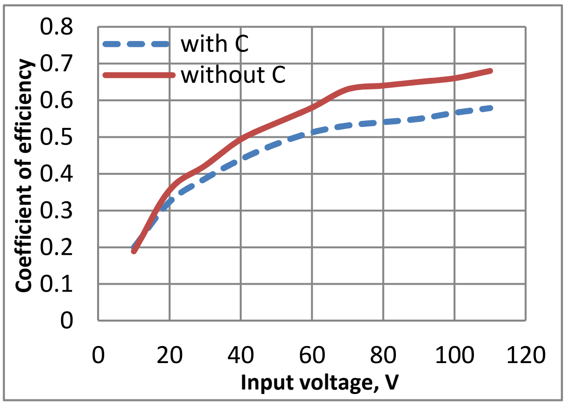
a b

Figure 12. Impact of distance between the DD coils on the electrical parameters when the capacitor C_2 is connected and absent on the receiving side for the transmitting frequency of the resonance circuit f_{res} = 85 kHz and U_c = 50 V (a – on load voltage of receiving contour; b – on coefficient of power efficiency)

Figure 12.a demonstrates the dependences of load voltage on the receiving side of transformer without capacitor $\boldsymbol{C_2}$ and with capacitor $\boldsymbol{C_2}$. When the capacitor is absent, load voltage extremum decreases and shifts slightly. Fig.12.b demonstrates the dependences of the power transfer coefficient from distance between DD coils. It is seen that the distance d are equally influences on the power transfer coefficient as with a capacitor $\boldsymbol{C_2}$ and without capacitor $\boldsymbol{C_2}$, but the values of the transmission power coefficient greater when disconnecting a capacitor $\boldsymbol{C_2}$.

The output power depends quadratically from the voltage $\boldsymbol{U_c}$ both with the capacitor $\boldsymbol{C_2}$ and without the capacitor $\boldsymbol{C_2}$ at the receiving side of resonant transformer. However, when no resonance properties on the receiving side the steepness of the output power more. This is because the load voltage and load current of resonant transformer increase simultaneously. Since the output power is higher for any U_c in the absence of contour capacitor C_2, so increasing of voltage U_c leads to a growth of the power transfer coefficient (Fig. 13.b).

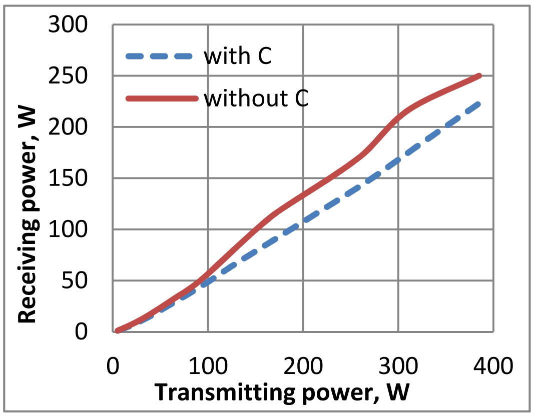


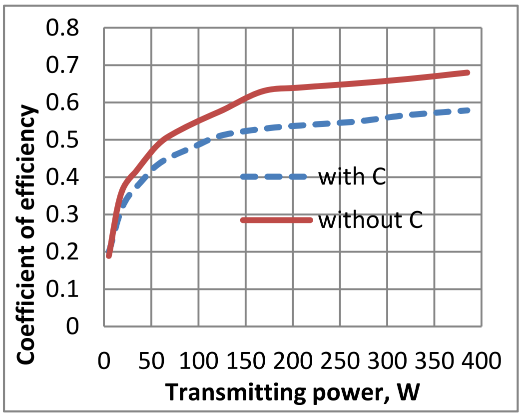


a b

Figure 13. Impact of voltage U_c on the efficiency of power when the capacitor C_2 is connected and absent on the receiving side for the transmitting frequency of the resonance circuit f_{res} = 85 kHz and U_c = 50 V (a – on output power; b – on coefficient of power efficiency)

Figure 14 demonstrates the dependences of output power of resonant transformer (Fig.14.a) and dependences of power transfer coefficient (Fig.14.b) from power transfer with the employment of DD induction coils when contour capacitor C_2 is absent on the receiving side (receiving contour has no the resonance properties) and when contour capacitor C_2 is connected to the receiving coil L_2 of resonant transformer. It is seen that the output power depends on the transmitted power almost linearly in both cases, but contour capacitor C_2 was disconnected the dependence of the output power has a greater steepness. Therefore, power transfer coefficient has larger magnitude when contour capacitor C_2 is not on the receiving side at any values of the input power (Fig.14.b).





a b

Figure 14. Efficiency of power transfer with d = 12 cm between DD inductance coils when the contour capacitor is disconnected on the receiving side (a - the dependence of receiving power to transmitting power; b – the dependence of coefficient of power efficiency to transmitting power)

The research results are presented in Fig.12, Fig.13 and Fig.14 show that the efficiency of the wireless power transfer with the employment of DD induction coils is higher when the receiving side of resonant transformer has not the resonance properties. This is because the amplitude frequency characteristic of resonant transformer is determined by the amplitude frequency characteristic of the transmitting contour (by its resonance frequency and quality factor) when contour capacitor C_2 is not on the receiving side: and Q factor.

6. Conclusions

The results of the above research allow making the following conclusions:

- for the researched DD coils with the length of the bigger side 290 mm the coefficient of connection is less than 0,1 (sign of any weak connection) at distances more than 12 cm for any mutual position of the transmitting and receiving coils;
- increasing the distance between the transmitting and receiving DD coils results in the decreasing the resonance frequency of the transformer which aims at the resonance frequency of the transmitting inductance coil;
- effective wireless transmission of power with the use of the DD inductance coils of the resonance transformer is provided under the optimal distance between them;
- decreasing the resonance frequency of the transmitting circuit increases the efficiency of the wireless power transmission and increases the optimal distance between the coils of the resonance transformer;
- absence of resonance properties at the receiving side allows increasing the capacity of the load and the coefficient of the capacity transmission;
- increase of the coefficient of the capacity transmission up to the values close to 1 can be provided by increasing the coefficient of transformation of the stimulating transformer and the temperature stability of the parameters of the transmitting DD inductance coil;
- to use the DD inductance coil for the wireless charge of the automobile accumulator on move with the account of the modern transport means clearance it is required to provide the following: parameters of the DD inductance coils, the level of capacity of the transmitted power source, the level of capacity produced in the transmitting circuit of the resonance transformer, the temperature stability of the constructive elements of the transmitting circuit.

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References

1. Budhia, M., J. Boys, T., G., Covic, A. and Chang-Yu, H. (2013) Development of a single-sided flux magnetic coupler for electric vehicle IPT charging systems. *IEEE Trans. Ind. Electron.*, vol. 60, no. 1, pp. 318–328.
2. Covic, G. and Boys, J. (2013) Modern Trends in Inductive Power Transfer for Transportation Applications. *IEEE journal of emerging and selected topics in power electronics*, vol. 1, no. 1, pp. 38–48.
3. Grajski, K. A., Tseng, R. and Wheatley, C. (2012) Qualcomm Incorporated. Loosely-Coupled Wireless Power Transfer: Physics, Circuits, Standards. – *IEEE*.
4. Kurs, A., Karalis, A., Moffatt, R., Joannopoulos, J. D., Fisher, P. and Soljačić, M. (2007) Wireless Power Transfer via Strongly Coupled Magnetic Resonances. *Science*: Vol. 317 no. 5834 pp. 83-86.
5. Li, S. and Mi, C. (2015) Wireless power transfer for electric vehicle applications. *IEEE journal of emerging and selected topics in power electronics*, vol. 3, no. 1, pp.4-17.
6. Miller, J., White, C. P., Onar, O. C. and Ryan, P. M. (2012) Grid side regulation of wireless power charging of pulg-in electric vehicles. IEEE Energy *Conversion Congress and Exposition (ECCE)*, pp. 261 – 268.
7. Pereirinha, P. G. and Trovão, J. P. (2013) Standardization in Electric Vehicles. http://www.uc.pt/en/efs/research/EESEVS/f/XIICLEEE_1844_PereirinhaTrovao.pdf
8. Wu, H. H., Gilchrist, A., Sealy, K., Israelsen, P., and Muhs, J. (2011) A Review on Inductive Charging of Electric Vehicles. *IEEE International Electric Machines and Drives Conference*, IEMDC, pp. 866-871.

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LAYERS AND PROCESSES IN THE MODEL OF TECHNOLOGICAL POSTAL SYSTEM

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The paper include important aspects of layer model of postal technological system such as makes the possibility to define rules for regulating, technical and technological requirements and interfaces to communicate with other postal systems. The current postal reform is mainly attributable to release of network access and ensuring full interoperability between technological systems. Not only to ensure the development and protection of competition but also in respect to the conservation of requirements to provide the universal service, which is the performance of public interest. There is a space here to examine the postal system, not only from a procedural point of view, but to be viewed as an open communication system. It is possible to find there the commonalities with other communication sector branches and to handle the technological postal system in more layers; similarly as the electronic communication systems are handled. Model of layer postal system, based not only on the processes but on layers functionality, will enable to identify communication protocols and interfaces determining interoperability. It also opens the question of appropriate regulation model.

Keywords: Layer, Process, Model, Postal System, Interconnection, Regulation

1. Introduction

Postal services continue to have a central role in the development of an effective and dynamic Single Market. However, the role of postal services is changing fundamentally. Demand for distribution of letters, newspapers, advertisements, and other documents is declining due to the rise of advanced electronic communications. At the same time, demand for parcel delivery services is increasing due to the development of e-commerce, and also just-in-time manufacturing. But the big threat is substitution by electronic services and other business trends driven by the new electronic technologies.

Designated postal operator shall ensure that users enjoy the right to a universal service involving the permanent provision of a postal service of specified quality at all points in their territory at affordable prices for all users. It must be allow all postal operators non-discriminatory access to elements of their postal infrastructure (as an address databases and post office boxes) when necessary to protect the interest of users or to promote effective competition. A lot of designated postal operators have not developed a consensus on how to implement this requirement. The requirement of non-discriminatory access is complicated in both legal and regulatory aspects (Švadlenka, Chlaň, 2009). It shows the complexity of technical and technological feasibility which is related with ensuring the interoperability of technological systems. The question that arises is the determination of access points in the network of an universal service provider and the establishment of conditions for access and connection to other postal operators. This requires the confrontation of processes for collection and distribution of packages with the construction of postal transmission network and it also requires a search of common intersections in the postal systems. This fact leads to the idea to examine the postal system not only from a procedural point of view, but also to look at it as an open communication system, what is typical for other departments of communication sector (transport, electronic communication) (Vaculík, Tengler, 2012).

2. Current state and starting points

Normative and regulatory aspect in defining and assessing of the postal services is often completed by an analysis of the entire postal chain consisting of four basic activities/processes that form the postal service (collection, sorting, transport, delivery) (Figure 1).

This kind of postal services is apparent also in the evaluation reports by European Commission (2010, 2013) or in the professional reports and discussions of many authors (Čorejová, Imríšková, 2008; Madleňáková, 2013). It is a view of the postal service to the analysis of processes and sub-processes taking place in the networks, which is particularly relevant in recent times in terms of addressing interoperability and control access to the public network.

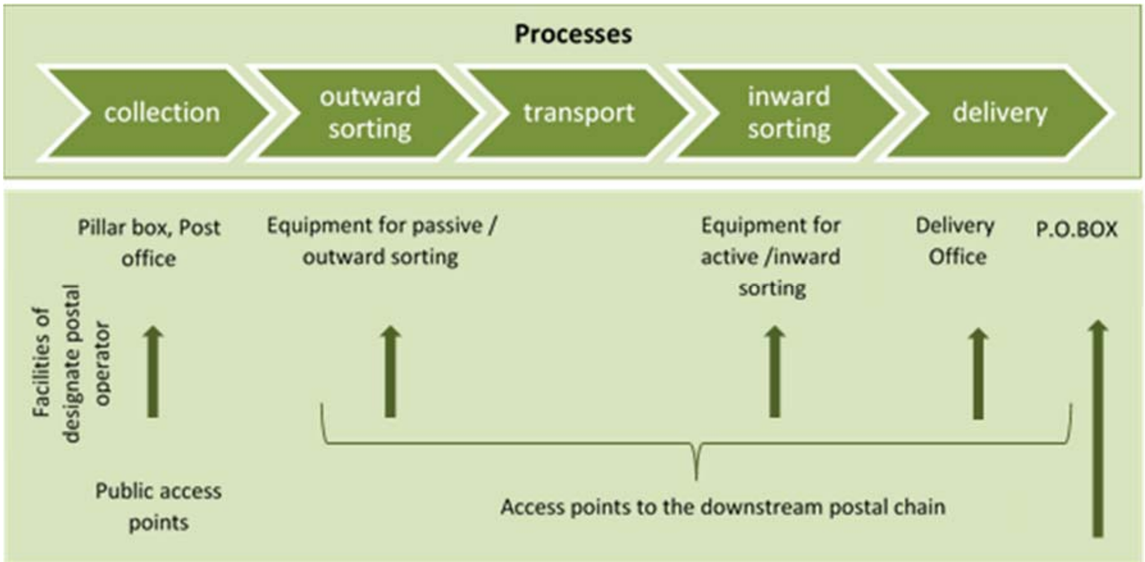

Figure 1. Postal chain and points for access to the public postal network

The network character of postal services is not different from other network systems. The overlapping of common features is apparent mainly in transport and communicational systems, whether we speak about construction and organization of networks or in the character and requirements for coverage of territory, mainly in the connection with regulated services of general public interest. Although we are accustomed to portrayal of postal services through the processes and sub-processes, it is possible to see the postal system at a certain level of abstraction also in layers as in the case of telecommunication services and transport systems. Agreement is significant especially in terms of the service provided through the model of layers, in which the basis consists of the physical layer, network layer, and layer of services. The physical layer represents a means of transport or vehicle of transport and it is responsible for the physical realisation of transmission in the case of telecommunication. The network layer expresses mainly the creation of interconnection for transport requirements or for the transfer of message in telecommunication.

3. Layers of the postal systems

The selection of package and its distribution can be describe between postal systems and the way of its connection on the basis of the model principles for communication of open systems. We will describe not only the immediate shipment of package between the systems, but also the abilities of the system to collaborate and to create the interconnected postal systems on the basis of grouping that consists of one or more access points, related hardware, terminals / hubs / depots, human features and vehicles used for the carriage of postal substrate, etc (Zeman, Madleňák, 2010).

In the postal system the communicating devices will be represented by the means of the "layer architecture". This layer architecture is characterized by the hierarchical organisation of the functions (entities) that are needful for linking system. The highest layer allows the contact with the user interface (e.g. with network subscribers) and the lowest layer allows the contact with the physical transmission medium. Different functions are allocated to the individual layers of model that enable the realisation of "the system interconnection" (Carvalho, Suri, Arguedas, Rebeschini, Breedy, 2007). The architecture of the open system is made up from number of subsystems - layers that are stored on each other. Every layer contains interface between the nearest higher and the nearest lower layer. The highest layer has the interface towards the user environment and the lowest layer towards the transmission medium.

3.1. Characteristics of basic elements of postal layer model

The model of opens system for communication defines a hierarchical architecture that logically partitions the functions required to support system-to-system communication. And the layered approach offers several advantages. By separating networking functions into logical smaller pieces, network problems can more easily be solved through a divide-and-conquer methodology (Table 1). The layers model also allows extensibility. New protocols, requirements and other network services are generally easier to add to a layered architecture (Madleňáková, Madleňák, 2014).

Table 1. Basic elements of the postal layer model

Element of the postal layer model	Basic characteristics
Layer	• part of the network´s function • those functions depend on each other- one function provides its services to another while using the services of other layers. • It is important to note, that only the same layers (equal) of the postal system will communicate between the sender and the addressee during the relocation process and transport of the package
Function / Functionality	• constitute a certain functioning, security operation or determination of specific activities in the transfer process. • also determine the relationship between two layers. • limits the layer competence, role and its importance in ensuring of goal achievement- the transfer of the package from the sender to the recipient.
Protocol	• It may be characterised as a register, report, record of the process or a result of the activity or operation, for example a book of records about the acceptance and dispatch of packages. On the other hand, it may be a sum of the procedures and rules determining the operation of the installation or method of communication between endpoints in the postal system.
Interface	• is defined as a border between two layers. It can be a set of elements that are necessary for the connection of one device to another, for the purpose of ensuring communication or shipment relocation. • The interface in layer postal model is formed by a physical point (mailbox, post office box), but it is formed also as a set of norms, regulations and protocols defining characteristics of a connection that may be virtual/ electronic.
Security	• as a minimization of the "vulnerability" whether of the postal substrate that enters the technological system or instruments and procedures that ensure the distribution of the postal substrate. Security features provided in the architecture of open systems will be effective only if they are used together with the safety instruments that belong also beyond the specified architecture.
Quality	• as a degree of achievement of the customer´s expectation with the provided service and as a disproportion between expectations and perceptions. • is determined by the normative requirements and its level is dependent not only on the perception of impact- the output process, but mainly on the quality of the whole process.

3.2. Basic characteristics of the layers formation in the postal system

In the formation of the layer model (Madleňáková, Madleňák, 2014) that is applicable for postal systems, it is necessary to preserve the possibility of using different kinds of transport (physical media) with the different management practices (Table 2).

We can divide layers on the basis of their characteristics and functional content into two basic groups: either in terms of their functions within the network, or from the perspective of user access (Kolarovszki, Vaculík, 2014). Division of layers in terms of their ***functions*** within the network:

1. *End-oriented layers*- they are implemented only into the terminals (applicative, presentational, relational, transporting).
2. *Network-oriented layers*- they are dependent on the network technology that is used and they have to be at least partially implemented into the network (network, line, physical).

Division of layers in terms of their ***users***:

1. *User-oriented layers* (applicative, presentational, relational) - they play important roles in interpretation of the data to user.
2. *Transport-oriented layers* (transporting, network, line, physical) - they are related to the distribution of the package.

The transport layer can be described also as so called interlayer that forms an interface between user-oriented layers and network-oriented layers. (La Red Martínez, Agostini, 2014)

Table 2. Basic characteristics of the layers formation in the postal system

Type of the layer in the postal system	Basic characteristics of the layer
Application - layer number 7	The application layer includes the postal service of which disclosure is required by the sender through the entry of the postal system.
Presentation - layer number 6	The presentation layer transforms the package into the shape that is used by application. It determines the conditions for the requested service and it sets rules for the choice and distribution of packages. The protocols are based on legislative measurement. It deals with the formal aspect of package (cover, address information) and with the preservation of information content during the transport. Its task is to ensure the secrecy of correspondence.
Session - layer number 5	The relational layer organizes and synchronizes dialog between co-relational layers of both systems and it controls the exchange of data between them. It creates a connection between the sender and the addressee through the application of defined protocols- the selection of suitable cover for package and the presentation of personalized features, followed by submission of package- the enter into the postal system. The mailbox or partition are considered to be the interface. In the case of system´s failure to deliver the package, it may be returned to the sender on the basis of referred synchronized data- address (sender, recipient).
Transport - layer number 4	The transport layer manages the transport of postal item from end node source (open system), into targeted end node (open system) that is not realised in internodes. This layer reminds us an illusion as if each node in the network had direct connections with any other node. It ensures the creation of transport units from expedition of packages and their deconsolidation in delivery. Its purpose is to provide such quality distribution that is required by higher layers. This required quality is maintained throughout whole time of the transport connection. Higher layer is informed in the case of quality failure (service T & T). This includes for example the application of protocols related to the requirements for distribution with guarantee (recorded packages as registered mail, insurance ...) and the requirements for distribution without guarantee (non-registered mail). The guarantee can be applied also to loss and damage of the package.
Network - layer number 3	The network layer takes care about the direction of packages within the network and network addressing. It provides the connection between the systems that are not neighbouring ones. It means, that some systems have a function of an end source (post) and a goal of dispatched package (the delivery post office, PO Box...) and vice versa. Some open systems have functions of internode link (processing centres) that ensures the handover of distributed postal substrate to another systems. The basic function of this layer is a collection of network-oriented protocols for the goal of correct shipment (sorting feature, e.g. Zip code) and crossing of different technological characteristics that are applied in individual networks. This layer provides a connecting path between endpoints (the sender and the addressee), including the use of internodes. It is responsible for the selection of the best path between the terminal equipment and transport between them, as well as the delivery.
Line - layer number 2	The line (data link) layer provides a connection between two neighbouring systems, respectively nodes. It identifies and organizes packages from the physical layer into logical units and it provides the connection of neighbouring nodes and enables the setting of transmission data between two nodes. Its function is also to ensure the formation of transport units on the basis of codes such as: (ZIP, ZIP code, label of direction...), and it announces the errors of sorting and loading. Its task is to ensure the functions in transport of postal substrate between the network units and the detection of errors that occur in physical layer.
Physical - layer number 1	The physical layer (the lowest layer of architecture) is identified as a physical communication (shipment) in available infrastructure (road, rail, air, water), that is provided through physical media (a means of transport). This layer specifies the characteristics of individual vehicles (postal rates), such as capacity, loading surface and it also defines the way of shipment. Another devices that belong into this layer are different types of nodes for example (depots, hubs ...).

4. Case study - Basic conception of layer postal system model

During application of the layer model into environment of the postal system, it is possible to think about the integration of chosen layers. This is possible just in the case of insufficiency of functional filler, or in the functional intersection of the individual layers, in which the interface identification between layers or setting of communicating protocols will be not possible. (Madleňáková, 2013).

One option is the creation of a model that works in three layers, established on the basis of their functionality, in which the theory of network systems works with them on the basis of ISO/OSI recommendations. User-oriented part of the layer model is the same as in the previous case, it is more oriented on the field of determining the commercial-marketing parameters and defining of the relationship: user-provider. Modelling of other parts is based on the assumption that an important part of the model, that contains clear rules regarding the determination of technological processing of the package (the type of the service is important), is a transport layer. This is the reason why, its function is irreplaceable in the model, and it is not appropriate to combine it with lower network-oriented layers that are equally important.

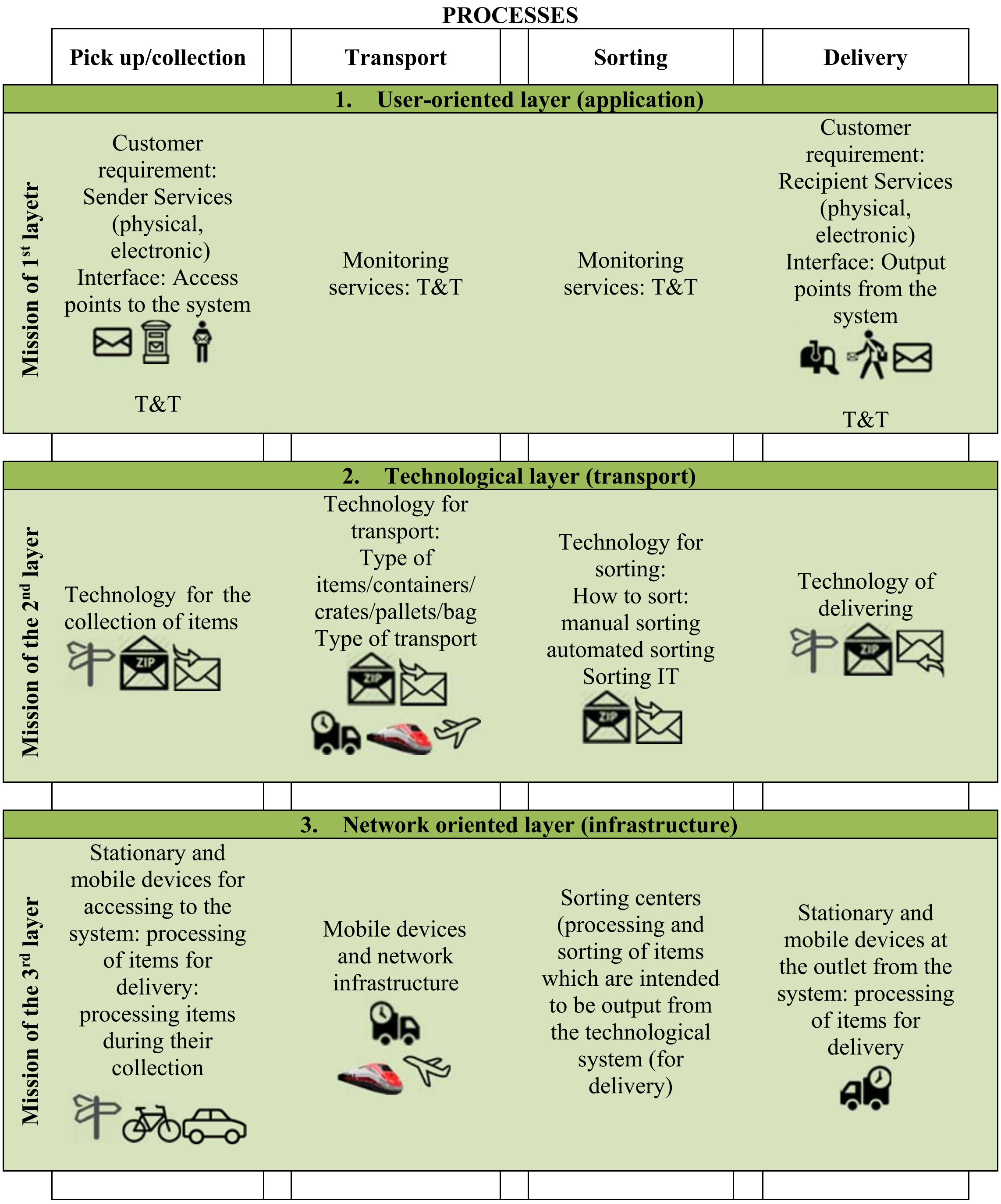

Figure 2. Missions and processes of the layer oriented model

The Figure 2 shows that by use of sufficient disaggregation, the postal market can be analysed both along processes as well as along layers. The result is the same in both approaches. The layers show the access points to the postal system, methods of communication and management. Penetration of ICT services (in the form of supplementary services) in the postal sector in the layered system allows better control and set regulatory rules for both areas (postal and telecommunications) (Heitzler, 2009).

Table 3. This is an example of a Table

1. User oriented layer	**Basic function**	• the creation of consignments to the required service • activities and related processes along the way from the sender to the postal system / postal provider (mailbox, post office box, courier ...) and pick up, collection • customer contact with the postal provider and access to the postal system.
	Protocol	• postal contract and postal conditions • the operational documents for entry into the postal technological system and output from the postal technological system • the certificate of posting, the certificate of delivery, …
	Interface	• post office, mailbox, courier, hub, …
	Quality	• accessibility of the access and contact points of the postal network • time accessibility of the postal service • on time performance of transport of the items (speed) • security of the items and information on the postal service
	Security	• postal secrecy
2. Technological layer	**Basic function**	• way of processing shipments and choice of technological processes • routing shipments and way of consolidation and deconsolidation of shipments
	Service provided for user-oriented layer	• identification of points on the network using directional address • mapping application for the distribution of postal substrate (shipment, container, ...)
	Protocol	• traffic rules - determine the method of processing shipments, monitoring consignments and rules for delivery of the shipment.
	Interface	• border with user-oriented layer is given access point (mailbox, post office counter, courier, PO Box ...).
	Quality	• level in relation to the requirements of the user layer • it depends on the quality of the network layer • maintained during the whole period of the distribution process. • information on non-compliance with quality standards for user-oriented layer
	Security	Security services and their combinations: • identification of the postal substrate (postal items, transport unit) • the source site (endpoints, pick up points, points of processing) • management of the postal substrate processing (routing of consignments) • integrity of the distributed postal substrate (postal secrecy and integrity of postal items, consignment, transport unit)
3. Network oriented layer	**Basic function**	• utilization of available infrastructure and the relevant type of transport to ensure the transport of postal substrate by the operational postal courses/line haul • create topological links between existing network nodes, creating a connection of two neighboring nodes • addressing, routing and tracing cargo / transport units to their destination.
	Service provided for technological layer	• transport of postal substrate in the prescribed form by the selected network path, • addressing network based on the identification elements (identifier) • making network connections from point to point, • ensuring quality of service and local error detection.
	Protocol	• network address - directional character that uniquely identifies each of the end systems (to ensure access to the subnet, or the network of other postal system) • rules for the management of flows between nodes (transport order, postal traffic plan, timetable ...) • administration and management of the physical connection (postal traffic plan, transport schedules, timetables ...)
	Interface	• node in the network • place for transshipment traffic units (shipments, containers) / loading ramp
	Quality	• quality depends on the agreement between the technological infrastructure services layer and the layer when selecting the network path (end point will be the same as declared at the beginning), derived from used topological connected nodes to the network and the means of transport • ensure the performance parameters, such as: availability, reliability, network bandwidth speed - transportation time (a failure), network error, error associated with the wrong delivery, and will like
	Security	• security services, from one end to another end of the system are the same as in providing access to the subnet or network. • security protection is always carried out before the enforcement of the common features pre-shipment in the stream and the normal functions of film - after acceptance of delivery by the next node (confidentiality relocation). • to protect the entire flow of shipments and implementation of confidentiality flows and connections between nodes. In particular: o identification of the location of the mail substrate / shipment o secret connection between nodes (end) o confidentiality transported flows and integrity relocation.

5. Conclusions

Layer model offers an alternative view of a mail system in which different phases of the distribution process can describe by the layers instead of process. The task of the layers is to ensure the obligation to use a particular type of technology or equipment, to provide guidance where necessary to ensure consistency in communication and set the rules for the interconnection of networks. The determination of the individual layers functionality contributes to the identification of several facts that can serve as an innovative element for the future arrangement of postal networks (Table 3).

Functions, tasks and rules for communication between different postal systems in the infrastructure part of the model point to the possibilities of ensuring a transparent access to the incumbent´s (operator´s) postal network and interoperability between postal systems. The aim of the interoperability between postal systems is to build a monolithic block of services of the sub components for users. These components are technically different and managed by different operators. For interoperability, it is necessary to consider three essential aspects: organization of the system, hierarchy, the legislative environment and applied standards. The organization of the system is given by organizational interoperability. It consists in defining the aims of modelling business processes and collaboration postal subjects. Organizational interoperability can be achieved by identifying and determining the interface (eg. access points), declaring the technical requirements to ensure the functional interconnection of postal systems and services.

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References

1. Ahuja, R.K., Magnanti, T.L., Orlin, J.B. (1993) *Network Flows: Theory, Algorithms, and Applications*. Prentice Hall, New Jersey, ISBN 978-0-136-17549-0.
2. Boldron, F., Cremer, H., De Donder, P., Joram, D., Roy, B. (2009) Network externalities and the USO: a two-sided market approach. Article in book: *Progress in the competitive agenda in the postal and delivery sector.* Elgar, p. 184-195, ISBN 978-1-8484-4060-9.
3. Carvalho, M., Suri, N., Arguedas, M., Rebeschini, M., Breedy, M. (2007) A cross-layer communications framework for tactical environments, In: *Proceedings - IEEE Military Communications Conference MILCOM*, art. no. 4086619, DOI:10.1109/MILCOM.2006.302357
4. Čorejová, T. and collective (2010) *Economics of networks*. Second Edition. Žilina: University of Žilina - EDIS, - 322 p., ISBN 978-80-554-0155-3
5. Čorejová, T., Imríšková, E. (2008) Integracja na rynku usług pocztowych (Convergence at the postal market). *Eksploatacja i Niezawodność*. Volume 39, Issue 3, 2008, p 74-76 ISSN 1507-2711
6. Čorejová, T., Rostášová, M., Chrenková, A., Madudová, E. (2013) Regional dimensions of knowledge processes in the sector of transport and logistics and ICT in the Žilina region In: *Communications: scientific letters of the University of Žilina*. Volume 15, No. 2, p. 25-33. - ISSN 1335-4205
7. Heitzler, S. (2009) "Traditional Regulatory Approaches and the Postal Service Market", Competition and Regulation in Network Industries. In: *Econ Papers*. Volume 10, Issue 1, pages 77-106.
8. Hrudkay, K., Šestáková, S. (2014) Systémy riadenia terminálov intermodálnej prepravy. In: *vedecko-odborný seminár „Výskumné aktivity v doprave, staviteľstve a príbuzných odboroch"*, Herľany, 21.-22. január 2014. Herľany: Slovenská spoločnosť logistiky, ISBN 978-80-971604-6-3
9. Knieps, G, Zenhäusern, P., and Jaag, C. (2009) Wettbewerb und Universaldienst in europäischen Postmärkten, In: *Fallstudien zur Netzökonomie*, Wiesbaden: Gabler, 87-110
10. Kolarovszki, P., Vaculík, J. (2014) Middleware - Software support in items identification by using the UHF RFID technology In: *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, LNICST, 131, pp. 358-369. DOI: 10.1007/978-3-319-11569-6_28
11. Luo, W., Han, P., Gao, F. (2009) Study on System Modeling and Analyzing of Supply Chain Network, In: *IEEE International Conference On Automation And Logistics (ICAL 2009)*, Vols: 1-3, pp. 1598-1602, ISBN: 978-1-4244-4794-7
12. Madleňák, R., Madleňáková, L., Dydňanský, P. (2013). Global postal network - a trade facilitator for the small and medium enterprises for entering the global market. *International Journal of Arts and Commerce*. Vol. 2, No. 5, p.109-114. ISSN 1929-7106.

13. Madleňáková, L. (2013). *Layer model of the postal system*. Habilitation Thesis - University of Žilina, Faculty of Operation and Economics of Transport and Communications. Žilina: 112 pages.
14. Madleňáková, L., Madleňák, R. (2014) Layer model of the postal system In: *Reliability and statistics in transportation and communication (RelStat´14)*, Riga, Latvia, October 2014. Riga: Transport and Telecommunication Institute, p 106-113 ISBN 978-9984-818-70-2.
15. Maegli, M., Jaag, Ch., Koller, M., Trinkner, U. (2010) Postal Markets and Electronic Substitution: What is the Impact of Convergence on Regulatory Practices and Institutions? In: *ECPR conference: 'Regulation in the Age of Crisis'*, Dublin
16. La Red Martínez, D.L., Agostini, F. (2014) ISO/OSI model and data communication by animations, In: *WIT Transactions on Information and Communication Technologies*, 58 VOL I, pp. 963-970, DOI: 10.2495/ICTE131162
17. Pastor, O., Tuzar, A. (2007) *Theory of transport systems*, ASPI Praha, ISBN 978-80-7357-285-3
18. Sutanto, S., Heller, R. (1993) Utility Communications Architecture Review, In: *ISA Transactions*, Volume: 32, Issue: 3, pp. 297-300, DOI: 10.1016/0019-0578(93)90029-V, ISSN: 0019-0578
19. Švadlenka, L., Chlaň, A. (2009) Principles of the Proposed Czech Postal Sector Price Control Model. *PROMET Traffic & Transportation*. Scientific Journal on Traffic and Transportation Research. Sveučilište u Zagrebu, Fakultet prometnih znanosti, Zagreb, Croatia. No. 1, Vol. 21, p. 33-40. ISSN 0353/5320
20. Vaculík, J., Tengler, J. (2012) Potential of new technologies in logistics services, In: *Congress Proceedings - CLC 2012: Carpathian Logistics Congress*, pp. 242-250.
21. Zeman, D., Madleňák, R. (2010) Application of the OSI reference model in terms of the design creation of postal transportation networks. In: *Perner´s Contacts*. ISSN 1801-674X. Volume 5, č. 3, s. 422-429.
22. ITA Consulting & WIK-Consult (2009) The Evolution of the European Postal Market since 1997

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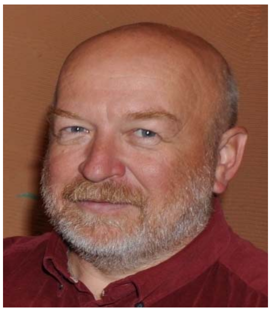

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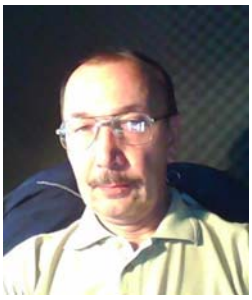

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, volume 16, no. 4, 2015
(Abstracts)

Rymarz, J., Niewczas, A., Stoklosa, J. Reliability Evaluation of the City Transport Buses under Actual Conditions, *Transport and Telecommunication*, vol. 16, no. 4, 2015, pp. 259-266.

The purpose of this paper was to present a reliability comparison of two types of city transport buses. Case study on the example of the well-known brands of city buses: Solaris Urbino 12 and Mercedes-Benz 628 Conecto L used at Municipal Transport Company in Lublin was presented in details. A reliability index for the most failure parts and complex systems for the period of time failures was determined. The analysis covered damages of the following systems: engine, electrical system, pneumatic system, brake system, driving system, central heating and air-conditioning and doors. Reliability was analyzed based on Weibull model. It has been demonstrated, that during the operation significant reliability differences occur between the buses produced nowadays.

Keywords: reliability, Weibull model, city transport buses

Vikovych, I., Zubachyk, R. "Bus Lane within the Area of Intersection" Method for Buses Priority on the Intersections, *Transport and Telecommunication*, vol. 16, no. 4, 2015, pp. 267-276.

The primary objective of this article is to formalize the "special bus lanes within the area of intersection" method that allows providing buses with space-time priority at signalized intersections (mostly of the isolated type), including those with no more than two traffic lanes in each direction at the approaches to the intersection. The article establishes the limits for efficient application of this method, and describes the results of a simulation experiment conducted in the VISSIM environment to investigate the functioning of the method on an actual intersection. The most critical phase of implementation of this method is to determine the optimum length of the special bus lane at the approach to the intersection. The optimum length of special bus lanes at the approaches to isolated or coordinated intersections is determined based on the maximum length of queued vehicles which is computed using the simulation models developed in the Objective-C language. The article covers the basic characteristics of those models, their structure and building principles, and also provides the model validation results. Simulation models can be used both for determination of the optimum length of special bus lanes at the approaches to signalized intersections and for analysis of intersection performance based on the maximum length of queued vehicles.

Keywords: bus lanes, bus signal priority, priority at the intersection, maximum length of queued vehicles

Prause, G., Schröder, M. KPI Building Blocks for Successful Green Transport Corridor Implementation, *Transport and Telecommunication*, vol. 16, no. 4, 2015, pp. 277-287.

The green transport corridor concept represents a cornerstone in the development of integrated and sustainable transport solutions. Important properties of green corridors are their transnational character and their high involvement of large numbers of public and private stakeholders, including political level, requiring sophisticated approaches for implementation, management and governance. The current scientific discussion focusses on Key Performance Indicators (KPI) for monitoring and management of green transport corridor performance emphasizing the operational aspects.

The green corridor balanced scorecard approach tried to mitigate the strategic weakness of KPI concept by integrating cooperative and long-term views in order to come closer to a comprehensive green corridor control system. Until now all discussed KPI sets are too small and narrow for a successful implementation of green corridors so there is a need for the development of an user-oriented model for green corridor control systems based on building blocks integrating existing KPI sets.

The building block approach for implementation has been successfully used for implementation and simulation in supply chain management. Based on these results the paper will present a holistic control system for successful implementation of green transport corridors based on building blocks integrating recent results about KPIs and balanced scorecards approaches. The research will empirically be verified by empirical results from European green corridor projects.

Keywords: green transport corridors, management control systems, networks, key performance indicators, corridor governance

Lukinskiy, V., Lukinskiy, Vl. Analysis of the Logistics Intermediaries Choice Methods in the Supply Chains, *Transport and Telecommunication,* vol. 16, no. 4, 2015, pp. 288-295.

The increase of the supply chains efficiency requires optimization of all types of logistic operations and functions. One of such functions is the choice of intermediaries (carriers, freight forwarders, suppliers, service enterprises etc.) and, according to some specialists, it is a major strategic decision in management supply chains. The methods of choosing the logistic intermediaries are considered in many works, however, some questions remain debatable. The article discusses the analytical and expert approaches which serve as a basis to choose the intermediaries; along with it, in the article a comparative evaluation of choice expert methods is done: point-rating assessment, analytic hierarchy process and the general algorithm for selecting; the conclusions have been drawn about the applicability of each method.

Keywords: choice of intermediaries, point-rating assessment, analytic hierarchy process (AHP), general algorithm for selecting intermediaries

Bulycheva, E.V., Krek, A.V., Kostianoy, A.G., Semenov, A.V., Joksimovich, A. Oil Pollution of the Southeastern Baltic Sea by Satellite Remote Sensing Data and In-Situ Measurements, *Transport and Telecommunication,* vol. 16, no. 4, 2015, pp. 296-304.

Results of operational satellite monitoring of oil pollution of the sea surface together with in-situ measurements of the oil products concentration in the water column for the first time allowed to establish relation between the surface pollution originated from ships, and the general characteristics of spatial and temporal distribution of oil products in the water column in the Southeastern Baltic Sea. Areas with heightened concentrations of oil products in the surface and bottom layers were determined for the study area. The main directions of the contamination propagation are agreed with the main direction of annual mean transport of substances in the Gdansk Basin.

Keywords: the Southeastern Baltic Sea, oil pollution, satellite monitoring, field measurements, geochemical barriers, D-6 oil platform

Mironov, A., Doronkin, P., Priklonsky, A., Kabashkin, **I.** Condition Monitoring of Operating Pipelines with Operational Modal Analysis Application, *Transport and Telecommunication*, vol. 16, no. 4, 2015, pp. 305-319.

In the petroleum, natural gas and petrochemical industries, great attention is being paid to safety, reliability and maintainability of equipment. There are a number of technologies to monitor, control, and maintain gas, oil, water, and sewer pipelines. The paper focuses on operational modal analysis (OMA) application for condition monitoring of operating pipelines. Special focus is on the topicality of OMA for definition of the dynamic features of the pipeline (frequencies and mode shapes) in operation. The research was conducted using two operating laboratory models imitated a part of the operating pipeline. The results of finite-element modeling, identification of pipe natural modes and its modification under the influence of virtual failure are discussed. The work considers the results of experimental research of dynamic behavior of the operating pipe models using one of OMA techniques and comparing dynamic properties with the modeled data. The study results demonstrate sensitivity of modal shape parameters to modification of operating pipeline technical state. Two strategies of pipeline repair – with continuously condition-based monitoring with proposed technology and without such monitoring, was discussed. Markov chain reliability models for each strategy were analyzed and reliability improvement factor for proposed technology of monitoring in compare with traditional one was evaluated. It is resumed about ability of operating pipeline condition monitoring by measuring dynamic deformations of the operating pipe and OMA techniques application for dynamic properties extraction.

Keywords: pipelines, reliability, damages detection, operational modal analysis, modelling of dynamic deformations

TRANSPORT and TELECOMMUNICATION, 16. sējums, Nr. 4, 2015 (Anotācijas)

Rymarz, J., Niewczas, A., Stoklosa, J. Sabiedriskā transporta autobusu uzticamības novērtēšana faktiskajos apstākļos, *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 259.-266. lpp.

Šī darba mērķis ir piedāvāt divu veidu sabiedriskā transporta autobusu uzticamības salīdzinājumu. Situāciju analyze uz pazīstamu pilsētas autobusu zīmolu piemēra: Solaris Urbino 12 un Mercedes-Benz 628 Conecto L, ko izmanto Ļubļinas Pašvaldības transporta uzņēmums. Bija noteikts uzticamības indekss uz visvairāk neveiksmīgām daļām un sarežģītām sistēmām neveiksmes laika posmiem. Analīze ietver sekojošām sistēmu bojājumiem: dzinējs, elektriskās sistēmas, pneimatiskā sistēma, bremžu sistēma, braukšanas sistēma, centrālā apkure un gaisa kondicionēšana un durvis. Uzticamība tika analizēta, balstoties un Weibull modeļa. Bija nodemonstrēts, ka darbības laikā rodas būtiskas uzticamības indeksa atšķirības starp autobusiem, kuri tiek ražoti mūsdienās.

Atslēgvārdi: uzticamība, Weibull modeļa, sabiedriskā transporta autobusi

Vikovych, I., Zubachyk, R. "Autobusu līniju krustošanās apgabalā" Autobusu prioritātes metode krustojumos, *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 267.-276. lpp.

Šī raksta galvenais mērķis ir iepazīstināt "Īpašo autobusu joslu krustošanās zonu" metodi, kas ļauj nodrošināt autobusus ar laika prioritāti pie regulējamiem krustojumiem (galvenokārt izolēta veida), ieskaitot tos, ar ne vairāk kā divām braukšanas joslām katrā virzienā pie pieejas krustojumam. Rakstā nosaka efektīvus limitus, kas piemēroti šai videi un ir aprakstīti simulācijas eksperimentā, ko veica VISSIM vidē izpētot darbību metodi uz faktiskajiem krustojumu rezultātiem. Būtiskākai posms lai īstenotu šo metodi, ir noteikt optimālo īpašo autobusa joslu garumu tuvojoties krustojumam. Optimālais īpašo autobusa joslu garums pie pieejām izolētajos vai koordinētajos krustojumos nosaka, pamatojoties uz maksimālo transportlīdzekļus rindas garumu, kas tiek aprēķināts, izmantojot simulācijas modeļus izstrādātās Objective-C valodā.

Raksts aptver pamatīpašības šiem modeļiem, kuru struktūra un apbūves principi, un arī nodrošina modeļa apstiprināšanas rezultātus.

Simulācijas modeļus var izmantot gan optimālā autobusa joslu garuma pie pieejas regulējamajiem krustojumos noteikšanai un analizēt krustošanās sniegumu, pamatojoties uz transportlīdzekļu rindas maksimālo garumu.

Atslēgvārdi: autobusa līnija, autobusa signālu prioritāte, krustojumu prioritāte, transportlīdzekļu rindas maksimālais garumus

Prause, G., Schröder, M. KPI Celtniecības bloku veiksmīga izmantošana zaļā transporta koridora īstenošanai**,** *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 277.-287. lpp.

Zaļā transporta koridora koncepcija ir stūrakmens integrētu un ilgtspējīgu transporta risinājumu attīstībā. Zaļo koridoru svarīgas īpašības ir to transnacionālo būtību un to augstais iejaukšanās līmenis valsts un privātajā sektora, tostarp politiskā līmenī, kas prasa sarežģītu īstenošanas pieeju īstenošanai vadībā un pārvaldībā. Pašreizējās zinātnes apspriešana koncentrējas uz galveno darbības rādītāju (KPI) zaļā transporta koridora sniegumu uzraudzību un pārvaldību, uzsverot darbības aspektus.

Zaļā koridora līdzsvarotā rezultāta pieeja mēģināja mazināt KPI stratēģisko vājumu koncepciju, integrējot kooperatīvus un ilgtermiņa skatījumu, lai tuvinātu visaptverošu zaļo koridoru kontroles sistēmu. Līdz šim visi apspriesti KPI komplekti pārāk mazi un šauri, lai veiksmīgi īstenotu zaļo koridoru tāpēc ir nepieciešams attīstīt uz lietotāju orientētu modeli zaļā koridora vadības sistēmu, pamatojoties uz celtniecības blokiem, kas integrē esošos KPI komplektus.

Celtniecības bloka pieejas īstenošana jau ir veiksmīgi izmantota piegādes ķēžu pārvaldības īstenošanā un simulācijā.

Pamatojoties uz šiem rezultātiem, tiks iesniegts papīrs par vienotu kontroles sistēmu, lai sekmīgi īstenotu zaļo transporta koridoru, pamatojoties uz celtniecības blokiem, integrējot jaunākos rezultātus par KPI un līdzsvarotu rādītāju kartes pieeju. Pētījums empīriski pārbauda empīriskos rezultātus no Eiropas Zaļo koridoru projekta.

Atslēgvārdi: zaļie transporta koridori, vadības kontroles sistēmas, tīkls, galvenais darbības rādītājs, koridoru pārvaldība

Lukinskiy, V., Lukinskiy, Vl. Loģistikas starpnieku izvēles piegādes ķēdēs metožu analīze, *Transport and Telecommunication,* 16. sējums, Nr. 4, 2015, 288.-295. lpp.

Piegādes ķēžu efektivitātes palielināšanai ir nepieciešama visu loģistikas operāciju un funkciju veidu optimizācija. Viena no šādām funkcijām ir starpnieku izvēle (pārvadātāji, ekspeditori, piegādātāji, pakalpojumu uzņēmumi u.c.) un, pēc dažu speciālistu domām, tas ir nozīmīgs stratēģisks lēmums piegādes ķēžu vadībā. Loģistikas starpnieku izvēles metodes tiek aprakstītas daudzos darbos, tomēr daži jautājumi paliek diskutējami. Rakstā ir izskatītas analītiskās un ekspertu pieejas, kas kalpo par pamatu, lai izvēlētos starpniekus; kopā ar šo, šajā rakstā tiek veikts salīdzinošs ekspertu izvēles metožu novērtējums: punktu likmes novērtējums, analītiskās hierarhijas process un izvēles vispārējais algoritms; secinājumi ir izdarīti par katras metodes piemērojamību.

Atslēgvārdi: starpnieku izvēle, punktu likmes novērtējums, analītiskās hierarhijas process (AHP), vispārējais algoritms starpnieku izvēlei

Bulycheva, E.V., Krek, A.V., Kostianoy, A.G., Semenov, A.V., Joksimovich, A. Naftas piesārņojuma mērījumi Baltijas jūras dienvidaustrumu reģionā ar attālinātas zondēšanas pavadoni, *Transport and Telecommunication,* 16. sējums, Nr. 4, 2015, 296.-304. lpp.

Naftas piesārņojuma jūras virsmas operatīvas satelītnovērošanas rezultāti kopā ar naftas produktu koncentrāciju ūdens stabā in-situ mērījumiem pirmoreiz ļāva izveidot saikni starp virsmas piesārņojumu no kuģiem, kā arī atzīmēt naftas produktu sadalījuma telpiskas un laika raksturīgās īpašības ūdens stabā Baltijas jūras dienvidaustrumu reģionā. Teritorijas ar paaugstinātu naftas produktu koncentrāciju virsmas un grunts slāņos bija noteikti kā izpētes objekti. Galvenie piesārņojuma izplatīšanas virzieni ir tādi paši kā galvenie ikgadējie transporta pārvadājumu virzieni Gdaņskas baseinā.

Atslēgvārdi: Baltijas jūras dienvidaustrumu reģions, naftas piesārņojums, satelītnovērošana, lauka mērījumi, ģeoķīmiskās barjeras, D-6 naftas platforma

Mironov, A., Doronkin, P., Priklonsky, A., Kabashkin, **I.** Darbojošu cauruļvadu tehniskā stāvokļa kontrole ar operacionālās modālās analīzes metodi, *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 305-319. lpp.

Naftas, dabasgāzes un naftas ķīmijas industrijā liela uzmanība tiek veltīta drošībai un aprīkojuma uzticamībai, kā arī savlaicīgai apkopju nodrošināšanai. Pastāv vairākas tehnoloģijas kā uzraudzīt, kontrolēt un uzturēt gāzes, naftas, ūdens un citus cauruļvadus. Šis raksts koncentrē uzmanību uz operacionālo modālo analīzi (OMA) un tās pielietojamību darbojošu cauruļvadu stāvokļa uzraudzīšanai. Īpašu uzmanību veltot OMA aktualitātei kad jānosaka darbojoša cauruļvada dinamiskās funkcijas (frekvences un svārstību formas). Pētījumu veica izmantojot divus darbojošus laboratorijas modeļus, kas imitēja daļu no darbojoša cauruļvada. Modelējot gala elementu rezultātus, tika apspriestas un identificētas caurules dabīgās svārstību formas un to izmaiņas virtuālu bojājumu ietekmē. Darbs apkopo darbojoša cauruļvada dinamiskās „uzvedības” modeļu eksperimentālos rezultātus pielietojot OMA metodi un salīdzina ar modelēto dinamisko īpašību datiem. Pētījumu rezultāti parāda modālo formu parametru jutīgumu uz darbojoša cauruļvada tehniskā stāvokļa izmaiņām. Tika apspriestas divas cauruļvadu uzturēšanas un remonta stratēģijas – ar nepārtrauktu tehniskā stāvokļa uzraudzību pielietojot augstāk piedāvāto metodi un bez šādas uzraudzības. Katra stratēģija tika izanalizēta ar Makarova ķēžu uzticamības modeļiem un uzlabojumu uzticamības faktors piedāvātajai uzraudzības tehnoloģijai salīdzinājumā ar tradicionālajām metodēm. Apkopojot augstāk minēto, pastāv iespēja veikt darbojoša cauruļvada tehniskā stāvokļa uzraudzību mērot tā dinamiskās deformācijas un pielietojot OMA metodi, iegūt dinamiskās īpašības.

Atslēgvārdi: Cauruļvadi, drošība, bojājumu atklāšana, operacionālā modālā analīze, dinamisko deformāciju modelēšana

Stopka, O., Simková, I. Priekšlikums par atkritumu poligona modeli konkrētajā teritorijā, *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 320.-329. lpp.

Mūsdienās, atkritumu loģistika ir būtisks elements pasaules loģistikas sistēmā. Šis raksts ir fokusēts uz priekšlikumu par atbilstošu modeli sadzīves atkritumu likvidēšanu atkritumu poligonos. Šī problēma attiecas uz atkritumu loģistiku pilsētu teritorijās. Šajā saistībā tiek izskatīti trīs dažādi alternatīvi modeļi atkritumu poligonos. Atkritumu poligona modelis var ievērojami ietekmēt atkritumu apsaimniekošanas produktivitāti un efektivitāti uzņēmumā. Šajā rakstā viena no problēmu lēmumu pieņemšanas metodēm tiek izmantota. Šī konkrētā metode ļauj izvērtēt katru atkrituma poligona modeli attiecībā uz katru norādīto kritēriju un sakārtot modeļus atbilstoši sasniegtajiem rezultātiem.

Atslēgvārdi: atkritumu poligons, atkritumu loģistika, sadzīves atkritumi, problēmu lēmumu pieņemšana, pilsētas teritorija

Krivchenkov, A., Sedykh, D. Bezvadu datu tīklos pakešu aizkavēšanās analīze, *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 330.-340. lpp.

Datu pārraides tīkli ar bezvadu saites priekš automatizācijas vadības aplikācijām, kad paketēm ir maza izmēra un datplūsma ir prognozējama tiek izskatīti. Analītisks modelis pakešu aizkave par viņu pavairošanas ceļu caur tīklu tiek ierosināts. Aplēses priekš tīkla arhitektūras, pamatojoties uz WiFi un Bluetooth bezvadu tehnoloģijas tiek veikti. Fiziskā slāņa specifikācijas 802.11 a/b /g /n un 802.15.1 tiek izskatīti. Analītiskie un eksperimentālie rezultāti piegādāto tīkla joslas platumu priekš tīkla dažādu arhitektūru, datu plūsmas struktūru un bezvadu tehnoloģijas tika salīdzinātas un ir apstiprināts, ka modelī galvenie mehānismi tiek pareizi ņemti vērā. Ir pierādīts, ka tālākai precizitātes "pilnveidošanai" modeļa bāzes efekti dos ne vairāk kā 5%. Kā rezultātā, kas ir svarīgs automatizācijas vadības aplikācijām, mēs esam droši saņēmuši zemāko iespējamo līmeni pakešu aizkavēšanās vienā bezvadu saiti. 802.11 tas ir kārtībā 0.2 ms un 802.15.1 tas ir 1.25 ms. Tam ir taisnība, kad paketes var tikt pārvietots ar vienu datu kadru.

Atslēgvārdi: WLAN, WiFi, Bluetooth, 802.11, 802.15.1, pakešu aizkavēšanās

Kraiņukovs, A., Ļaksa, I., Saltanovs, R. Bezvadu enerģijas pārraides efektivitātes izpēte izmantojot DD spoles, *Transport and Telecommunication*, 16. sējums, Nr. 4, 2015, 341.-352. lpp.

Raksts tiek veltīts bezvadu elektroenerģijas pārraidei izmantojot DD indukcijas spoles. Pētījuma mērķis ir noteikt rezonanses transformatora parametru ietekmi uz bezvadu enerģijas pārraides efektivitāti izmantojot DD indukcijas spoles. Visi eksperimenti tika veikti ar bezvadu enerģijas pārraides izstrādātās uz indukcijas metodes pamata eksperimentāla iekārtās palīdzību. Pētījumu rezultāti parāda attāluma starp indukcijas spolēm, transformatora rezonanses frekvences, avota uzkrāšanas sprieguma, kā arī temperatūras ietekmi uz bezvadu enerģijas pārraides efektivitāti.

Atslēgvārdi: DD indukcijas spole, bezvadu jaudas pārraide, rezonanses transformatori, induktīvās jaudas pārraides rezonanse

Madleňáková, L., Madleňák, R., Droździel, P., Kurtev, I. Slāņi un procesi pasta tehnoloģiskajos sistēmu modeļos, *Transport and Telecommunication,* 16. sējums, Nr. 4, 2015, 353.-360. lpp.

Darbs ietver svarīgus aspektus pasta tehnoloģisko modeļu sistēmā, piemēram, padara iespēju definēt noteikumus, lai regulētu, tehniskās un tehnoloģiskās prasības un interfeisu, lai sazinātos ar citām pasta sistēmām. Pašreizējā pasta reforma ir galvenokārt attiecināma uz tīkla piekļuves atbrīvošanu un pilnīgu sadarbspēju nodrošināšanu starp tehnoloģiskajām sistēmām. Ne tikai, lai nodrošinātu attīstību un konkurences aizsardzību, bet arī lai saglabātu prasību sniegt universālo pakalpojumu, kas ir sabiedrības interesēs. Šī ir vietas, lai pārbaudītu pasta sistēmu, ne tikai no procesuālā viedokļa, bet arī kā atvērta komunikāciju sistēmas. Ir iespējams atrast kopīgas iezīmes ar citiem komunikāciju nozarēm un apstrādāt tehnoloģisko pasta sistēmu vairākās kārtās; līdzīgi kā tiek apstrādātas elektronisko sakaru sistēmas. Pasta sistēmu slāņu modelis tiek balstīta ne tikai uz procesiem, bet arī uz slāņu funkcionalitāti, kas ļaus apzināt komunikācijas protokolus un saskarnes, kas nosaka savstarpējo izmantojamību. Tas arī paver jautājumu par atbilstīgu regulēšanas modeli.

Atslēgvārdi: slāņi, process, modelis, pasta sistēma, starp savienojums, regula

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$$\sqrt{a^2 + b^2} \tag{1}$$

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Acknowledgements (if present) mention some specialists, grants and foundations connected with the presented paper.

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3. Ministerial Council on Drug Strategy. (1997) *The national drug strategy: Mapping the future*. Canberra: Australian Government Publishing Service.
4. Nikora, V. (2006) Hydrodynamics of aquatic ecosystems. *Acta Geophysica,* 55(1), 3–10. DOI:10.2478/s11600-006-0043-6.
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