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A DYNAMIC TRAFFIC LIGHT MANAGEMENT SYSTEM BASED ON WIRELESS SENSOR NETWORKS FOR THE REDUCTION OF THE RED-LIGHT RUNNING PHENOMENON

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The real-time knowledge of information concerning traffic light junctions represents a valid solution to congestion problems with the main aim to reduce, as much as possible, accidents. The Red Light Running (RLR) is a behavioural phenomenon that occurs when the driver must to choose to cross (or not) the road when the traffic light changes from green to yellow. Most of the time the drivers cross even during transitions from yellow to red and, as a consequence, the possibility of accidents increases. This often occurs because the drivers wait too much in the traffic light queue as a consequence of the fact that the traffic light is not well balanced. In this paper we propose a technique that, based on information gathered through a wireless sensor network, dynamically processes green times in a traffic light of an isolated intersection. The main aim is to optimise the waiting time in the queue and, as a consequence, reduce the RLR phenomenon occurrence.

Keywords: Wireless Sensor Networks; RLR; Traffic Lights; Real-time; Intelligent Transportation Systems

1. Introduction

The number of vehicles constantly grows up both in small and large cities. One of the main goals of Intelligent Transportation Systems is to ensure road security, especially where there is the greatest number of accidents: traffic light junctions. Accidents at traffic lights occur for several reasons including the lack of care and the wrong management of traffic lights. Although many researchers focused on the study of innovative traffic lights management techniques, today most of the traffic lights are fixed cycles or manually controlled introducing human evaluation errors. These solutions can be adopted in road sections with low traffic flows. On the contrary, they produce several problems in areas with high vehicles density, such as the wrong green-time balancing, excessive fuel consumption and accidents caused by the Red Light Running phenomenon (RLR). The RLR phenomenon is a frequent and highly dangerous driving act. When a driver comes across a traffic light signal, changing from green to yellow, he must decide if accelerate or to brake according to his current speed and the distance to the stop signal. A wrong decision will lead him to a RLR violation or to an abrupt stop at the intersection. According to the authors of [1], [2] and [3], the proneness to RLR violations depends on two main factors, which influence the decision to stop or keep going at the intersection. These factors are as follows:

- human factor, related to population characteristics;
- road factors, related to traffic, geometric and operational characteristics of the intersection.

The technology can certainly play an important role in favour of these issues. Wireless sensor networks (WSNs) allow making different measures on the monitored traffic. Sensor nodes can be placed everywhere and provide several mechanisms to support energy savings [35]. They are also easy to deploy and manage. As a consequence, WSNs are particularly useful to monitor highly crowded roads. A distributed and clustered network infrastructure, for the real time evaluation of traffic flows, represents a concrete solution to the problem of road congestion monitoring. In this paper we present an experimental technique that allows the dynamic management of traffic light cycles using traffic flows information gathered through a WSN deployed near a traffic light junction. The main goal is to dynamically vary the green times based on the queue length, assigning then a greater green time to the road with the longest queue. In this way, by reducing the waiting times in the queue, it is possible to obtain a reduction of accidents caused by the RLR phenomenon. In most cases, accidents are caused by stress from excessive waiting times in queue. The paper is organized as follows. The Section 2 reports main literature works on road monitoring techniques using wireless sensor networks and on RLR. The Section 3 describes the proposed architecture. The Section 4 analyses the innovative and dynamic traffic lights management approach here proposed. The Section 5 shows performance evaluation of the proposed architecture while the Section 6 reports on the conclusions.

2. Related Works

2.1. Traffic lights management techniques using wireless sensor networks

Currently, most of traffic control systems use a wired communication infrastructure and this involves considerable maintenance costs reducing the architecture scalability. WSNs can be used [4] in order to solve these problems. In fact, an important application field of WSNs is road monitoring [5], as well as home automation [6], [7], health [8], agriculture [9] and industry [10], [11]. WSNs can be used for vehicular traffic detection in order to know real-time traffic information and help the drivers to make several decisions in order to optimise arrival time and to avoid queues. For these reasons, several works in literature deal with WSNs used for road traffic monitoring. In [12] the authors propose a compressing sensing technique which main aim is to reduce necessary communication among sensor nodes placed along the road. A solution based on a new network topology applied to sensor networks for road monitoring in order to improve performance in terms of throughput and energy savings is proposed in [13].

The authors of [14] propose a traffic flow segmentation technique based on the discrete Fourier transform using a data aggregation algorithm in order to minimize communication costs among the wireless sensor network nodes for urban traffic monitoring. The authors of [15] show a WSN application combined with video surveillance cameras. They describe novel network architecture in which surveillance cameras are dynamically enabled or disabled through a fuzzy logic controller based on information collected by sensors placed along the road. The aspect of queue management is discussed in [16]. In this work the authors describe a traffic scheduling mechanism through an algorithm for queues management called TRED (Traffic Random Early Detection). On the contrary, the Random Early Detection (RED) algorithm, the most common type of Active Queue Management (AQM) algorithms, is used in [17]. The authors propose an approach in which the road congestion is monitored based on the average queue length of vehicles and when a road is close to the congestion, the scheduler will forward the car on a different road. In literature several works show WSNs architectures for safety warnings signalling and for traffic lights management. In fact, in the approach proposed in [18], a WSN is used to automatically generate safety warnings at black spots along the road network. Instead, an architecture in which sensor nodes detect road information and send them to the nearest Intersection Control Agent, which determines the flow model of the intersection depending on data gathered by sensor nodes, is proposed in [19]. Moreover, the same authors propose in [20] results obtained using one sensor and two sensors. In both approaches, the obtained results show how to place the sensors close to each others produces the best performance in terms of quality of the data and reduces the energy consumption prolonging, as a consequence, the life time of the whole network. An intelligent traffic signals control system based on a WSN is shown in [21]. The authors propose an approach that uses the vehicle queue length during red cycle in order to perform a better control in the next green cycle. Their goal is to minimize the average waiting time in order to reduce the queues' length. In [22] and [23] the authors proposed an adaptive traffic light control algorithm that adjusts both the sequence and length of traffic lights in accordance with the real time traffic detected. The proposed algorithms consider several traffic factors (traffic volume, waiting time, vehicle density) in order to determine the optimal green light duration. The authors of [24] propose a fuzzy logic controller in order to dynamically adjust green time of traffic lights. According to the proposed approach, traffic flow can be detected by the single-axis magnetic sensors and transmitted through a wireless sensor network. The time for vehicles passing during the green lights is dynamically adjusted through the fuzzy algorithm according to the current volume of vehicles.

2.2. RLR analysis of road intersections

Some behavioural researches have clarified the role of the two different factors on RLR in terms of "dilemma zone" [25] and circumstances that make the red light running possible. In [26] it is suggested that in drivers' stop and go decisions, they should be considered the expectations due to previous knowledge of the intersection (especially waiting times at red lights), the assessment of the consequences of a violation and the estimation of the consequences of stopping. The study of [27] illustrates that the tree models are helpful to recognize and predict how the drivers make stop and go decisions and participate in red-light running violations, simply taking into account the traffic parameters. In urban areas, the optimisation of signal timings is really important to ensure the respect of traffic signals. The authors consider speed effects on RLR mostly associated with the human factor element. The FHWA (the Federal Highway Administration) recommends that signal timings must be regularly reviewed and updated (every 2 years) in order to ensure the satisfaction of current traffic demands. Indeed, the proper duration of each signal-cycle can reduce drivers' frustration that might result from unjustified short or long cycle lengths. The duration of each signal phase is based on the characteristics of the intersection and on the individual approaches. There are several philosophies and considerations, which support both shorter and longer cycle lengths in order to reduce signal violations. A driver, knowing that the waiting time is not excessive, may be less inclined to cross the road during the yellow or, even, during the red signal. On the contrary, in case of high traffic volumes, a short cycle length may not be enough to well manage all the queues and, as a consequence, the drivers may wait two or more cycles before to cross the road junction. Several previous researches, based on potential conflicts analysis, have provided a quantitative evaluation of 'proneness' to the red-light running behaviour at urban signalised intersections by varying geometric, traffic flow and driver characteristics. A recent study [28] demonstrated the potential of the use of micro-simulation models to evaluate the 'proneness' to RLR behaviour at urban signalised intersections in Milan (Italy), by varying flow characteristics and stop line distances. The micro-simulation, although at its early phase of development, is really promising especially for its ability to model unintentional RLR behaviour and to evaluate alternative junction designs. However, in order to make more robust the new modelling framework, the need to demonstrate the transferability of the modelling approach has been addressed in this paper [29]. The transferability has been tested and evaluated using a 4 arms junction in Enna (Italy), where has been realized a continuous video recording lasted 13 days. Moreover, in collaboration with the local Police, different cycle and green time's settings have been implemented in order to measure the effects on the RLR rates. Then, the measured RLR rates have been evaluated and compared to the theoretical and modelling results as validation exercise. In this way, the prediction capability of the proposed potential conflict model has been improved. The evaluation of the proneness to the RLR behaviour, as it results from human and road factors, can be useful to help a proper selection of the sites to be treated, thereby increasing benefit of the countermeasures to reduce the red-light running phenomenon. Starting from the conceptual framework of a model based on potential conflicts analysis, the authors of [30] show that a quantitative evaluation of the proneness to the red light running behaviour can be obtained both from the analysis of the effective operational characteristics of the intersection and from the actual number of red light running violations. According to the behavioural models referred in the literature, which emphasize the influence that both human and road factors have on the users' decisional process at red lights, the proposed approach also accounts for the impact of the local (site) and general (population) characteristics on the phenomenon. Field observations, for a case study in an urban area are discussed in order to illustrate the methodological approach. Some behavioural researches have clarified the role of the two different factors on the RLR decision. According to the authors of [26] in drivers' stop and go decision process three fundamental criteria are present:

- expectations and knowledge of intersection (especially regarding waiting times at red lights);
- estimation of the consequences of a violation;
- estimation of the consequences of a sudden stop.

From these considerations, it is possible to imagine a possible intentional RLR driver, impatient about a probable wait and not very worried about the risks of a violation. At the same way, it is possible to imagine the unintentional RLR driver that cannot suddenly brake or is approaching the intersection with insufficient attention. The authors of [31] observed that each user takes on a different role when is faced with the stop and go decision, depending on a given situation, on his/her mind set and on chance. In the light of this, four user categories can be distinguished, each characterized by a different inclination to infringe the red lights: reasonable and prudent; temporarily inattentive; reckless and mistaken driver. Although these studies qualitatively consider the influence of both human and road factors on the decisional process, they still do not provide any quantitative evaluation in terms of proneness to the red light violation. However, from an engineering standpoint, the qualitative data is unsatisfactory in order to establish appropriate countermeasures against the RLR phenomenon. Over the recent two decades, the RLR at signalised junctions has been well researched because of the human and financial costs to individuals and Governments due to accidents. Also, the effects of this phenomenon on road safety are well documented by several statistics [32], [31] highlighting both a very high frequency (up to an average value of 1 violation every 3.5 minutes) and the respective gravity of the consequences [33] with a growing intensity in recent years. In [32] a study of data from four States in the U.S. shows that RLR crashes account for 16% to 20% of the total crashes at urban signalised intersection. Evidence in [30] showed that about 5% of urban crashes are the result of red light runners.

3. System Architecture and Requirements

3.1. WSN System requirements

The knowledge of the real time situation of a certain road section is a fundamental condition for a better interpretation of the traffic flows. To achieve this goal, it is necessary to realize a monitoring environment based on different technologies in order to ensure the timely processing of information coming from the street. The Figure 1 shows the proposed system architecture.

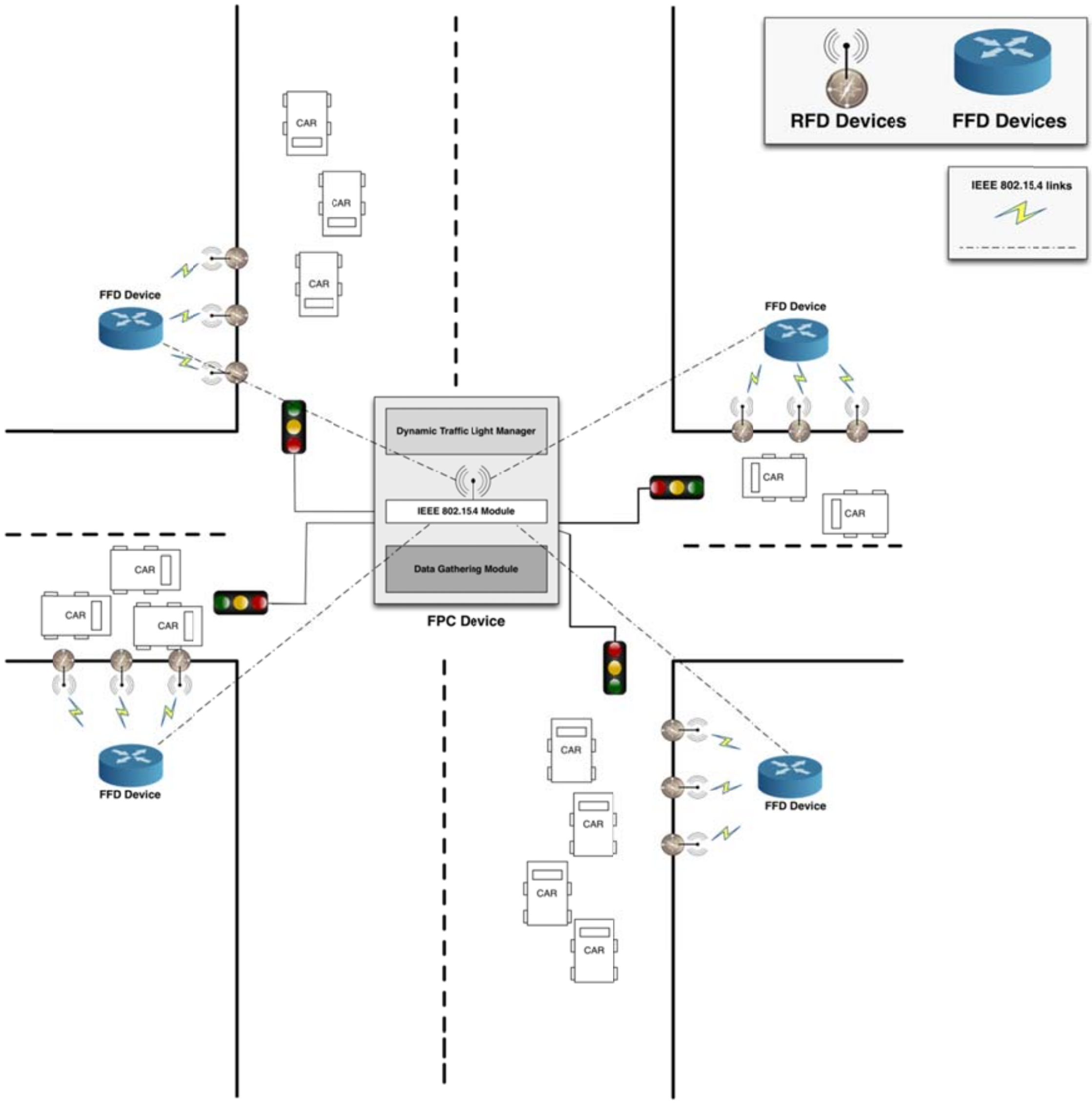

Figure 1. The system architecture

Road sections, near the traffic light junction, are monitored using appropriate nodes, Reduced Function Devices (RFD), provided with magnetic sensors in order to detect the presence of ferrous objects. The information gathered by the RFD is then forwarded to their relative Full Function Device (FFD), which collect information of their cluster and forward them to the First Pan Coordinator (FPC). As shown in Figure 1, the main modules provided by the FPC are as follows:

- a module for IEEE 802.15.4 [34] communication;
- a data gathering module;
- a dynamic traffic light manager characterized by an algorithm that, based on real time data detected by the network, determines the green times to be assigned to the road sections ensuring higher priority to longer queues.

The proposed system, as described above, can take over only the management of the traffic light and its optimisation. It can forecast the violations resulting from the traffic light variation but it cannot adjust the geometry of the intersection in order to prevent violations. The system, in other words, could lead to the base of knowledge about the violation rate, and in some case it highlights geometry deficiency in order to improve safety and reduce the RLR phenomenon.

3.2. Dynamic Traffic Light Manager

Considering the Figure 2, we indicate with R_A the road section containing traffic lights 2 and 4 and R_B the road containing traffic lights 1 and 3.

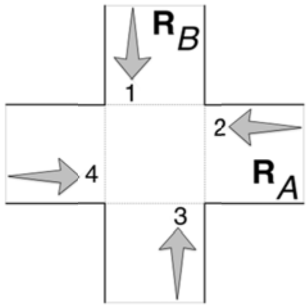

Figure 2. Road intersection

In static traffic lights, each cycle can be approximated to a periodic task with period **T** divided in a fixed green time ($\mathbf{T_g}$), a fixed yellow time ($\mathbf{T_y}$) and a fixed red time ($\mathbf{T_Y}$). Of course, under these conditions, each road section queue will be handled in the same way regardless of its length and not considering the dynamic behaviour of the queue. Our goal is to realize a mechanism in order to dynamically determine the traffic light cycles based on vehicles number in queue. The Figure 3 shows a road section of length $\boldsymbol{L}$ subdivided into smaller sub-sections, each one of length $\boldsymbol{l_i}$.

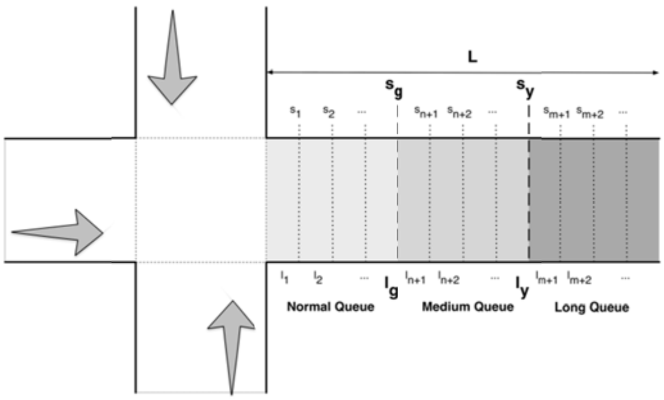

Figure 3. Monitored road section by wireless sensor networks

Each subsection $\boldsymbol{l_i}$ is monitored by a node in order to detect the presence of vehicles through a magnetic sensor [35]. Each node communicates with other nodes and the FPC according to the IEEE 802.15.4 [34] standard protocol. The algorithm evaluates the traffic light cycles considering three fundamental parameters: the road section length ($\boldsymbol{L}$) to be monitored; the sub-sections length ($\boldsymbol{l_i}$); the approximate crossing speed ($\boldsymbol{v}$). Most of vehicles, waiting at the traffic lights, are cars. The average length of a car is between 3.5 and 5 meters. Considering that vehicles may be shorter or longer, the length of each subsection ($\boldsymbol{l_i}$) can assume values between 4 and 8 meters. We decided to places the RFD nodes every 12 meters while the FFD nodes every 60 meters. Finally, the FPC can be placed at the end of the road near the traffic light. In a small city, the average speed ($\boldsymbol{v}$) of a vehicle crossing a traffic light intersection is 15 Km/h. Let consider $\boldsymbol{l_g}$ the maximum value within which a traffic light queue is considered normal while l_y is the maximum value within which the queue can be considered medium. Above this value, the queue is considered long. The number of subsections is calculated as L/l_i while the l_g value can be determined by the following relation (1):

$$l_g = \frac{\left(\frac{L}{l_i}\right)}{3} + 1 \quad . \tag{1}$$

The number 3 at denominator represents the number of categories into which the queue has been divided (normal, medium and long) while the 1 represents a guard value arbitrarily chosen.

The l_y value, therefore, is calculated through equation (2):

$$l_y = \left(\frac{L}{l_i}\right) - 1_g \quad . \tag{2}$$

In case of vehicles detection in a section $l_i < l_g$ the traffic light works under standard conditions. In case of vehicles detection, in a section $l_g < l_i < l_y$, the estimated queue length is considered medium. Instead, $l_i > l_y$ is the condition of long queue. The crossing time of a single subsection can be easily estimated through the following equation (3):

$$t_i = \frac{l_i}{v} \quad , \tag{3}$$

where l_i represents the i-th section length while v is the approximate crossing speed of the relative road section. In case of medium or long queue, the green time must be recalculated according to the estimated queue length.

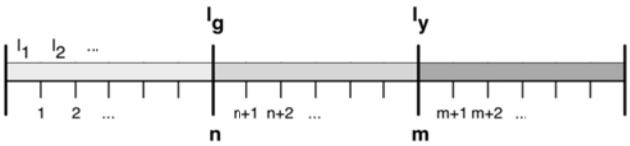

Figure 4. Sections subdivision

Considering the subdivision of the sub-sections shown on Figure 4, the standard green time t_g and the real-time green time t_{grt} can be calculated through the following relations (4):

$$\begin{cases} t_g & if\ l_i \le l_g \\ t_{grt} = t_g + \dfrac{l_j + l}{v} & if\ l_g < l_j \le l_y\ with\ j = n+1, n+2, \ldots, m \\ t_{grt} = t_g + \dfrac{l_k + l}{v} & if\ l_k > l_y\ with\ k = m+1, m+2, \ldots \end{cases} \quad . \tag{4}$$

The terms $(l_k + l)/v$ and $(l_j + l)/v$ represent each one ratios between space and speed. In other words, they represent values of time to be added to the standard green time t_g in case of increasing queue in order to slightly increase the total green time and to allow the real-time management of the traffic light according to the queue behaviour. Clearly, the road that has the longest green time has higher priority. Each traffic light independently calculates, during each period, its green time in order to determine its priority level according to the following relations (5):

$$\begin{aligned} p_i &= t_g \quad if\ l_i < l_g \quad with\ i = 1,2,3,4 \\ p_i &= t_{grt} \quad if\ l_i > l_g \quad with\ i = 1,2,3,4\ , \end{aligned} \tag{5}$$

where p_i is the priority of the *i-th* traffic light. At the end of the period T_i, the algorithm determines the road with highest priority determining which traffic light needs more green time. The priority of each road is calculated through equation (6) and (7), as the average of the individual priorities calculated by each traffic light adding a Δ value (that can be positive or negative). This Δ value is then divided by two in order to avoid that the priority, acquired by a road, can be too high (excessive green times).

$$P_{R_A} = \frac{(p_1 + p_3)}{2} + \frac{\Delta_A}{2} \quad , \tag{6}$$

$$P_{R_B} = \frac{(p_2 + p_4)}{2} + \frac{\Delta_B}{2} \quad . \tag{7}$$

4. Performance Evaluation

4.1. Traffic lights manager evaluation

The simulations have been carried out both in case of fixed and dynamic traffic light cycle in order to demonstrate the goodness of the proposed approach. Performance have been evaluated considering a 4-arms junction placed in Enna-Italy, where up to 160 vehicles can be measured on each road. In both cases, the reference cycle was 60 seconds and measurements have been gathered for 60 cycles (1 hour). The length of each road approaching the traffic light junction is 1.5 Km. For completeness, durations of fixed traffic light cycles are: minimum duration: 30"; normal duration: 50"– 75"; maximum duration: 90"– 120". The Figure 5 shows the number of vehicles measured and smoothed in Road A in case of Fixed Cycle (left side) and Dynamic Cycle (right side) respectively. As it is possible to see, in case of fixed cycle, the queue it is not correctly managed. In fact, on average 23.08 vehicles/minute are measured near the traffic light but, of these, just 11.33 vehicle/minute are smoothed (about 49 %). On the contrary, in case of dynamic cycle, 21.083 vehicles/minute are smoothed (about 91 % of the total number of vehicles transited).

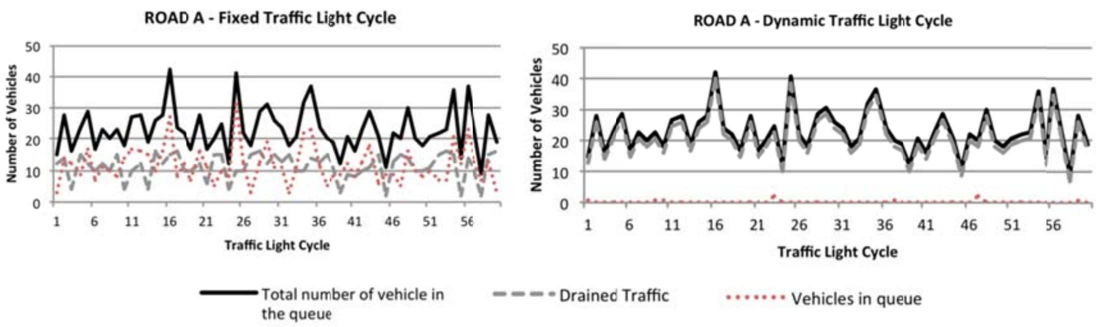

Figure 5. Road A – measures obtained with fixed and dynamic Traffic Light

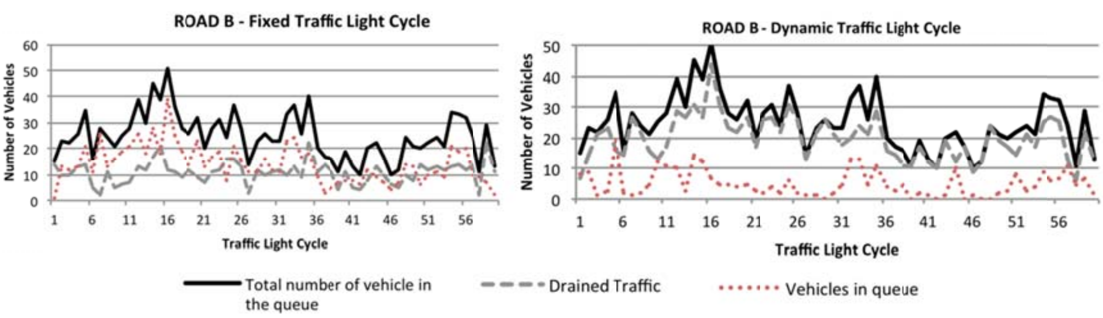

Figure 6. Road B – measures obtained with fixed and dynamic Traffic Light

The Figure 6 shows measurements carried out along the road B in case of "fixed-cycle" traffic light (left side) and dynamic traffic light (right side). In the first case, on average 24.95 vehicles/minute have been detected. Of these, just 10.81 have been smoothed (about 43.35 %). Otherwise, considering a dynamic traffic light that uses our approach, 19.93 vehicles/minute have been smoothed (about 80 % respect to the total number of vehicles transited).

4.2. Evaluation of driver behaviour in Italian signalised intersections

The intersection number and several human factors influence the RLR phenomenon. It is important to examine how these factors interact to increase or decrease the RLR risk in order to identify the several reasons of RLR occurrences. The Red Light Runners can be categorized into intentional and unintentional violators. In general, appropriate countermeasures should help to manage them.

Excluding users who did not use drugs and alcohol, the main factors that lead to the occurrence of RLR can be divided as follows:

- Drivers characteristics: gender, age and type of driven vehicle (heavy or light);
- traffic-light characteristics: cycle and change of phases;
- intersection characteristics: geometry, triangles of visibility, presence and analysis of the black spot, different types of construction presence that can adversely affect the driver and therefore distract him from driving manoeuvres;
- when the phenomenon occurs: evaluation of the peak traffic flow considering every different moment of the day such as morning, afternoon or evening.

Considering the yellow phases in the traffic-light cycle, in several states there are two types of restrictive laws described below:

- vehicles can not enter the intersection or be in the intersection during red light;
- vehicles must stop upon receiving the yellow light indication, unless it is not possible to do it safely.

These factors need to be considered in combination with the intersection definition when developing a plan in order to manage the RLR phenomenon. Public information and education campaigns would be needed in order to have an exhaustive knowledge regarding to the meaning of the yellow indication. Another characteristic refers to the demographics category that includes the age, the gender and the vehicle occupancy. It is also important to consider whether or not the red-light runner was wearing a seat belt. In fact, younger drivers, between 18 to 25 years old, are more likely to run on red lights compared to older drivers. Moreover, the majority of red-light runners are males and are less likely to wear safety belts. Specifically, the drivers run on red lights when they drive alone or have an older car.

Regarding to the driving speed, the drivers may:

- accelerate during yellow in order to anticipate a signal indication change. If a driver misjudges the time of signal change, he will enter the intersection against the red signal indication;
- to drive above the speed limit, decreasing the available distance to react to a traffic signal indication change.

The drivers who closely follow another vehicle are more likely to run a red light. Taking into consideration the different types of vehicles transiting, it is statistically significant that there are differences between RLR rates if a driver follows a smaller or a larger vehicle. In fact, there are higher rates of RLR if a driver drives behind a larger vehicle due to the visibility. Moreover, the traffic volume is an important factor of direct increase of the RLR phenomenon. In order to fit the problems related to the traffic-light cycle and the RLR phenomenon, the Figure 7 shows the correlations obtained in regarding the number of violations related to traffic light cycles on main and secondary direction.

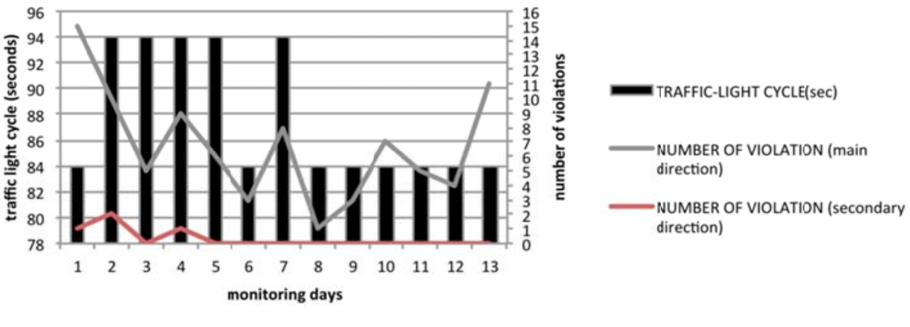

Figure 7. Trend of violations according to the traffic-light cycle about a typical 4-arm signalised intersection

Furthermore, the study shows a correlation between the frequency of the signal variations and the current red light. If the time cycle increases, the hourly frequency variations of the signal decrease reducing, as a consequence, the exposure of drivers to potential red light situations. The presence of a wireless sensor network that detects the possible transgression and dynamically adapts the traffic-light cycle, leads to a reduction of the RLR phenomenon occurrences. Recognizing the importance of this issue, it's possible to consider the studies of University of Florida (Transportation Research Centre) where some researchers started a program to develop the necessary hardware and software to support field studies in efficient and effective way. The central element of the system for collecting data from the American University is a red light Analysis Package (RLRAP) which provides the enabling technology to observe vehicles in violation of a red signal superimposing the state of all traffic signals on a video image of the complete intersection. Through the implementation of wireless sensors therefore, in agreement with what has been said, it is possible to see all vehicles and all signals simultaneously.

5. Conclusions

Increasing traffic volumes and congestion in many urban areas, determine drivers impatience and frustration. Sometimes these conditions lead to an aggressive drivers' behaviour and disregard for road laws and signals. These violations, including the RLR phenomenon, decrease the safety of drivers and pedestrians. In this paper we proposed a novel technique for the dynamic management of traffic light cycles in order to reduce the queues in road sections and, as a consequence, accidents due to the RLR phenomenon. To this end, a wireless sensor network has been implemented with the aim to gather real time information about roads' congestion. These information are then processed by a central node (the First Pan Coordinator) equipped with a special module that, based on a novel algorithm, dynamically processes the traffic light cycles reducing, at the same time, waiting times and drivers frustration. The results shown, clearly demonstrate how the proposed algorithm improves the queue management near a traffic light.

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TOWARDS AUTOMATED ROAD INFORMATION FRAMEWORK A CASE STUDY OF TANZANIA

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Traffic congestion problem has been noticed to have a serious impact on the economy of the country in terms of time wastage, energy consumption costs, human loss and environmental effects. Different strategies have been used so far all over the world as shown in the literature review. Intelligent Transportation System (ITS) is a multi-technology approach that can help to handle the issues and create a complete congestion reduction framework. This paper presents a case study for implementing automated road management system using networks in Tanzania, where three cities highly affected by traffic congestion have been studied. Study results show that these cities have not yet implemented new technologies in road traffic management; instead the traffic is controlled using traffic police officers and traffic lights only. The traffic lights use an old technology that cannot manage traffic in relation to the real-time situations. This study proposes components for a framework, which will assist automation in road traffic management. From the review of various existing ITS of which Advanced Traffic Management System (ATMS) and Advanced Travel Information System (ATIS) are subsystems, we have identified the possibility to integrate the two sub-systems within the framework. Three-phase traffic theory has been referred, FOTO and ASDA models are applied to the automatic recognition and tracking of congested spatiotemporal traffic patterns on roads.

Keywords: Traffic Congestion, Urban Transportation, Intelligent Transportation Systems (ITS)

1. Introduction

Traffic congestion is a growing problem in most urban areas all over the world. Tanzanian urban areas are among the most affected. Intelligent Transportation Systems (ITS) apply Information and Communications Technologies (ICT) to the real-time management of vehicles and transportation system as a whole involving the movement of people, goods and services. When integrated into the transportation system's infrastructure, and into vehicles, these technologies relieve congestion, improve safety and enhance productivity [1]. Despite of the benefits and opportunities brought by ITS, the major problem is how to introduce them in developing countries with many challenges in network infrastructure and economic problems.

Therefore, Tanzania as one of the developing countries can embark technology, which is suitable in relation to the country set-up and culture, in order to solve the traffic congestion problem. Development of a framework to be adopted is important so as not to cause failure in solving the problem. This paper attempts to explicitly investigate, evaluate, analyse and present the state of traffic congestion control together with issues and challenges as results of current ongoing research conducted in three urban networks located in three cities of Tanzania, namely (1) Arusha, (2) Mwanza and (3) Dar es Salaam. Tanzania has been chosen as a case study for two reasons. First, two of the authors live and work in this country and know its problems best of all. Second, Tanzania is a typical country of sub-Saharan Africa with the GDP per capita of $1,700, and it is in early stages of applying technology in traffic management.

Hassan [2] stated that reasons such as inadequate transport infrastructure, rapid increase in urban population, income and automobile ownership etc., had been noted to contribute to traffic congestion in many of the urban areas. However, expanding the transportation systems is not always fruitful, if the demand is not satisfactorily met by the existing capacity. As such it is necessary to optimise the use of existing transportation system by using certain management techniques [3]. There exist a number of traffic control mechanisms, which either controls supply side of the traffic only or demand side of the traffic information only. The demand reflects both origin destination patterns and the combination of all individual decisions of travellers. ATIS, by influencing drivers' travel decisions, are therefore designed to influence transportation demand side. The supply reflects the state of transportation network in terms of infrastructure, traffic flow and traffic control. ATMS impose certain restrictions and constraints on traffic flows, which result in modification of the capacity of networks. Therefore they affect transportation supply side [4].

This paper proposes an automated road information framework, which will enable the implementation of better traffic control networked systems in Tanzania. The framework considers issues and challenges in managing the traffic flow faced by the country. These include (1) poor infrastructure, (2) limited budget and (3) lack of expertise in technology advancements. The review of available ITS, in relation to the challenges faced by the country, has revealed that the automation in three studied cities should also involve integration of supply and demand sides of the transportation systems.

The general objective of the study is to develop an automated road information framework this will enable better traffic flow management in Tanzanian cities, through the use of networked systems. The specific objectives are as follows:

(1) To identify issues and challenges of using networked systems in urban traffic flow management

(2) To identify strengths and weaknesses of existing ITS

(3) To identify components of the automated road information framework and links between them.

The paper structure is as follows: introduction; overview and state of traffic congestion control; research methodology; results; discussion, conclusion and further work.

2. Overview of Road Traffic Management

2.1. Technologies available

The overview of currently available within Tanzania road traffic management systems such as traffic lights has shown that these systems have no ability to adjust to the recurring or non-recurring situations [8]. Instead they continue to function like in a normal situation. Traffic lights behave in the same way during the peak and normal hours and even during special situations such as parade, accident, floods and etc.

As explained in [9], the traffic lights were implemented in the period where there was no technology advancement. Tanzania like other developing countries still relies on traffic lights. Whenever the traffic lights fail to perform their work of controlling traffic flow at the road junctions, they are substituted by traffic police officers who manually manage the traffic flow. This arrangement has not been helpful in solving the traffic congestion problem the country is currently facing. Tanzania could integrate the currently used mechanism of controlling the traffic with advanced systems to mitigate the traffic congestion problem. There are several systems, which have been implemented in various countries with the purpose of managing the traffic flow. Table 1 gives a list of some countries, which have implemented ITS. It also indicates strengths and weaknesses of the systems. While developing the automated road information framework, the authors tried to incorporate strengths and avoid weaknesses of the existing systems.

Table 1. Some examples of the existing ITS

Country	Implemented ITS	Strengths	Weaknesses
South Korea [5]	Real-time traffic information provision; Advanced public transportation Information systems; Electronic fare payment and electronic toll collection	Built on city by city basis, formed ITS Model cities	High implementation cost
Japan [6]	VICS (Vehicle Information and Communication System), ETC (Electronic Toll Collection) AHS (Advanced Highway System), UTMS (Universal Transportation Management System)	Satellite based, guide users everywhere including minor roads	High implementation cost
The Unites States of America [5]	Variable rate high way tolling; Electronic toll collection; Advanced traffic management systems such as ramp metering, and travel information provision	ITS effort focuses on research	ITS vary significantly by state and region and are not integrated into a national ITS
South Africa [7]	An automated system, including incident management for providing incident information, ramp metering, toll collection and public transport priority system	Implementation in stages	Non digitised road networks

2.2. Implementing ITS

It has been reported in [10] that ITS as a whole is too large and complex to install all at once even in the wealthiest and most technically advanced countries. In most countries, including both developed and developing countries, the right approach is to introduce ITS gradually and in stages, focusing first on the parts of ITS that provide the greatest value in proportion to cost. Therefore, the successful introduction of ITS must include staging, and planning for change, growth, and ongoing integration as new functions are introduced and existing.

An ITS architecture is a valuable tool for describing how ITS will work and for defining its major building blocks. There already exist many good ITS architectures like these presented in Table 1.Therefore, it is not necessary for a country with limited resources like Tanzania to develop its own ITS architecture from scratch. It is generally faster and less expensive to start from an existing architecture and adjust it step-by-step to the country's requirements [10].

2.3. ITS subsystems

The Intelligent Transportation System (ITS) uses sensing, processing and communication technologies. As reported in [11], ITS comprises four main subsystems presented on Figure 1, these are Advanced Traffic Management System (ATMS), Advanced Travel Information System (ATIS), Advanced Public Transport System (APTS) and Emergency Management System (EMS).

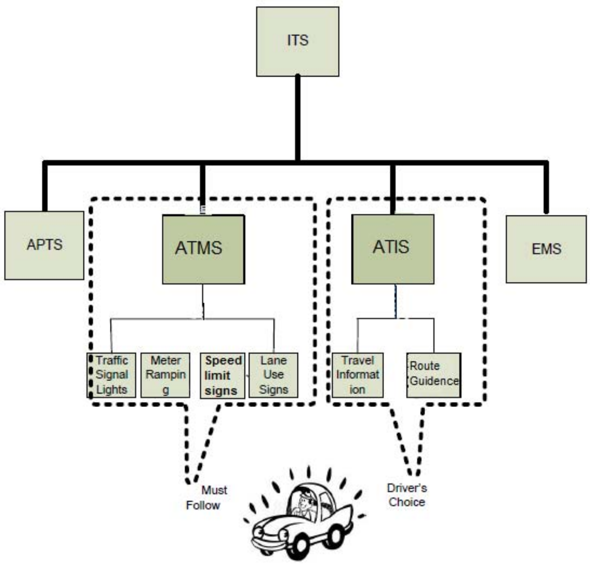

Figure 1. ITS and subsystems of ITS (Source: [11])

Of those subsystems ATMS and ATIS are most important to the proposed automated road information framework. Their functions listed in Table 2 can easily complement the functions of the existing road management system (namely traffic lights), which currently operates in Tanzania.

Table 2. Functions of ITS subsystems

ITS Subsystem	Functions	Cited in
Advanced Public Transport System (APTS)	Public Transport Management	[10]
Advanced Traffic Management System (ATMS)	Sets constraints and limits on the traffic flows	[11]
Advanced Travel Information System (ATIS)	Provide travellers with the travelling information	[11]
Emergency Management System (EMS)	-Emergency notification and personal security -Emergency vehicle management	[12]

ATMS integrates the management of various roadway functions. It predicts traffic congestion and provides alternative routing instructions to vehicles. ATMS collects, utilizes and disseminate real-time data to road users and further alerts for alternative routes to improve transit operations. Devices used to form the ATMS include(1) traffic signal lights, (2) meter ramping, (3) speed limit signs and(4) lane use signs.

The ATIS combines travel information and route guidance systems. Drivers can access the information while they are in their vehicles, in their homes or at their places of work. Information provided includes: (1) location of incidents, (2) weather problems, (3) road conditions, (4) optimal routings, (5) lane restrictions, and (6) in-vehicle signing. Information can help drivers, passengers and even pedestrians to decide what transport mode and route they should opt for.

Incident detection is of high importance for ATMS and ATIS to function well, as they respond in relation to what has been detected. In relation to the research findings, Tanzania is in good position to start with the implementation of ATMS and ATIS subsystems, since the two systems can easily integrate with the existing traffic control systems such as traffic lights.

3. Methodology

Research methodology is based on qualitative and quantitative research methods. Research process is divided into two stages. The first stage included literature review in the area of road traffic management and automation. The second stage employed a research survey, whereby questionnaires and in-depth interviews were conducted in order to collect the relevant data.

Three Tanzanian cities (Dar es Salaam, Mwanza and Arusha) have been identified as most affected by road traffic congestion problem [13]. Three government organizations responsible for roads management in each city have been approached, namely: (1) Traffic Police;(2) Municipal Councils and (3) Tanzania National Roads Agency (TANROADS). Road users – drivers and non-drivers (passengers) – have been also included into survey.

Different types of questionnaires were delivered to the targeted interviewees based on their levels within the organization. These levels included: (1) strategic level (directors and decision makers), (2) technical level (senior technical staff) and (3) operational level (technical staff). 10 questionnaires were distributed in each organization, in all the three cities. A total of 90 respondents were contacted during the interview; of those 86 responded. For the road users, the sample size was calculated based on Eq. (1) [14]:

$$s = \frac{X^2 NP(1-P)}{d^2(N-1) + X^2 P(1-P)}, \tag{1}$$

where

s is the required sample size;

X^2 is the table value of chi-square for the first degree of freedom at the desired confidence level (3.841);

N is the population size;

P is the population proportion (assumed to be 0.50 since this would provide the maximum sample size);

d is the degree of accuracy expressed as a proportion (0.05).

For the three cities, a total of 1,200 road users were contacted, but only 1,100 of those responded to the questionnaires.

3.1. Traffic Flow Theory

In this paper, three-phase traffic theory by Kerner is referred. In this theory, the phases in traffic are consisting of free flow and two congestion phases: synchronized flow and wide moving jam. Forecasting of Traffic Objects (FOTO) model, which identifies traffic phases and tracks synchronized flow, together with Automatische Staudynamik analyse: Automatic Tracking of Moving Jams (ASDA) model are applied to the automatic recognition and tracking of congested spatiotemporal traffic patterns on roads [15].

As inputs, ASDA/FOTO model needs traffic volumes and speeds; the output is the current situation of traffic objects over the detected section. In this paper we are focusing on ATMS and ATIS as main components of the proposed framework. The main requirement of these two components is the real time traffic information. This information is derived from ASDA/FOTO model and then applied to the components. Road users' decision to travel depends on the information disseminated to them using ATIS.

In three phase theory, velocity v , density ρ and flow rate q of vehicles are related by the expression

$$q = \rho v \ . \tag{2}$$

FOTO/ASDA analyses average speeds and flow rates. Traffic phases are identified based on the following rules:

(i) FOTO/ASDA detects synchronized flow, when

$v \leq v_{syn}$;

(ii) FOTO/ASDA detects a wide moving jam, when

$v < v_{jam}$ and $q < q_{jam}$;

(iii) FOTO/ASDA detects free flow, when

$v > v_{syn}$,

where by v and q are average speed and flow rate measured at each time step. The speeds v_{syn} , v_{jam} and the flow rate q_{jam} are model parameters.

4. Results and Discussion

4.1. Field Survey Data Analysis

4.1.1. Roads Management

It has been found in the field survey that traffic flow management is mainly controlled by traffic police officers (42.0%) and traffic lights (36.3%). These responses, as summarized in Table 3, indicate higher percentage compared to other means of traffic management.

Table 3. Responses to applied traffic management procedures

Implemented Procedure	Frequency	Percent
Use of traffic lights	729	36.3%
Use of traffic police officers	844	42.0%
Speed limit signs	168	8.4%
Real-time electronic sign boards	26	1.3%
Radio announcements	100	5.0%
Use of road bumps	143	7.0%

The results also show that there is no automated traffic flow management system currently implemented in Tanzania. However, there is high utilization of electronic devices such as mobile phones, computers, radio and television. These devices can be easily integrated into the transportation systems allowing users' access to the information.

Dissemination of the road status information to the road users is very important because the users would like to have a pre-informed travel. The study found that 82.6% of the respondents from the responsible organizations, agreed to disseminate road information to road users, while only 17.4% of the respondents disagreed.

Different kinds of information disseminated by the road management organizations are presented on Figure 2. Mainly the disseminated information concerns road construction work in progress (39.2%) and closed/fault roads (22.5%). Information concerning traffic congestion and road accidents is provided in less than 20% of cases.

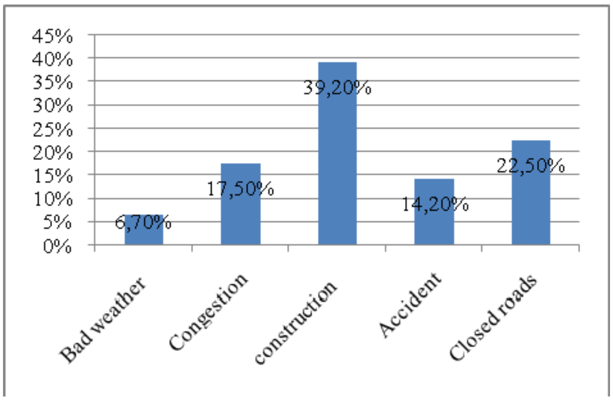

Figure 2. Distribution of different kinds of road information disseminated by road management organizations

As explained in Section 2.1, it is important to consider both recurring and non-recurring situations when disseminating road information to the road users. The study has shown that the disseminated information in the three cities is only concentrating on recurring situations. It is not automated, and the dissemination is done using the wooden signboards. This does not allow the road users to be able to plan for their travel. Therefore a system that can consider both recurring and non-recurring situations in road traffic management is needed.

4.1.2. Road users

It has been noted that road users are experiencing traffic congestion problems during the peak hours when most of them use the roads for either going to the workplace in the morning or going back home in the evening. This statement is supported by the results from three surveyed areas as presented in Table 4. These results show that congestion happens mostly in the morning and evening as per evidenced percentages of 49.3% and 47.2% respectively. This was measured based on the time road users spent to reach a specific destination from a pre-set origin.

Table 4. Distribution of congested periods during the day

Time of the Day	frequency	Percentage
Morning (06:00am – 11:59am)	943	49.3%
Afternoon (12:00 pm – 04:59pm)	66	3.5%
Evening (05:00pm – 08:00pm)	903	47.2%

Regarding possible means by which the road users could access the road information, the respondents indicated that majority of them would be able to receive the information through radio and mobile phones; this is evidenced by 31.4% and 30.9% respectively as indicated in Table 5.

Table 5. Possible means of receiving road information for the road users.

Means	Frequency	Percent
Internet / Website	301	14.7%
Mobile phone	631	30.9%
Radio	641	31.4%
Television	385	18.8%
Visiting information source	85	4.2%

4.2. Components of the Proposed Framework

Figure 3 indicates how components are networked in the proposed automated road information framework for managing Tanzania roads' traffic flow. The framework considers integration of systems, which controls both the traffic demand and supply sides. The road users require both sides information for enabling smooth traffic flow. The central control connects road users to the supply and demand services of the transportation system.

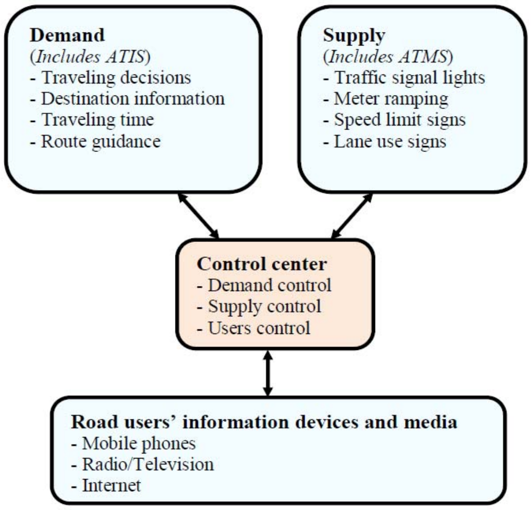

Figure 3. Networked components of the proposed automated road information framework

4.2.1. Demand side systems

The demand side of the proposed automated road information framework is considered in this study as an integration of all systems and services, which deals with road information distribution and management. Pre-trip information helps the road users to plan and travel while knowing the current situation on the road. This helps the users not to waste their time in traffic jams, but instead make an informed decision of using alternative roads with lower or no congestion.

The demand side includes ATIS. Its components provide the following functionality:

(1) *Travelling decisions systems* help travellers decide what roads to choose to avoid congestion

(2) *Destination information systems* give an alert concerning situations occurring on specific destinations

(3) *Travelling time systems* estimate the time needed to travel from a specific origin to destination

(4) *Route guidance systems* decide on the routes to be followed in order to reach a particular destination.

4.2.2. Supply side systems

The supply side includes ATMS. It mainly concentrates on the management of the traffic flow on the roads network. ATMS components provide the following functionality:

(1) *Traffic signal lights,* which control the traffic flow at road junctions using the timed signals for allowing or stopping the traffic flow

(2) *Meter ramping* controls the number of vehicles allowed to enter a highway

(3) *Speed limit signs* assist drivers in keeping within the given speed limit

(4) *Lane use signs* alert drivers on the main lanes the presence of merging vehicles and send appropriate warnings.

4.2.3. Control Centre

This is a central merging unit, where all ITS sub-systems are controlled. Road users are connected to the demand and supply services through the control centre.

4.2.4. Road Users' Information Devices and Media

Road users' information retrieves or requests to the central control are done through communication devices and media such as mobile phones, radio/ television and Internet.

5. Conclusion and Further Work

The study has shown that currently in Tanzania the traffic flow is managed manually while the only implemented road management systems are traffic lights. ITS existing in developed countries cannot be adopted as-is due to their high cost, size and complexity, so the best way is to introduce them gradually, step-by-step. In this paper we have indicated procedure for Tanzania to introduce ITS by effective utilization of available technologies, such as mobile phones and Internet. This study has identified the components that can be integrated into ITS. These include (1) demand side systems such as ATIS; (2) supply side systems such as ATMS; (3) control centre; (4) road users' information devices and media. Future work will involve integrating more services into the supply and demand side, as well as implementation and testing of the prototype of the automated road information system.

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SPATIAL ASPECTS OF EUROPEAN AIRPORTS' PARTIAL FACTOR PRODUCTIVITY

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This research is devoted to discovering of spatial effects in European airports' partial factor productivity (PFP). A set of study PFP indicators includes infrastructural (air transport movements per runway), labour (workload units per employee), and financial (revenue and profit per workload unit) ratios. We utilised a number of appropriate statistical tests (Moran's I., Geary's C., Mantel test, and spatial auto-regression) for revelation of spatial relationships between PFP indicator's values. The tests were separately applied to samples of Spanish (2009–2010) and UK airports (2011–2012) and provided evidences of significant spatial effects in data.

Keywords: airport, partial factor productivity, spatial heterogeneity, spatial dependency, spatial statistics

1. Introduction

During the last two decades estimation of airport efficiency became a point of attention both for practitioners and academic researchers [1], [2]. After legislative liberalisation of EU air transportation market, airport industry began transforming from a historical form of natural monopolies to free market. Efficiency is one of the key requirements for a company acting in a competitive environment, and estimates of airport efficiency become important for airport management, industry regulators, and other stakeholders.

Airport efficiency measurement is not a straightforward task due to a complex structure of airport business. A common definition of efficiency (as a ratio of the useful output to the total input) requires setting of airport's output and inputs, which are very diverse. A set of outputs of an airport includes both technical and financial components. Technical outputs includes served flights (air transport movement, ATM), carried passengers (air passenger movement, PAX), loaded cargo, and others (e.g. served passengers and cargo are usually combined into workload units, WLU). Financial outputs include revenue (split to aeronautical and non-aeronautical), costs, profit (e.g. in form of earnings before interest, taxes, depreciation, and amortization, EBITDA), and others. Inputs of an airport are also very heterogeneous – infrastructural (runways, terminals, surface), labour (employees), financial (expenses).

Partial factor productivity (PFP) indexes are one of the simplest tools of efficiency estimation. A PFP index is generally constructed as a simple ratio of a particular output to a particular input (for example, a yearly number of carried passengers per runway). Some financial ratios (like a ratio of revenue to employment cost) also can be considered as PFP indicators. PFP indexes reflect efficiency of specific aspects of airport activity and don't represent the whole picture. Nevertheless, simplicity of PFP indexes makes them very attractive and frequently used tool. PFP indexes are used in many recent researches of airport efficiency both as a primary([3–5]) and complementary tool.

An extensive development of European airline network during later 1990s [6] has been affecting EU airports' business substantially. Nowadays airports cannot be analysed as independent units, but multi-way interactions between neighbour airports should be taken into account. Significant relationships between characteristics of geographical neighbours are widely acknowledged in the regional science [7], but, to best of our knowledge, there are no systematic studies of spatial effects in airport productivity. Omitting of liable spatial effects can lead to serious problems with analysis and interpretation of estimates of airport efficiency, but then spatial structure of airport industry can provide additional essential information on this topic.

Development of spatial statistics provided excellent tools for analysis of spatial effects in data[8]. There are many developed statistical tests, which allow discovering spatial relationships of different kinds. In this research we apply those tests to discover probable spatial effects between PFP indicators of airport efficiency for a sample of UK and Spanish airports.

2. Airports' Partial Factor Productivity

The research data set includes information about following parameters of UK and Spanish airports:

- Air transport movements (ATM) served by an airport;
- Passengers carried (PAX) by an airport;
- Workload units (WLU) served by an airport;
- Number of airport's terminals;
- Number of airport's runways;
- Airport's revenue;
- Airport's EBITDA;
- Airport's employment costs.

Data on traffic flows (ATM, PAX, WLU) is collected from the Eurostat Database [9] (some observations were supplemented with data from bodies of national statistics). Indicators of airport infrastructure (terminals, runways) are collected from airport official reports.

Collecting values of financial indicators is one of the most problematic areas of airport efficiency research. Firstly, approaches to calculation vary for different countries and even for different airports within the same country. Secondly, values of financial indicators require transformation to be comparable between countries. Finally, some airports can be managed by the same operator, and data is provided to the public in a consolidated form only.

In this research we collected financial data on UK airports directly from their annual reports for 2011 and 2012 years. The UK airports subsample includes 49 airports, and full financial data are available only for 21 of them.

Financial data of Spanish airports was collected from the auditor's report [10], provided by Spanish airports operator (AENA). The Spanish airports subsample includes 48 airports with full financial information about 46 of them. Information for Spanish airports is available for 2009–2010 years only.

Summary statistics of the research sample are presented in the Table 1.

Table 1. Data set descriptive statistics. Source: author's calculations

	ATM, number of flights	**WLU, number of workload units**	**PAX, number of passengers carried**	**Revenue, thousand euro**	**EBITDA, thousand euro**	**Employee cost, thousand euro**
Spanish airports 2009						
Min	1419	6228	6228	165	-6190	817
Median	13129	1040443	1040374	8829	393	4336
Mean	40758	4043217	4041918	40131	14330	7472
Max	427168	47976523	47943507	590369	219501	52176
Spanish airports 2010						
Min	1243	5906	5906	21	-6411	761
Median	12561	980307	980252	8470	21	4522
Mean	40371	4168557	4167065	41384	14925	7620
Max	426941	49837683	49797635	614076	247171	52810
UK airports 2011						
Min	10	57	493	2895	332	2735
Median	10171	413870	413837	63559	26376	14169
Mean	41204	4472293	4467158	224348	98071	44977
Max	476293	69545035	69388105	2456000	1207000	314000
UK airports 2012						
Min	63	250	445	3128	-733	4151
Median	9405	601553	601550	84064	28197	23224
Mean	40662	4503164	4498009	276823	113267	61551
Max	471452	70139072	69983473	2718000	1237000	356000

Selection of UK and Spanish airports for this research is substantiated by significant differences in economic environments and airport industry organisation (including spatial) in these countries.

UK airports are generally concentrated in the North West of the country, in area with higher population density and economic activity. After a set of airport sales and acquisitions, initiated by UK Competition Commission, airports are generally managed by of different operators (M.A.G., Heathrow Airport Ltd., Stansted Airport Ltd., Gatwick Airport Ltd., and London Luton Airport Operations Ltd.). Different operators are supposed to act as competitors, enforcing economic efficiency of each other. Government regulation of UK airports is implemented on the base RPI-X approach[11].

Economic environment of the airport industry in Spain is significantly different. Almost all Spanish airports are managed by one operator (AENA), which obviously has an extensive market power. Spatial patterns of Spanish airport also significantly differ from UK one. Besides the main airport (Madrid Barajas), where traffic flows are considerably explained by economic activity, there are a wide range of airports, generally served tourist flows and located near the seaside (or on islands).

We chose these two subsamples of EU airports to test presence of spatial effects in different economic and spatial settings.

For research purposes a number of PFP indicators were calculated. The final list of indicators includes:

- ATM per runway;
- WLU per employee cost;
- Revenue per WLU;
- Revenue per ATM;
- EBITDA per WLU;
- EBIDTA per revenue.

Summary statistics of PFP indicators' values are presented in the Table 2.

Table 2. Summary of PFP indicators. Source: author's calculations

	ATM per Runway	WLU per Employee Cost	Revenue per WLU	Revenue per ATM	EBITDA per WLU	EBITDA per Revenue
Spanish airports 2009						
Min	1419.00	5.56	4.96	14.59	-270.87	-10.21
Median	12966.00	239.72	9.24	748.07	0.45	0.04
Mean	25158.00	278.85	13.93	648.38	-24.53	-1.26
Max	106792.00	919.51	97.46	1607.52	5.40	0.59
Spanish airports 2010						
Min	1243.00	4.10	5.77	14.64	-343.48	-11.65
Median	12408.00	214.21	9.48	750.40	0.35	0.03
Mean	25145.00	274.80	14.49	663.70	-32.39	-1.32
Max	106735.00	943.72	75.34	1617.43	5.49	1.00
UK airports 2011						
Min	629.50	15.50	2.23	290.10	0.59	0.05
Median	43769.80	324.20	14.59	1417.80	5.60	0.34
Mean	53523.60	307.20	22.07	1679.20	5.62	0.33
Max	158764.30	527.00	152.59	5156.50	17.36	0.67
UK airports 2012						
Min	3634.00	88.64	2.93	383.90	-1.06	-0.06
Median	51045.00	238.05	15.06	1431.80	4.87	0.31
Mean	59291.00	263.54	16.84	1676.40	5.42	0.32
Max	157151.00	513.39	38.75	5765.20	17.64	0.71

Comparison of PFP indicators' values of UK and Spain airports are presented on Figure 1 in a form of box plots.

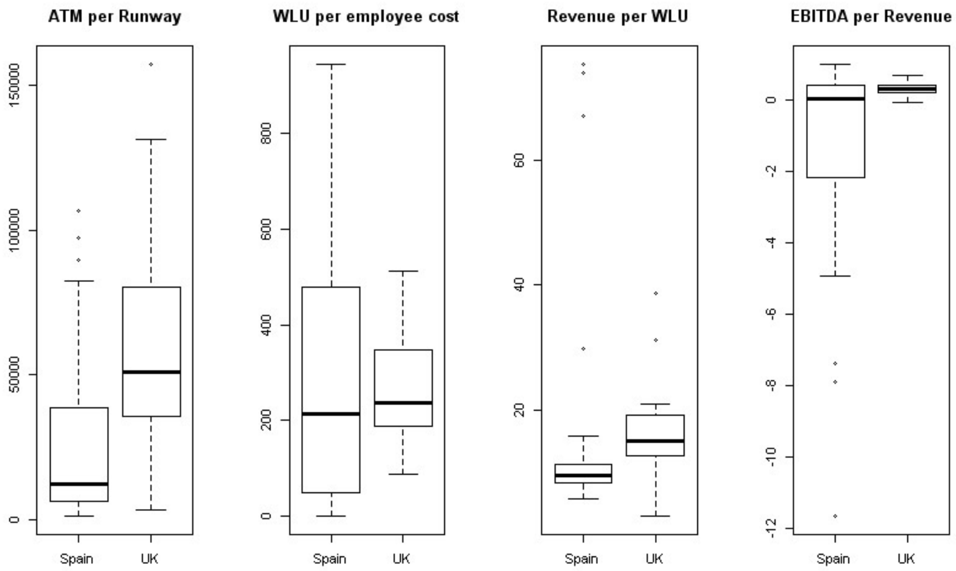

Figure 1. Box plots of UK and Spanish airport PFP indicators. Source: author's calculations

The box plots support our assumption about significant differences in performance of UK and Spanish airports. Loading of airports' infrastructure (ATM per runway) is significantly higher in UK airports; technical performance of employment (WLU per employee cost) is similar in both countries, but has larger variance within Spanish airports subsample. Revenue PFP (revenue per WLU) indicates higher financial performance of UK airports, but with higher variance between them. The most significant difference between two subsamples is indicated by EBIDTA per revenue financial ratio. A significant share of Spanish airports provided negative values for EBITDA. These financial losses are explained by reduction of airline tourists flows after the world crisis, and a high level of dependence between these flows and Spanish airports activity (and economy of Spain in general).

Also we note that there are a set of possible outliers in the sample – a problem to deal with in further statistical analysis.

3. Spatial Effects in Airports' PFP Values

Values of all used PFP indicators are non-uniformly distributed over the geographic space. Patterns of spatial distribution vary between indicators (see Fig.2 for a spatial distribution of revenue per WLU indicator).

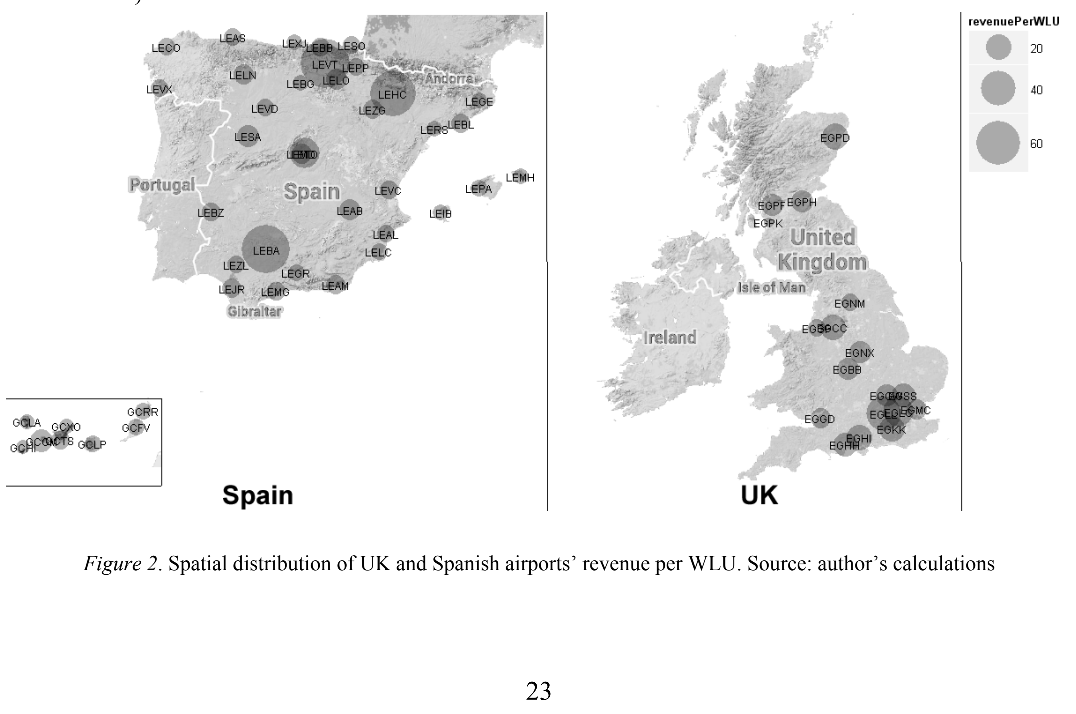

Figure 2. Spatial distribution of UK and Spanish airports' revenue per WLU. Source: author's calculations

We applied the following statistical procedures to discover spatial relationships between values of selected PFP indicators:

- Moran's I test;
- Geary's C test;
- Mantel test;
- Spatial auto-regression.

All used approaches are well-known in spatial data analysis and their formal description can be found in literature (e.g., [12], [13]).

All specified tests require predefined information about spatial structure of research parameters. Generally a proximity of *i* and *j* units are defined by a spatial weight w_{ij}. Specification of spatial weights assumed that units with higher values of spatial weights are more closely related. Conventionally, spatial weights w_{ii} (proximity of a unit with itself) are set to 0. There are a wide range of approaches, which can be used to define spatial weights. For example, spatial weights can be defined as an inverse geographical distance between objects, inverse travel times and costs. In this research we use a simplest form of spatial weights – inverse geographical distances between airports (with a linear distance decay). Realising all shortcomings of this specification, we found it sufficient for the goal of this research – discovering presence of spatial relationships. If spatial effects will be discovered under this specification of spatial weights, their presence will be highly probable under more careful (and complicated) specification.

There are two possible sources of spatial effects widely acknowledged in regional science. The first type of spatial effects (the so-called spatial heterogeneity) is based on factors, common for a geographic area. For airports these factors can include economic activity of a region, population density, weather conditions, and others. These factors are distributed non-uniformly over the space (for example, concentrated economic activity in Great London area or attractiveness of Spanish sea-side and islands as tourist destinations), which affect values of PFP indicators. Spatial heterogeneity usually leads to a positive spatial correlation.

The second type of spatial effects (called spatial dependency) is explained by interrelation between neighbour airports. This relationship can be two-directional – negative (e.g. competition between neighbour airports for traffic flows) or positive (direct or indirect collaboration of neighbour airports). Separation of these two types of spatial effects is a very important practical task, lying outside of this research's scope. All statistical tests we applied to the research samples are designed to discover aggregate spatial effects, which can be a problem in case of different direction of spatial interactions between airports. This fact decreases the power of the tests (increases Type II errors), but doesn't affect their significance. So if statistically significant spatial effects will be discovered, we can conclude their presence, but if spatial effects will be found as not significant, additional research on their structure will be required before a conclusion of their absence.

All 4 subsamples (Spanish airports 2009–2010, and UK airports 2011–2012) have possible outliers – airports, which show significantly different PFP values (according to the box plots above and standard z-scores). We run all tests in two versions – with and without filtering of outliers. Estimation results of spatial test statistics (Moran's I., Geary's C., and spatial auto-regression) with filtered outliers are presented in the Table 3.

Table 3. Results of statistical tests for spatial dependency. Source: author's calculations

	ATM per runway	WLU per employee cost	Revenue per WLU	Revenue per ATM
Spanish airports 2009				
Moran's I	-	-0.262*** (0.006)	0.072** (0.043)	-0.193* (0.055)
Geary's C	1.336*** (0.019)	1.496*** (0.000)	1.258* (0.100)	1.254** (0.016)
SAR	-	-	0.035** (0.013)	-0.031** (0.032)
Spanish airports 2010				
Moran's I	-	-0.257*** (0.007)	0.111*** (0.002)	-0.209** (0.035)
Geary's C	1.306** (0.031)	1.486*** (0.000)	1.471** (0.015)	1.286*** (0.007)
SAR	-	-	0.035*** (0.004)	-0.032** (0.027)

The continuation of Table 3

UK airports 2011				
Moran's I	0.104** (0.012)	0.093** (0.036)	0.156*** (0.002)	0.103*** (0.009)
Geary's C	-	-	-	-
SAR	0.049* (0.062)	-	0.050** (0.031)	0.045* (0.089)
UK airports 2012				
Moran's I	0.067* (0.063)	-	0.083** (0.025)	-
Geary's C	-	-	-	-
SAR	-	-	0.046** (0.045)	-

***, **, * – significant at 1, 5, and 10% level accordingly; insignificant values are excluded (–).

Statistically significant spatial effects are discovered for different PFP indicators and in different subsamples. A sign (direction) of spatial correlation for some PFP indicators is not stable over subsamples.

ATM per runway has a weak negative spatial autocorrelation for Spanish airports' subsamples (according to Geary's C., sensitive to local spatial relationships) and a weak positive value for UK airports (according to global Moran's I. test). Distinction of these results can be explained by different spatial patterns of UK and Spanish airports, but requires additional research for a detailed conclusion.

Technical performance of employment costs (WLU per employee cost) has highly significant negative spatial autocorrelation for Spanish airports (both for Moran's I. and Geary's C. tests). Technically speaking, this result means that stronger neighbour airports (with higher value of WLU per employee cost indicator) negatively affect a value of this indicator in a given airport. These effects present for Spanish airports and absent for UK airport subsamples. Economic interpretation of these negative spatial effects (for example, competition between airports for employment) is also a matter of further research and discussion.

The most consistent results are received for value of revenue per WLU indicator. The indicator's values show significant positive spatial autocorrelation for all 4 subsamples. These results can be explained by spatial heterogeneity (concentration) of economic activity and income both in Spain and UK. Note that Geary's C. tests point negative local spatial dependence.

4. Conclusions

The main goal of this research was to test presence of spatial effects in PFP values of airports. A study set of PFP indicators includes performance values of infrastructure (WLU per runway), employment (WLU per employee cost), revenue (revenue per WLU, revenue per ATM), and profit (EBITDA per WLU, EBIDTA per revenue). We applied a set of statistical tests (Moran's I., Geary's C., and Mantel test, spatial auto-regression) to discover spatial effects in 4 subsamples – Spanish airports in 2009–2010 and UK airports in 2011–2012. Selection of these subsamples is substantiated theoretically by testing of spatial effects presence in different economic and spatial environments and technically by available financial data.

Significant spatial effects were discovered in many cases; a sign of these effects differs between PFP indicators in different countries. These effects have an aggregative nature and can be explained both by spatial heterogeneity and spatial dependency. General statistical tests applied in this study don't allow distinguishing between different types of spatial effects.

Presence of statistically significant spatial effects should be included into consideration in academic and empirical airport benchmarking models. Omitted spatial effects can lead to biased estimates of airports' efficiency and incorrect interpretation of results. This study is a proof of concept; a detailed investigation of spatial effects nature and technical aspects of their estimation is considered by the author as a direction for further research.

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PATTERN-ORIENTED ARCHITECTURE DESIGN OF SOFTWARE FOR LOGISTICS AND TRANSPORT APPLICATIONS

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Software architecture design plays the key role for logistics and transport software engineering. One of the design approaches is to reuse the architectural patterns, which express a fundamental structural organization of software systems and its behaviour. The usage of the proven and tested solutions allows us to increase the software quality and reduce potential risks.

In this paper the technique that allows selecting and evaluating suite of architectural patterns is proposed. It can be used for logistics and transportation software, which is constructed using Multi-tier architecture. The technique allows us to consistently evaluate the impact of specific patterns to software characteristics with a given functionality. Effectiveness and efficiency of the described method is confirmed by a case study.

Keywords: multi-tier architecture, pattern, functional points, coupling and cohesion, logistics and transport software, optimisation, decision

1. Introduction

It's important to construct architecture for logistics and transportation software properly and with the use of best practices, so we need to pay a lot of attention when building software architecture for such systems.

Architectural design provides an understanding of the system organization. Also it creates a framework for the proper representation of a system. The creation of architecture is the first and fundamental step in the software designing. It creates software system representation base that satisfies to the full range of detailed requirements [1, 2, 3].

As long as there is no effective method for the architecture building we should rely on used techniques as well as past experience in that area. One of the common approaches is to use architectural patterns for creation of the software architecture.

Architectural patterns organize the essence of architecture which was used in various software systems. Today the patterns are widely used during the software development process. They help to reuse the knowledge and best practice [4, 5, 6].

Architectural patterns can be seen as a generalized description of best practice. The patterns were tested and proven in a variety of systems and environments, as a result of that, the architectural pattern describe the system organization which has been successful in previous systems.

It's obvious what we need to have some technique that allows selecting the optimal suite of patterns from a number of patterns, also such selection should take into account the specific requirements for the logistics and transport system.

2. Selection of an Optimal Patterns Suite

To select an optimal patterns suite we need to define a model, choose a set of patterns and examine their impact on system characteristics.

2.1. Model definition for selection of an optimal patterns suite

Let's assume that there is a set of patterns which can be separated into groups according to their corresponded functionality. Also we know numerical values of system characteristics which depend on used patterns for the given system. So we need to develop a model which helps us to determine the optimal suite of patterns for logistic and transport system with a given functionality.

Suppose that there is a set of input pattern groups — $\{P_i \mid i = 1, ..., g\}$.

Each group can have different number of patterns, so we can define it as follows:

$$\{P_{ij} \mid i = 1, ..., g;\ j = 1, ..., m_j\},$$

where P_{ij} — i-th pattern from group j, m_j — number of pattern in group j which is a variable number.

Let's assume that from some groups we aren't obligated to select a pattern (this is due to the fact that the selection of some patterns can exclude a whole group of patterns). On the other hand, we can select several patterns from some of the groups.

Thus the input data for our model makes a complete set of patterns for each group, and such set can be represented as a multiset.

For simplicity, we reduce the multiset to a uniform set of patterns $\{P_1,...,P_n\}$ where we use special restrictions for partitioning to the groups.

At the output, the model with the specified constrains should select the optimal combination of patterns which should be used for software development.

The produced restrictions should exclude those combinations of patterns that are logically inconsistent or interchangeable. In addition, some restriction should allow selection of multiple patterns from specified group of patterns.

The objective function for finding the optimal suite of pattern defined as follows:

$$W = f(P_1)\times x_1 + f(P_2)\times x_2 + \ldots + f\left(P_n\right)\times x_n \to min\ ,$$

where:

$f(P_i)$ — function which reflects a numerical changes of the system characteristics depending on used pattern P_i;

x_i — variable which indicates the usage of the *i-th* pattern.

It's obviously that the integrality constrain should be applied for a given variable x_i:

$$x_i = \{0,\ 1 \big| i = 1, 2, ..., n\},$$

where n — number of patterns in the one dimensional set which were transformed from the original multiset of patterns.

To indicate the fact that we can select only one pattern from the group, let's introduce the following restriction:

$$\sum_{i=start}^{i=end} x_i = 1,$$

where

start, end — the start and end indices of patterns in a group.

To take in to account that the selection of the *j-th* pattern excludes patterns from a different group, we use the following restrictions:

$$x_j + \sum_{i=start}^{i=end} x_i = 1.$$

If we can select any number of patterns from the group we specify the following constrains:

$$\sum_{i=start}^{i=end} x_i \le (end - start + 1).$$

On the base of the mentioned definitions and assumptions, we obtain the classical integer programming problem where we need to find the optimal solution.

We should pay special attention for choosing the function $f(P_i)$. Such selection should be based on the requirements for a software system.

2.2. The choice of patterns for Multi-tier architecture

According to the statistics on architecture types used for transportation and logistics systems, which are represented in the global ISBSG database, most of these systems are based on client-server architecture model [7]. Nowadays the most used subtype of such architecture is Multi-tier architecture. Therefore, for our case study we select a set of patterns used for transportation and logistics systems' Multi-tier architectures.

There are patterns that can be divided into the following groups:

- **Domain Logic Patterns**. *Transaction Script*, *Domain Model*, *Table Module*, *Service Layer*.
- **Data Source Architectural Patterns**. *Table Data Gateway*, *Row Data Gateway*, *Active Record*, *Data Mapper*.
- **Object-Relational Behavioural Patterns**. *Unit of Work*, *Identity Map, Lazy Load*.
- **Web Presentation Patterns**. *Model View Controller*, *Page Controller*, *Front Controller*, *Template View*, *Transform View*, *Two-Step View*, *Application Controller*.
- **Distribution Patterns**. *Remote Facade*, *Data Transfer Object*.
- **Offline Concurrency Patterns**. *Optimistic Offline Lock*, *Pessimistic Offline Lock*, *Coarse Grained Lock*, *Implicit Lock*.

Fowler in [6] indicates the steps how to select a pattern from multiple groups taking into account the requirements for the software. The problem of his approach is that it isn't formalized enough. Also he indicates the relationship between groups of patterns, for example, it's allowed to choice only one pattern from multiple groups, etc. This selection technique can be represented as follows:

1. Initially we have to select the base pattern for *Domain Layer* implementation; such pattern should be selected from *Domain Logic Patterns* group.
2. Next, we need to select a pattern for *Data Source Layer* implementation (it should be selected from Data *Source Architectural Patterns* group). This choice also depends on the first step (for example, when we select *Domain Model* on the first step we can choose only *Data Mapper* on this step). Together with patterns from *Data Source Layer* we can use *Object-Relational Behavioural Patterns*, *Concurrency Patterns* and some other groups of the patterns.
3. In the final step we do select a pattern from *Presentation Layer* (from *Web Presentation Patterns* group).
4. Furthermore, in addition to the selected patterns, we select other patterns from the remaining groups.

Such dependencies are illustrated on Figure 1.

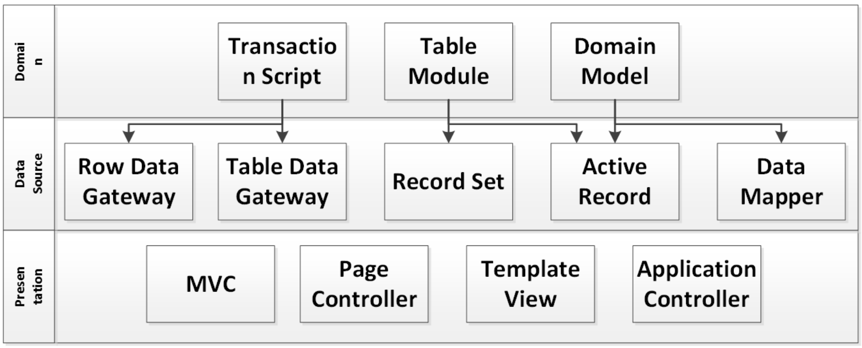

Figure 1. Pattern group's dependencies

As a result of this technique application, we have obtained the list of patterns listed in Table 1 which we use in our case study.

Table 1. List of patterns used for the case study

Group of patterns	Pattern	Pattern's notation
Domain Logic Patterns	Transaction Script	P_{11}
	Domain Model	P_{12}
	Table Module	P_{13}
	Service Layer	P_{14}
Data Source Architectural Patterns	Table Data Gateway	P_{21}
	Row Data Gateway	P_{22}
	Active Record	P_{23}
	Data Mapper	P_{24}
Web Presentation Patterns	Model View Controller	P_{31}
	Page Controller	P_{32}
	Template View	P_{33}
	Application Controller	P_{34}
Distribution Patterns	Remote Facade	P_{41}
	Data Transfer Object	P_{42}
Offline Concurrency Patterns	Optimistic Offline Lock	P_{51}
	Pessimistic Offline Lock	P_{52}
	Coarse Grained Lock	P_{53}
	Implicit Lock	P_{54}

2.3. The patterns usage restrictions

When we build the model we should take into account the following corresponding constraints:

- restrictions which are applied on pattern groups;
- restrictions applied on patterns compatibility.

For the considered patterns we have the following limitations:

1. We can choose only one pattern from the first three groups as well as from *Offline Concurrency Patterns*;
2. We can choose any patterns from the remaining groups (each pattern can be selected only one time);
3. If *Transaction Script* is selected from the first group we can choose *Table Data Gateway* or *Row Data Gateway* from the second group;
4. If *Table Module* is selected from the first group we are allowed to choose only *Table Data Gateway* from the second one;
5. If *Domain Model* is selected from the first group we can choose *Active Record* or *Data Mapper* from the second group.

2.4. Mathematical model building

Applying the above results we obtain the following objective function:

$$W = f(P_{11})\times x_1 + f(P_{12})\times x_2 + f(P_{13})\times x_3 + f(P_{14})\times x_4 + f(P_{21})\times x_5 + f(P_{22})\times x_6 + f(P_{23})\times x_7 +$$
$$+ f(P_{24})\times x_8 + f(P_{31})\times x_9 + f(P_{32})\times x_{10} + f(P_{33})\times x_{11} + f(P_{34})\times x_{12} + f(P_{41})\times x_{13} + f(P_{42})\times x_{14} +$$
$$+ f(P_{51})\times x_{15} + f(P_{52})\times x_{16} + f(P_{53})\times x_{17} + f(P_{54})\times x_{18} \rightarrow min$$

with the following restrictions which came from the patterns usage limitations:

a) We can choose only one pattern from the first three groups:

$$x_1 + x_2 + x_3 + x_4 = 1,$$
$$x_5 + x_6 + x_7 + x_8 = 1,$$
$$x_9 + x_{10} + x_{11} + x_{12} = 1,$$
$$x_{15} + x_{16} + x_{17} + x_{18} = 1.$$

b) We can choose any patterns from the remaining groups (or not to choose a pattern at all):

$$x_{13} \le 1,$$
$$x_{14} \le 1,$$
$$x_{13} + x_{14} \le 2.$$

c) If *Transaction Script* is selected from the first group we can choose *Table Data Gateway* or *Row Data Gateway* from the second group:

$$x_1 + x_7 + x_8 \le 1.$$

d) If *Table Module* is selected from the first group we are allowed to choose only *Table Data Gateway* from the second one:

$$x_3 + x_6 + x_7 + x_8 \le 1.$$

e) If *Domain Model* is selected from the first group we can choose *Active Record* or *Data Mapper* from the second group:

$$x_2 + x_5 + x_6 \le 1.$$

2.5. Selecting of $f(P_i)$ function

Using the above listed patterns we need to build a model for selecting the optimal suite of patterns; where the requirement for the software should be considered. For doing so we must determine the patterns impact on specific system characteristics. This means that we need to define the function $f(P_i)$.

During the architecture design stage we can operate the system requirements as well as make indirect measures of some system characteristics, so one of the most suitable metric for consideration is functional point (*FP*) metric, which indirectly measures software and the cost of its development. The value of this metric reflects the functional complexity of the product [1, 8]. In addition to the complexity metric, inner (cohesion) and outer (coupling) relations should be measured [1].

The selection of a pattern affects the overall system characteristics. Therefore, it is necessary that the metric for such system also reflects this influence. In our case the metric should reflect a change of *FP* metric, coupling and cohesion when we use a specific pattern.

In order to combine these three metrics let's use criterion of efficiency described in the publication [9]. As long as the calculation of the proposed metrics for coupling and cohesion is quite complicated we replace these metrics with alternatives which are supported by many tools for metric calculation. For example, we can use Coupling between Object Classes (*CBO*) and Lack of Cohesion of Methods (*LCOM*) metrics from Chidamber & Kemerer's metric suite [1, 10].

CBO and *LCOM* metrics are calculated for specific classes, but we need to evaluate the entire system. So it's necessary to make these metrics applicable for a group of classes. We define Coupling between Object Classes Factor (*CBOF*) and Lack of Cohesion of Methods Factor (*LCOMF*) metrics which could be used in our criterion of efficiency.

CBOF metric is defined as the arithmetic mean of the normalized values of *CBO* in the system (the value of this factor varies from 0 to 1):

$$CBOF = \frac{\sum_{i=1}^{N} \begin{Bmatrix} CBO_i\,, & if\ CBO_i < T_{CBO} \\ T_{CBO}\,, & else \end{Bmatrix}}{T_{CBO} \times N},$$

where

CBO — Coupling Between Object metric from Chidamber & Kemerer's metric suite;

T_{CBO} — threshold which cut down very large values of *CBO*. Such limitation is necessary as the theoretical value of *CBO* may vary indefinitely;

N — number of classes in the system.

The definition of *LCOMF* metric is similar, i.e. *LCOMF* defined as the arithmetic mean of the normalized values of *LCOM* in the system:

$$LCOMF = \frac{\sum_{i=1}^{N} \begin{Bmatrix} LCOM_i\,, & if\ LCOM_i < T_{LCOM} \\ T_{LCOM}\,, & else \end{Bmatrix}}{T_{LCOM} \times N},$$

where

LCOM — Lack Of Cohesion metric from Chidamber & Kemerer'c metric suite;

T_{LCOM} — threshold which cut down very large values of *LCOM*. Such limitation is necessary as the theoretical value of *LCOM* may vary indefinitely;

N — number of classes in the system.

Thus a metric of *original architecture efficiency K* defined as:

$$K = \frac{\alpha_1 \times FP}{(1-\alpha_2 \times CBOF) \times (1-\alpha_3 \times LCOMF)},$$

where

α_1, α_2, α_3 — weight coefficients of efficiency indicators;

FP — the value of functional points;

CBOF — the value of Coupling between Object Classes Factor;

LCOMF — the values of Lack of Cohesion of Methods Factor.

Based on listed above, our function which reflects numerical changes of the system characteristics depending on used pattern P_i defined as follows:

$$f(P_i) = \frac{K'_{P_i}}{K},$$

where

K — the metric of architecture efficiency;

K'_{Pi} — metric of partial *pattern-architecture efficiency* (if pattern P_i is used for software development).

Therefore metric of partial *pattern-architecture efficiency K'* defined as:

$$K'_{Pi} = \frac{\alpha_1 \times FP'_{Pi}}{(1-\alpha_2 \times CBOF'_{Pi}) \times (1-\alpha_3 \times LCOMF'_{Pi})},$$

where

FP'_{Pi} — the value of functional points if pattern P_i is used for software development;

$CBOF'_{Pi}$ — the value of *CBOF* if pattern P_i is used for software development;

$LCOMF'_{Pi}$ — the value of *LCOMF* if pattern P_i is used for software development.

FP' is a modification of the original *FP* and it is calculated as follows:

$$FP' = UFP \times \left(0.65 + 0.01 \times \sum_{i=1}^{14} CF_i\right) + P_{FP},$$

where

UFP — Unadjusted Function Point count;

P_{FP} — the value of functional points for specified pattern implementation;

and CF_i defined as follows:

$$CF_i = \begin{cases} 5, & \text{if } c_i \times F_i > 5; \\ round(c_i \times F_i), & otherwise, \end{cases}$$

where

CF_i — adjusted degree of influence coefficient which corresponds to F_i used in original *FP*;

c_i — pattern influence on *i*-th system's characteristic.

For getting c_i values, first, we need to evaluate a characteristic using the following scale:

- 1 — use of a pattern reduces the significance of a system characteristic;
- 2 — use of a pattern slightly reduces the significance of a system characteristic;
- 3 — no influence;
- 4 — use of a pattern slightly actualises a system characteristic;
- 5 — use of a pattern actualises a system characteristic (i.e. we must pay more attention to this characteristic when applying this pattern).

Next, these values are converted into c_i using scale conversion rule presented in Table 2.

Table 2. Characteristic's evaluation scale correspondence to c_i value

Score As	c_i
1	½
2	⅔
3	1
4	1½
5	2

CBOF' metric is modification of *CBOF* and it is defined as:

$$CBOF' = CBOF + \alpha \times CBOF \times (c_{Pi} - 3),$$

where

CBOF — the original value of Coupling between Object Classes Factor;

α — weight coefficient;

c_{Pi} — pattern influence on *CBOF* which is evaluated using scale similar to c_i and varies from 1 to 5.

LCOMF' metric is defined as:

$$LCOMF' = LCOMF + \alpha \times LCOMF \times \left(c_{Pi} - 3\right),$$

where

$LCOMF$ — the original value of Lack of Cohesion of Methods Factor;
α — weight coefficient;
c_{Pi} — pattern influence on $LCOMF$ which is evaluated using scale similar to c_i and varies from 1 to 5.

2.6. Obtaining values of indicators and coefficients

Prior the case study it's necessary to obtain the values of several indicators and coefficients. In our case, most of these values were obtained empirically.

Based on our requirements let's define the weight coefficient vector for metric of efficiency with the help of an expert evaluation. The weight coefficients of efficiency indicators for the functional points, coupling and cohesion factors are defined as:

$\alpha_1 = 0.5$, $\alpha_2 = 0.3$, $\alpha_3 = 0.2$.

So, functional points have the greatest weighting coefficient of efficiency indicator and *LCOMF* the least.

For obtaining *FP'* values we need to get the patterns influence coefficients. The Table 3 represents the patterns influence coefficients c_i with the given requirements. These figures are empirical and intended to demonstrate the proposed technique, so these values might be not optimal. To obtain more precise values of the coefficients, the values should be calibrated on a number of projects. These values also might be different for the software of the other domains, i.e. not transportation or logistics. In addition, the values might vary for systems with other requirements.

Table 3. Values of pattern influence coefficients c_i used in *FP* metric

Group of patterns	Pattern	Pattern's notation	c_1	c_2	c_3	c_5	c_8	c_9	c_{10}	c_{13}	c_{14}
Domain Logic Patterns	Transaction Script	P_{11}	3	4	1	2	4	2	5	4	5
	Domain Model	P_{12}	2	2	4	3	1	4	1	2	1
	Table Module	P_{13}	3	4	3	3	3	3	4	3	4
	Service Layer	P_{14}	2	1	3	2	2	3	2	2	2
Data Source Architectural Patterns	Table Data Gateway	P_{21}	2	3	2	3	3	2	4	3	3
	Row Data Gateway	P_{22}	3	4	2	2	4	3	5	4	4
	Active Record	P_{23}	3	3	3	3	3	3	2	2	3
	Data Mapper	P_{24}	2	2	4	2	2	4	1	2	2
Web Presentation Patterns	Model View Controller	P_{31}	4	2	3	2	3	3	2	2	3
	Page Controller	P_{32}	2	3	3	3	2	2	3	2	2
	Template View	P_{33}	4	3	2	2	4	3	3	2	2
	Application Controller	P_{34}	2	4	2	4	3	2	4	3	3
Distribution Patterns	Remote Facade	P_{41}	4	3	3	2	3	3	2	3	3
	Data Transfer Object	P_{42}	4	2	3	3	3	3	3	2	2
Offline Concurrency Patterns	Optimistic Offline Lock	P_{51}	4	2	2	2	4	3	3	3	3
	Pessimistic Offline Lock	P_{52}	3	3	4	4	2	3	3	3	3
	Coarse Grained Lock	P_{53}	3	3	3	3	3	3	3	3	3
	Implicit Lock	P_{54}	2	3	4	4	2	4	3	3	3

The coefficients c_i listed in the table have the following meanings:

- c_1 — pattern influence coefficient on system characteristic "Data Communications";
- c_2 — pattern influence coefficient on system characteristic "Distributed Data Processing";
- c_3 — pattern influence coefficient on system characteristic "Performance";
- c_5 — pattern influence coefficient on system characteristic "Transaction Rate";

- c_8 — pattern influence coefficient on system characteristic "Online Update";
- c_9 — pattern influence coefficient on system characteristic "Complex Processing";
- c_{10} — pattern influence coefficient on system characteristic "Reusability";
- c_{13} — pattern influence coefficient on system characteristic "Multiple Sites";
- c_{14} — pattern influence coefficient on system characteristic "Facilitate Change".

We consider only these system characteristics, since the described patterns do not affect other characteristics of the system, i.e. the pattern influence for them is 3.

To obtain the values of *FP′* we also need to determine the value of *FP* which is required for each pattern implementation. The empirically estimated values are shown in Table 4.

In addition to this we also need to evaluate the patterns impact on *CBOF* and *LCOM* values, so we need to obtain values of pattern influence coefficients c_{CBOF} and c_{LCOMF}. The values of pattern influence coefficients are listed in Table 4.

Table 4. Values of *FP* required for the patterns implementation and pattern influence coefficients

Pattern's notation	***FP***	c_{CBOF}	c_{LCOMF}
P_{11}	0	4	4
P_{12}	20	2	1
P_{13}	10	3	3
P_{14}	30	2	2
P_{21}	0	3	3
P_{22}	0	4	4
P_{23}	10	3	3
P_{24}	20	2	4
P_{31}	20	4	2
P_{32}	10	3	4
P_{33}	10	3	2
P_{34}	0	2	3
P_{41}	10	4	3
P_{42}	10	3	3
P_{51}	20	3	3
P_{52}	10	3	3
P_{53}	30	3	3
P_{54}	0	3	3

With the help of expert evaluation define the weighting coefficient used in for *CBOF* and *LCOMF* metrics as:

$$\alpha = 0.1.$$

After analysing all the values of *CBO* and *LCOM* for the considered programs the threshold values for metrics *CBOF* and *LCOMF* defined as:

$$T_{CBO} = 100;$$
$$T_{LCOM} = 1000.$$

3. Case Study

For the proposed technique validation let's perform a series of experiments using real logistics and transportation software systems.

3.1. Selection of logistics and transportation systems for case study

Based on the statistics on architecture types used for transportation and logistics systems in the global ISBSG database we can see that the majority of these applications based on multi-tier architecture.

For the case study we selected open source applications which are the most representative according to our requirements. We take into account the application domain (only logistics and transportation systems), popularity (number of download, ratio), commercial support, etc. As a result, the systems showed in Table 5 were selected.

Table 5. Considered software systems

	Name	URL	Programming language
1	Dolibarr ERP&CRM	http://www.dolibarr.org/	PHP
2	ERPNext	https://erpnext.com/	Python
3	Bookyt	http://bookyt.ch/	Ruby
4	koalixcrm	http://www.koalix.org/	Python
5	Vtiger CRM	https://www.vtiger.com/crm/	PHP
6	Openbravo ERP	http://www.openbravo.com/	Java
7	ADempiere ERP	http://www.adempiere.com/	Java
8	GO Gestionale Open	http://www.gestionaleopen.org/	Delphi
9	Libertya ERP	http://www.libertya.org/	Java
10	favesERP	http://www.faves-erp.com/	PHP

In addition we considered a simulation model for decision-making and risk analysis when releasing a new product on the market [11]. The model is developed in AnyLogic simulation tool using Java programming language. As long as architecture of this simulation model is different from the client-server, we will assume that we have to reengineer the program using client-server architecture (since this is requirement for our technique). Thus, we considered eleven logistics and transportation software systems.

3.2. Obtaining values of the metrics

As long as we take already existing products we use the conversion table to obtain *FP* values from *LOC* measures [1]. The obtained *FP* values from *LOC* measures showed in Table 6.

Table 6. The values of *LOC* and *FP* metrics

	Name	*LOC*	*FP*
1	Dolibarr ERP&CRM	371947	11623
2	ERPNext	59959	2855
3	Bookyt	11902	566
4	koalixcrm	5166	246
5	Vtiger CRM	284272	8883
6	Openbravo ERP	637924	7974
7	ADempiere ERP	1138181	14227
8	GO Gestionale Open	739622	25504
9	Libertya ERP	1217125	15214
10	favesERP	744134	23254
11	Simulation Model	17548	219

The presence of program source code allows us to obtain the values of *CBO* and *LCOM* for all available classes, which are used to obtain values of *CBOF* and *LCOMF* for each system (Table 7).

Table 7. The obtained values of *CBOF* and *LCOMF*

	Name	*CBOF*	*LCOMF*
1	Dolibarr ERP&CRM	0.10	0.38
2	ERPNext	0.05	0.10
3	Bookyt	0.06	0.23
4	koalixcrm	0.07	0.17
5	Vtiger CRM	0.12	0.61
6	Openbravo ERP	0.08	0.13
7	ADempiere ERP	0.07	0.22
8	GO Gestionale Open	0.02	0.43
9	Libertya ERP	0.09	0.10
10	favesERP	0.10	0.53
11	Simulation Model	0.02	0.16

System characteristics for *FP* metric were determined based on the requirements and existing implementation of the software systems (Table 8).

Table 8. The values of the system characteristics used for *FP* metric

	Dolibarr ERP& CRM	ERPNext	Bookyt	koalixcrm	Vtiger CRM	Openbravo ERP	ADempiere ERP	GO Gestionale Open	Libertya ERP	favesERP	Simulation Model
F_1	2	3	5	3	2	3	4	3	3	2	1
F_2	1	2	1	2	3	3	2	2	4	1	0
F_3	2	5	2	2	2	3	4	3	3	1	2
F_4	3	4	2	3	2	3	3	2	4	3	1
F_5	2	3	2	2	3	4	2	3	3	2	0
F_6	2	3	3	2	4	3	2	4	3	3	1
F_7	3	4	2	3	2	4	3	3	4	3	2
F_8	2	2	4	3	3	3	3	4	2	3	3
F_9	1	4	2	2	1	3	4	2	3	1	5
F_{10}	4	3	4	4	3	5	2	3	4	3	2
F_{11}	2	3	2	3	3	3	3	3	4	3	1
F_{12}	2	2	3	3	2	4	4	3	3	3	2
F_{13}	3	2	3	4	3	4	4	3	5	3	1
F_{14}	2	2	4	3	2	3	2	3	3	2	3

3.3. The solution of integer programming problems

Having value of UFP, F_i, $CBOF$ and $LCOMF$ we can obtain the objective functions for each considered system.

For example, let's find the optimal pattern suite for Dolibarr ERP&CRM system. To do so, we need first of all to obtain the objective function, which requires values of $f(P_i)$; and to get the value of the function it's required to have values K and K'_{Pi}.

When obtaining K'_{Pi} we must also define FP', $CBOF'$ and $LCOMF'$ values. Such calculations for P_{11} are given below:

$$FP'_{P_{11}} = UFP \times \left(0.65 + 0.01 \times \sum_{i=1}^{14} CF_i \right) + P_{11} = 12107 \times (0.65 + 0.01 \times 0.36) + 0 = 12228,$$

$$CBOF'_{P_{11}} = CBOF + \alpha \times CBOF \times \left(c_{P_{11}} - 3 \right) = 0.07 + 0.1 \times 0.07 \times (4 - 3) = 0.077,$$

$$LCOMF'_{P_{11}} = LCOMF + \alpha \times LCOMF \times \left(c_{P_{11}} - 3 \right) = 0.22 + 0.1 \times 0.22 \times (4 - 3) = 0.242.$$

Thus the values of K and K'_{P11} for pattern P_{11} are evaluated as follows:

$$K = \frac{\alpha_1 \times FP}{(1 - \alpha_2 \times CBOF) \times (1 - \alpha_3 \times LCOMF)} = \frac{0.5 \times 11622}{(1 - 0.3 \times 0.07) \times (1 - 0.2 \times 0.22)} = 6209,$$

$$K'_{P_{11}} = \frac{\alpha_1 \times FP'_{P_{11}}}{(1 - \alpha_2 \times CBOF'_{P_{11}}) \times (1 - \alpha_3 \times LCOMF'_{P_{11}})} = \frac{0.5 \times 12228}{(1 - 0.3 \times 0.077) \times (1 - 0.2 \times 0.242)} = 6576.$$

Having K and K'_{P11} values, we can obtain value of function, which reflects numerical changes of the system characteristics when pattern P_{11} is used:

$$f(P_{11}) = \frac{K'_{P_{11}}}{K} = \frac{6576}{6209} = 1.06\,.$$

After we get all $f(P_i)$ values using the same approach, we can obtain the objective function for Dolibarr ERP/CRM:

$$W = 1.06x_1 + 0.902x_2 + 1.032x_3 + 0.907x_4 + 0.99x_5 + 1.08x_6 + 0.98x_7 + 0.969x_8 + 0.961x_9 + 0.987x_{10} +$$
$$+ 0.953x_{11} + 1.003x_{12} + 0.998x_{13} + 0.99x_{14} + 1.001x_{15} + 1.011x_{16} + 1.002x_{17} + 1.01x_{18} \rightarrow min.$$

Once the objective function is defined as well as all restrictions, we can find the optimal solution for this integer programming problem. The optimal solution for Dolibarr ERP&CRM system is formed by the following values of the variables: $x_2 = x_8 = x_{11} = x_{13} = x_{14} = x_{15} = 1$. Thus, the optimal pattern suite for our system consists of the following patterns: P_{12}, P_{24}, P_{33}, P_{41}, P_{42}, P_{51}.

In the same way we obtained optimal pattern suites for other systems (Table 9).

Table 9. Optimal pattern suites

Group	Dolibarr ERP& CRM	ERPNext	Bookyt	koalixcrm	Vtiger CRM	Openbravo ERP	ADempiere ERP	GO Gestionale Open	Libertya ERP	favesERP	Simulation Model
1	P_{12}	P_{14}	P_{12}	P_{12}	P_{14}	P_{14}	P_{14}	P_{12}	P_{14}	P_{12}	P_{11}
2	P_{24}	P_{24}	P_{23}	P_{23}	P_{24}	P_{21}	P_{24}	P_{23}	P_{24}	P_{23}	P_{21}
3	P_{33}	P_{32}	P_{33}	P_{33}	P_{31}	P_{31}	P_{31}	P_{33}	P_{32}	P_{31}	P_{34}
4	P_{41}	-	P_{41}	-	P_{41}	P_{41}	P_{41}	-	-	-	-
	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}	P_{42}
5	P_{51}	P_{51}	P_{54}	P_{54}	P_{51}	P_{53}	P_{51}	P_{51}	P_{51}	P_{53}	P_{54}

The distribution of the considered patterns is illustrated on Figure 2.

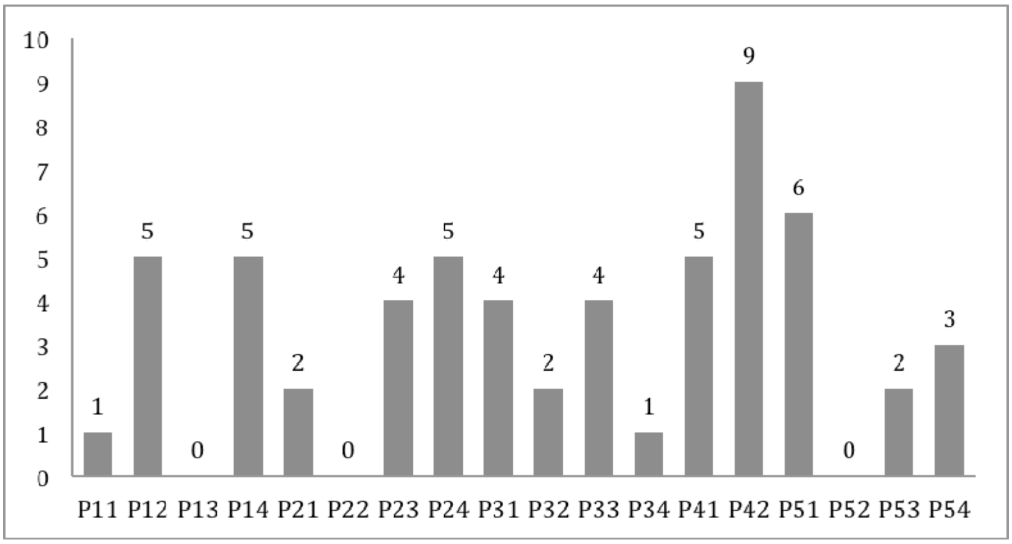

Figure 2. Distribution of the considered patterns

From these results we can conclude that the most frequently used patterns from the first group are Domain Model and Service Layer. From the second: Active Record and Data Mapper, which is logical since there are restrictions on pattern usage combinations from the first and second groups. In the third group the most frequently used patterns are Model View Controller and Template View. Results showed that the use of Data Transfer Object pattern is reasonable for the most of cases; and Remote Facade pattern is noticeably less used. The most preferred pattern for considered systems from the last group is Optimistic Offline Lock.

3.4. Results and analysis

For the optimal pattern suites (which are obtained as a result of solving integer programming problems) for considered software systems we can obtain pattern-architecture efficiency metric K'. Before that we need to find average values of CF_i, P_{FP}, c_{CBOF} and c_{LCOMF}. The results of obtained pattern-architecture efficiency metric K' for considered systems are shown in Table 10.

Table 10. The optimal pattern suite impact on pattern-architecture efficiency metric

	Name	*K*	*K′*	*ΔK=K-K′*	*ΔK%*
1	Dolibarr ERP&CRM	6310	6092	218	3.45%
2	ERPNext	1513	1487	26	1.72%
3	Bookyt	336	356	-20	-5.95%
4	koalixcrm	141	157	-16	-11.35%
5	Vtiger CRM	4625	4495	130	2.81%
6	Openbravo ERP	4334	4346	-12	-0.28%
7	ADempiere ERP	7532	7305	227	3.01%
8	GO Gestionale Open	15992	15086	906	5.67%
9	Libertya ERP	8417	8015	402	4.78%
10	favesERP	14107	13466	641	4.54%
11	Simulation Model	115	118	-3	-2.61%

Figure 3 shows the relation of original architecture efficiency (*K*) and pattern-architecture efficiency metric (*K′*) for all considered systems. Ideally the value of pattern-architecture efficiency metric (*K′*) must be lower than original architecture efficiency (*K*), since the values of coupling and cohesion should became better and the value of *FP* should be reduced.

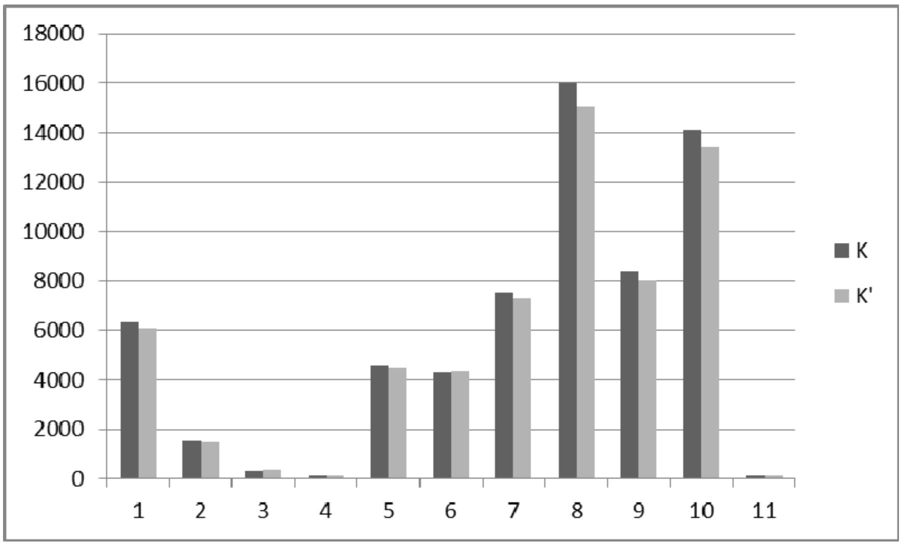

Figure 3. The values of architecture efficiency K and K' for the considered systems

Percentage difference between values of the original architecture efficiency and pattern-architecture efficiency metric is illustrated on Figure 4.

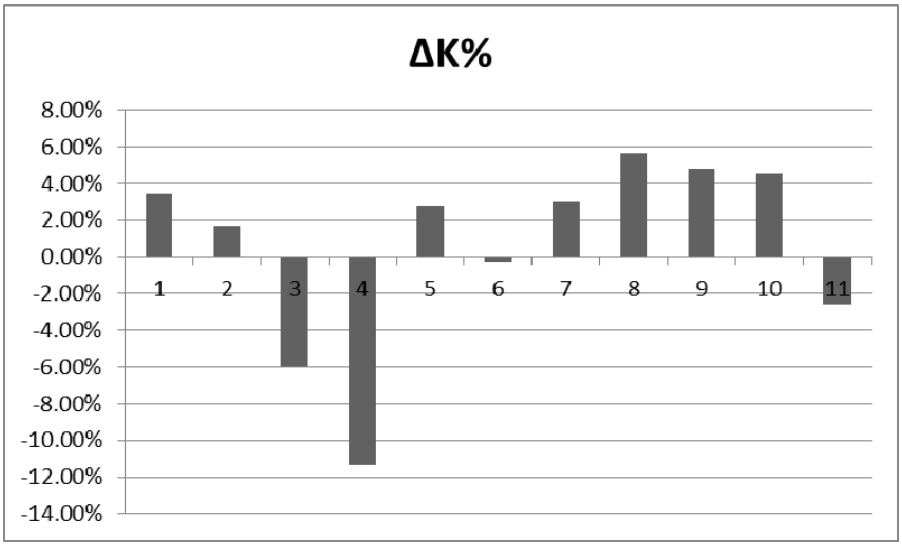

Figure 4. The changes of the architecture efficiency metric in percent

We can see that for lager system the architecture efficiency in improved by 2–5%, in contrast, it's deteriorated for small systems.

The results indicate that the use of optimal pattern suite isn't appropriate for each considered system. It can be noted that for systems where the value of *FP* is smaller than 1000 (i.e. small and medium software systems) the application of the proposed technique doesn't improve the architecture efficiency. The reason is quite simple: the pattern implementation itself requires reasonable effort which is costly for small systems, so such usage for small systems is overkill. For software system Openbravo ERP (number 6) we can conclude that the original figures were already close to the optimal. In addition, it is also possible that expert estimates of some indicators and coefficients aren't calibrated reasonably well.

To complete the picture we also need to discuss the changes in *FP* when using an optimal patterns suite.

Table 11. The changes of *FP* when using the optimal patterns suite

	Name	FP	FP'	ΔFP	ΔFP%
1	Dolibarr ERP&CRM	11623	11228	395	3.40%
2	ERPNext	2855	2837	18	0.63%
3	Bookyt	566	626	-60	-10.60%
4	koalixcrm	246	281	-35	-14.23%
5	Vtiger CRM	8883	8638	245	2.76%
6	Openbravo ERP	7974	8003	-29	-0.36%
7	ADempiere ERP	14227	13678	549	3.86%
8	GO Gestionale Open	25504	24611	893	3.50%
9	Libertya ERP	15214	15163	51	0.34%
10	favesERP	23254	22632	622	2.67%
11	Simulation Model	219	224	-5	-2.28%

Figure 5 shows the values of function pointer of original architecture (*FP*) and functional points of pattern-architecture (*FP'*) for each considered system.

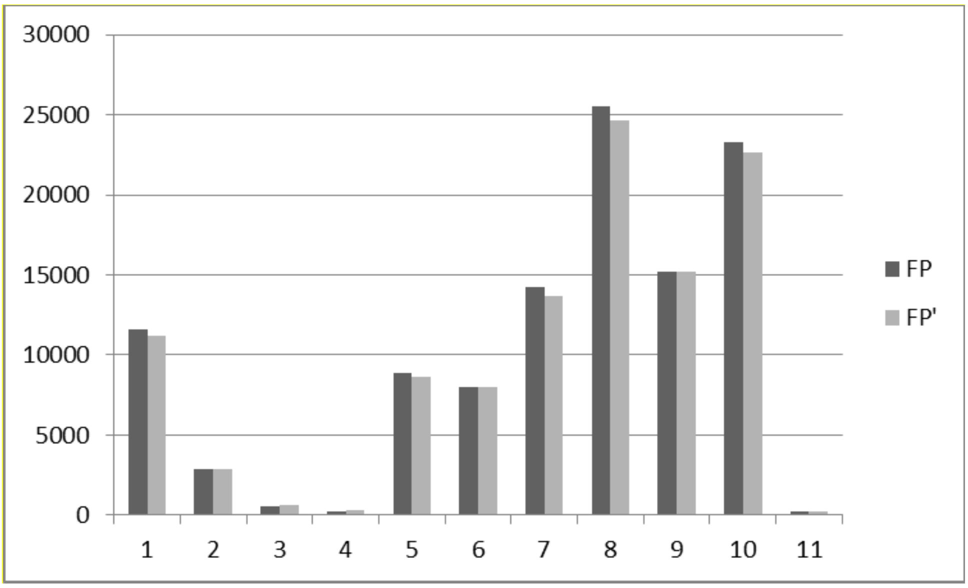

Figure 5. FP and FP' for the considered software systems

Percentage difference between the function pointer of original architecture and the functional points of pattern-architecture is illustrated on Figure 6.

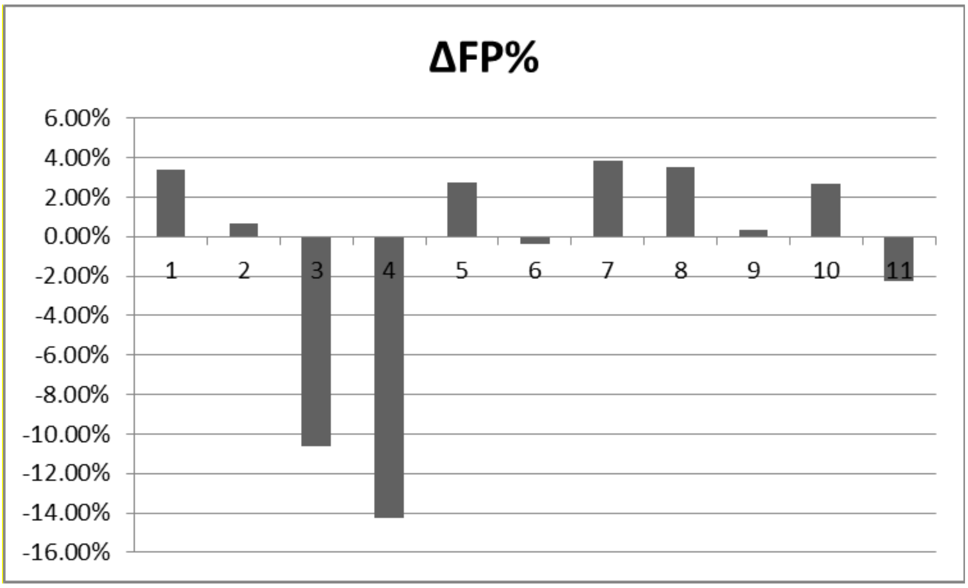

Figure 6. The changes of the functional point metric in percent

As we can see the picture is slightly different compared to *ΔK%*. It could be explained by the fact that *FP* is only a part of the architecture efficiency metric.

4. Conclusions

In this paper the technique that allows selecting the optimal suite of architectural patterns for logistics and transportation software is proposed. This selection technique is reduced to the classical problem of integer programming where the optimal solution should be found.

As long as the most of the modern logistics and transportation systems are based on Multi-tier architecture, we've considered a set of patterns that are suitable for its creation. The proposed technique is applied for this set of architectural patterns.

Pattern-architecture efficiency metric is used to measure patterns' numerical impact on a system. This metric is based on functional point (*FP*) metric, which indirectly measures the functional complexity of software. In addition to the complexity metric, inner (cohesion) and outer (coupling) relations are taken into account.

For the case study we've selected eleven logistics and transportation software systems. The objective functions are defined for the case study as well as constrains on the use of specific architectural patterns. The resulting solution reflects the optimal suites of architectural patterns that are suitable for the development of the systems with the specified requirements.

The quantitative study is given to evaluate the changes in the architectural decisions efficiency by applying the selected suite of patterns. The analysis of case study results allowed determining the appropriateness of this technique application, which is dependent on the functional size of the software system.

According to that, the results indicate that the proposed technique is applicable for solving problems of optimal architectural patterns' suite selection when we construct architecture for the large-scale logistics and transportation systems.

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A SELF-POWERED WIRELESS SENSOR NETWORK FOR DYNAMIC MANAGEMENT OF QUEUES AT TRAFFIC LIGHTS

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The dynamic management of traffic light cycles is a really interesting research issue considering modern technologies, which can be used in order to optimise road junctions and then improve living conditions of the roads. Wireless sensor networks represent the most suitable technology, as they are easy to deploy and manage. The data relating to road traffic flows can be detected by the sensor network and then processed through the innovative approach, proposed in this work, in order to determine the right green times at traffic lights. Although wireless sensor networks are characterized by very low consumption devices, the continuous information transmission reduces the life cycle of the whole network. To this end, the proposed architecture provides a technique to power the sensor nodes based on piezoelectric materials, which allow producing potential energy taking advantage of the vibration produced by the passage of vehicles on the road.

Keywords: Wireless Sensor Networks; Piezoelectric; Traffic Lights; Intelligent Transportation Systems

1. Introduction

During last years, research in the field of Intelligent Transportation Systems (ITS) is focusing on new techniques and technologies to be used in efficient and automated transportation systems aimed to save energy. The issue of self-powered ITS control systems has become particularly important, especially in areas, which use wireless technologies, where there are neither wired connections nor power-lines. Therefore the main aim is to find new solutions in order to power devices through the cars' movement detected by the same devices placed on the road. Most of traffic lights are characterized by "fixed cycles". As a consequence, green times are not balanced because a static management mechanism does not take into account the length of the queues. The waiting times, therefore, increase proportionally with the increase of the queue length. WSN are perfect for vehicular traffic flows detection [1] thanks to their ease of use and management. Moreover, they can be used anywhere regardless of the environmental conditions and support a high degree of energy saving. Energy harvesting applications have been developed in order to produce electric energy from vehicular, train or pedestrian traffic or from environmental vibration in general. However, there are no applications, which can develop energy from roads usable by themselves (by ITS systems). Several kinds of energy sources have been investigated by researchers. The vibration sources are the most ubiquitous and can be found everywhere [2-3]. The mechanical energy can substitute solar energy, sometimes with more potentiality. In both cases, the objective regards a greater amount of energy generated as efficiently and economically as possible. Energy harvesting, using smart materials such as piezoelectric, has been studied and developed in different scenarios [4]. Recently, an effective way for the electricity production is represented by the recovery of mechanical energy produced by vibrations. This can be obtained through the use of piezoelectric materials, taking advantage from piezoelectric effect that consists of the generation of an electric field produced by a mechanical deformation of the same piezoelectric material. During last years, this technology has been applied in several fields, like self-powered wireless sensor networks for data acquisition and processing [5]. This paper presents an innovative technique for the dynamic management of traffic light cycles based on real-time information detected by self-powered sensor nodes placed along road sections. The main aim of the approach is to reduce the waiting time in traffic light queues. The paper is organized as follow: section 2 proposes main literature related works while section 3 describes the network architecture. Section 4 proposes the experimental test-bed showing, at the same time, obtained results. Section 5 summarizes the paper and reports conclusion and possible future works.

2. Related Works

The work here proposed shows a dynamic management technique of traffic light cycles based on information gathered by self-powered sensors. To better understand the state of art, this section will be divided into two sub-parts. The first part will show the main techniques of road traffic information processing through the wireless sensor networks, while the second will show the main literature works dealing with energy harvesting.

2.1. Wireless Sensor Networks for road traffic management

WSNs can be used in several fields like home automation [6-7], health [8], biometric systems [9], industry [10-11] and road monitoring. Considering the increasing use of this technology, the researchers aim to develop architectures and techniques in order to obtain a high-performance use of WSNs in several and complex fields like Intelligent Transportation Systems. In [12], the traffic flows scheduling is managed using an algorithm called TRED (Traffic Random Early Detection) based on the RED algorithm, the most common Active Queue Management (AQM) algorithm [13] used to manage congestions in computer networks. The algorithm evaluates the saturation of a road, based on some measured information like the average length of vehicles, and forwards the cars along alternative ways in case of congestion detected. In [14], the authors describe an architecture in which sensor nodes detect road information and send them to the nearest Intersection Control Agent (ICA), which determines the flow model of the intersection depending on sensors data. In [15] and [16] the authors proposed an adaptive traffic light control algorithm that adjusts both the sequence and length of traffic lights in accordance with the real time traffic detected. This algorithm considers a number of traffic factors such as traffic volume, waiting time, vehicle density, etc., to determine green light sequence and the optimal green light duration. In [17] the authors propose an algorithm for vehicle detection, using magneto resistive sensors, in order to control road traffic. The system developed is able to detect vehicles and then to calculate the appropriate duration of traffic light cycles. In [18] the authors propose a fuzzy method in order to dynamically adjust the delay of green light according to the real-time vehicle flows detected by a wireless sensor network. The system mainly consists of four wireless sensor nodes (SN) and a traffic light control node (CN). Each sensor node contains one magnetic sensor, which is used to detect vehicles by measuring the change in the Earth's magnetic field caused by the presence of a vehicle near the sensor.

2.2. Energy harvesting in ITS systems

Energy demand in recent years is increasing: the reserves of fossil fuels are running out. Moreover the increasing cost of energy and related environmental problems have led researchers to investigate new energy sources [19]. Some innovative mechanisms have been studied to reduce greenhouse gas emissions by increasing energy efficiency of existing systems. Concrete solutions have been introduced for saving and energy recovery in both civil and industrial environments [20-21]. Some works discuss the energy harvesting using piezoelectric materials. Today, the energy recovery techniques using environmental mechanical vibrations are very interesting research issues. Recently, in the station of Shibuya (Tokyo), was installed an energy collection system that uses a piezoelectric transducer [22], under a proposal of the East Japan Railway Company. Also the society "Innowatech", in recent years, has proposed some applications based on piezoelectric stack transducer for the energy production taking advantage of vehicular traffic [22]. Some researchers have recently shown a mechanical device for energy harvesting using piezoelectric bimorph bender transducer, which can recover energy from road, pedestrian and rail traffic. The innovation of this technique is represented by the use of piezoelectric bender devices and by an innovative configuration to transfer mechanical vibrations of the main box to the piezoelectric transducer [23].

3. System Architecture and Requirements

Intelligent Transportation Systems (ITS) are characterized by several and smart embedded devices in order to support road monitoring and decision making. The proposed architecture consists, as said, in a self-powered wireless sensor network able to measure road traffic flows and determine the traffic-light cycles based on the queue length near the road junction. Main devices used are:

- Self-powered Reduced Function Devices (RFDs), each one with a magnetic sensor in order to evaluate the earth's magnetic field distortion caused by the presence of cars;
- Self-powered Full Function Devices (FFDs), which gather information received by their RFDs and forward them to the First Pan Coordinator (FPC);
- Self-powered First Pan Coordinator. It is the network coordinator. Its main aim is to gather all information in order to make decisions for a better management of the network.

In the proposed architecture, the FPC is characterized by three modules:

- a data gathering module;
- an IEEE 802.15.4 [24] module;
- a decision making module, which main aim is to dynamically adjust traffic light cycles based on information detected by the whole network.

The proposed architecture is really complex and this is the reason why, this section has been divided into sub-sections. In sub-section 3.1 we will analyse the dynamic traffic light manager explaining how the proposed algorithm works; sub-section 3.2 will show self-power technologies used for IEEE 802.15.4 sensors while in last sub-section will be explained the electrical circuit model and the battery charging system.

3.1. Dynamic traffic light manager

In order to explain our approach, let we consider a general road intersection (Figure 1), where R_A is the road section containing traffic lights 2 and 4 and R_B is the road containing traffic lights 1 and 3.

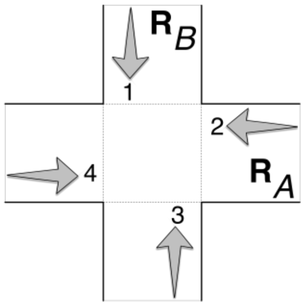

Figure 1. Road intersection

Our goal is to realize a decision making algorithm in order to dynamically evaluate traffic light cycles based on the queue length. Figure 2 shows a road section of length $\boldsymbol{L}$ subdivided into smaller sub-sections, each one of length $\boldsymbol{l_i}$. Each subsection $\boldsymbol{l_i}$ is monitored by a node in order to detect vehicles presence through a magnetic sensor, which measures the earth's magnetic field distortion due to the presence of ferrous objects (vehicles) [25]. Each node communicates with other nodes and the FPC according to the IEEE 802.15.4 [24] standard protocol. The algorithm evaluates the traffic light cycles considering three fundamental parameters

- the road section length ($\boldsymbol{L}$) to be monitored;
- the sub-sections length ($\boldsymbol{l_i}$);
- approximate crossing speed ($\boldsymbol{v}$).

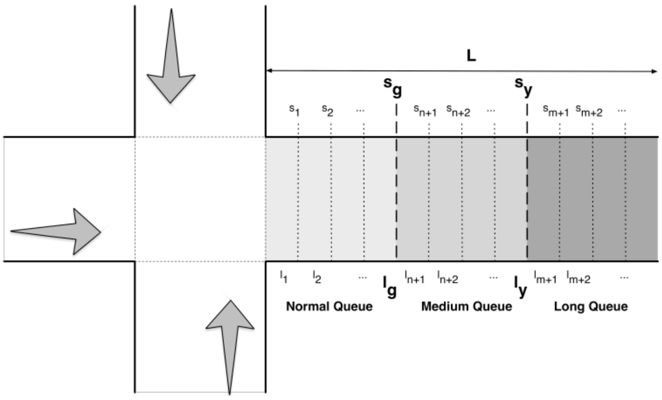

Figure 2. Monitored road section by the wireless sensor network

The average length of a car is between 3.5 and 5 meters even if there are vehicles both longer and shorter. As a consequence, the length of each subsection (**l_i**) can be between 4 and 8 meters. According to IEEE 802.15.4, the RFD nodes can be placed every 12 meters while the FFD nodes every 60 meters, while the FPC can be placed at the end of the road near the traffic light. In a small city, the average speed (**v**), of a vehicle crossing a traffic light intersection is, at about, 15 Km/h. Let consider **l_g** the maximum value within, which a traffic light queue is considered normal. **L_y** is the maximum value within, which the queue can be considered medium. Above this value, the queue is considered long. The number of subsections is calculated as **L/l_i** while the **l_g** value can be determined by the following relation (1):

$$l_g = \frac{L}{l_i} + 1. \tag{1}$$

The **l_y** value, therefore, is calculated through equation (2):

$$l_y = \frac{L}{l_i} - l_g . \tag{2}$$

In case of vehicles detection in a section **$l_i < l_g$** the traffic light works under standard conditions, with period **T_i**, green time **t_g** and yellow time **t_y**. In case of vehicles detection, in a section **$l_g < l_i < l_y$**, the estimated queue length is considered *medium*. Instead, **$l_i > l_y$**, is the condition of *long* queue.
The crossing time of a single subsection can be easily calculated through equation (3):

$$t_i = \frac{l_i}{v}, \tag{3}$$

where **l_i** represents the *i-th* section length while **v** is the approximate crossing speed of the considered road section. In case of medium or long queue, the green time is re-calculated taking into account the estimated queue length. Considering the subdivision of the sub-sections shown on Figure 3, the standard green time **t_g** and the real-time green time **t_{grt}** can be calculated through the following relations (4).

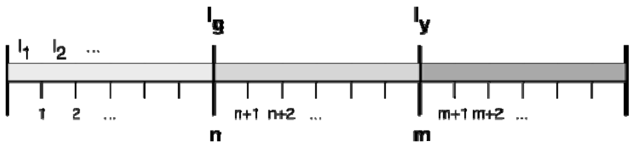

Figure 3. Sections subdivision

$$\begin{cases} t_g & if\ l_i \le l_g \\ t_{grt} = t_g + \dfrac{l_j + l}{v} & if\ l_g < l_j \le l_y\ with\ j = n+1, n+2, \dots, m \\ t_{grt} = t_g + \dfrac{l_k + l}{v} & if\ l_k > l_y\ with\ k = m+1, m+2, \dots . \end{cases} \tag{4}$$

The terms *$(l_k + l)/v$* and *$(l_j + l)/v$* represent, each one, ratios between space and speed. In other words, they represent values of time to be added to the standard green time **t_g** in case of increasing queue in order to slightly increase the total green time and to allow the real-time management of the traffic light according to the queue behaviour. Clearly, the road with the longest green time has higher priority. Each traffic light independently calculates, during each period, its green time in order to determine its priority level according to the following relations (5):

$$\begin{matrix} p_i = t_g & if\ l_i < l_g & with\ i = 1,2,3,4 \\ p_i = t_{grt} & if\ l_i > l_g & with\ i = 1,2,3,4 \end{matrix}, \tag{5}$$

where p_i is the priority of the *i-th* traffic light. At the end of the period T_i, the algorithm determines the road with the highest priority determining, which traffic light needs more green time.

The priority of each road is calculated through equation (6) and (7), as the average of the individual priorities calculated by each traffic light adding a Δ value (which can be positive or negative). This Δ value is then divided by two in order to avoid that the priority, acquired by a road, can be too high (excessive green times).

$$P_{R_A} = \frac{(p_1 + p_3)}{2} + \frac{\Delta_A}{2}, \tag{6}$$

$$P_{R_B} = \frac{(p_2 + p_4)}{2} + \frac{\Delta_B}{2}. \tag{7}$$

3.2. Self-power technologies used for IEEE 802.15.4 sensors

The adopted configuration, used to supply power sensor nodes, is characterized by a bimorph piezoelectric transducer rectangular clamped to an extreme [26]. This converter consists of two piezoelectric outside (active layers) and a thin metal plate in the middle section (passive layer). The passive layer performs both the connection between the two active layers, and the distancing of the same from the neutral axis, resulting in increased deformations and electric potential [26]. The converter is made of lead zirconate titanium (PZT-5A), a material with a high efficiency and flexibility in the charge production (Table 1).

Table 1. Electromechanical Parameters

Symbol	Quantity	Value	Units
lp	Piezo length	40,0	mm
wp	Piezo width	16,0	mm
tp	Piezo thickness	0,80	mm
tpu	Upper patch thickness	0,36	mm
tpl	Lower patch thickness	0,36	mm
tsp	Steel plate thickness	0,08	mm
ρp	Piezo density	7.750,0	kg/m^3
ρs	Steel density	7.850,0	kg/m^3
Ep	PiezoYoung's modulus	$6,6\ 10^{10}$	Pa
Es	Steel Young's modulus	$20,5\ 10^{10}$	Pa
K	Elastic constant	30,8	N/mm

Two different polarization configurations have been analysed: parallel and serial. The first involves the construction of three electrical connections for the extraction of the converted charge, while the latter requires the adoption of two electrical connections. Figure 4 shows the constructive characteristics of the two configurations adopted, with the electric connections and the polarization directions [27].

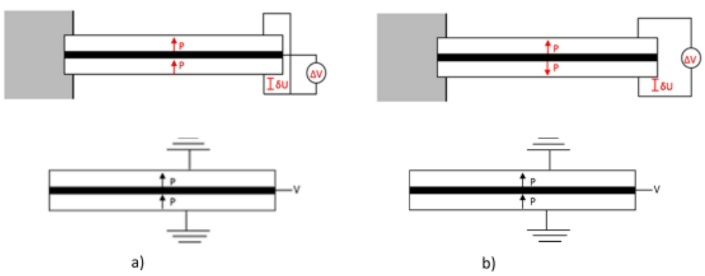

Figure 4. Bimorph piezoelectric. a) Parallel configuration (left); b)serial configuration (right)

The Energy Harvesting device will be installed within a road cavity in order to catch the external vibrations, caused by the passage of vehicles, in order to transform them in energy [28]. The system consists of a piezoelectric transducer bonded on the surface of the steel beam subjected to external impulse [29]. The beam undergoes a tensile stress and a compression producing, as a consequence, electrical potential [23] (Figure 5). This potential difference, generated at the extreme poles through an electrical circuit, is converted into electrical energy.

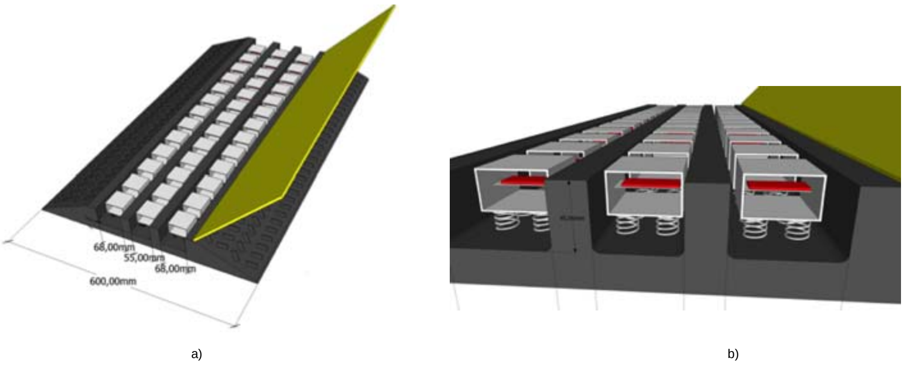

Figure 5. a) Road cavity; b) Detail of the Energy Harvesting installed inside the speed bump with cavity

3.3. Model electrical circuit and battery charging system

The energy obtained from the piezoelectric transducers, is not directly usable by electronic devices, because of random variations of power and voltage over the time. It is therefore necessary, a suitable circuit for the management of gathered power. The effort made to obtain efficient transducers, may be lost without the use of adapters able to convert signals of a few millivolts, or even less, without substantial losses. These circuits also consume energy and must be able to shut down when the source of energy is not enough to power the device in order to avoid unnecessary energy consumption. When the energy increases, the power management circuit must be able to automatically switch-on (self-starting). The simplicity of the circuital technology depends on the availability of space and energy. The general structure of the power manager circuit can be divided in three interfaces, as shown on Figure 6 a). The output voltage of a piezoelectric generator is generally characterized by a pseudo-periodic behaviour and assumes positive and negative values alternately. Therefore, it is always necessary to a rectifier circuit [30].

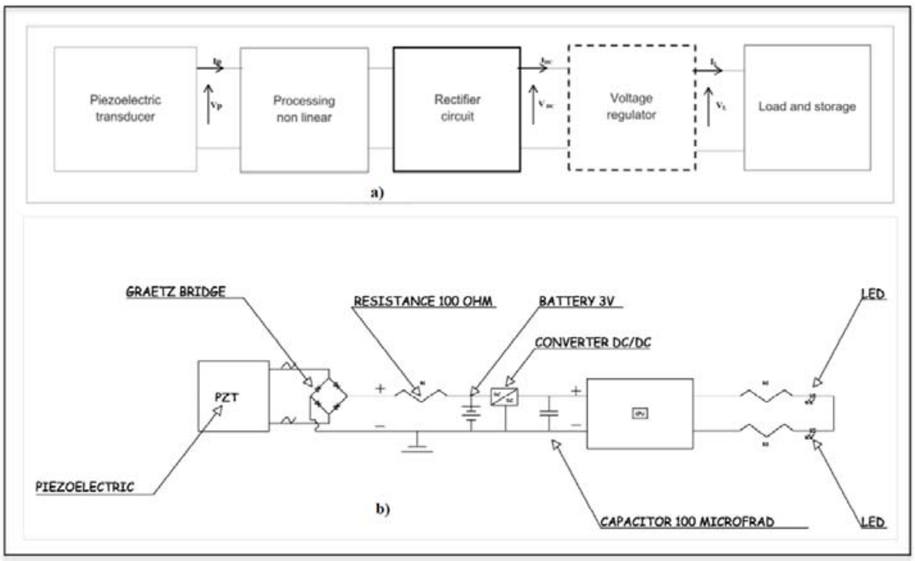

Figure 6. a) General structure of a power manager circuit [32];
b) Energy harvester simulation model including mechanical part and bridge diode rectifier power conditioning

The circuit uses a small piezoelectric transducer in order to convert the mechanical vibration into an AC voltage source that is powered inside the bridge rectifier internal of the LTC3588. It can recover small vibrations and generate system power instead of using traditional batteries. The LTC3588-1 is a very low quiescent current power supply, specially designed for energy recovery applications or step-down at low current. It can directly interface with a piezoelectric transducer or another AC power source, rectifying the voltage waveform and storing the energy recovered in an external storage capacitor. At the same time it dissipates the energy in excess through an internal derivation regulator, maintaining an output voltage regulated through a "buck" regulator with high efficiency. The full-wave bridge rectifier inside the LTC3588-1 is accessible from two differential inputs, PZ1 and PZ2, which rectify the AC inputs. The rectified output is stored in a capacitor to the VIN pin and can be used as an energy reserve for the "buck" converter. The low loss bridge rectifier has a total voltage drop of about 400 mV with typical piezoelectric currents, which are normally equal to about 10μA. This bridge is able to conduct currents up to 50 mA. The "buck" regulator is enabled as soon as an enough voltage is available on VIN in order to produce a regulated output. The "buck" regulator uses an algorithm for hysteretic voltage in order to control the output through the internal feedback of the detection pin VOUT. The "buck" converter loads an output converter through an inductor to a value slightly higher than the regulation point. To this end, the current inductor is increased to 260 mA through an internal PMOS switch and then decreased to 0 mA through an internal NMOS switch. In this way, the energy is efficiently supplied to the output capacitor. This hysteretic method reduces losses associated with FET switching and holds low the output loads. In the switching process, the "buck" converter provides at least 100 mA of average load current. On Figure 6 b) it is graphically represented the realized circuit that manages the output AC current from the piezoelectric transducer [31]. The AC standard is the simplest form of power conditioning and directly connects a resistive load between the two electrodes of the considered transducer. The DC standard rectifies the output transducer, through a full bridge diode rectifier, and connects a resistive load in parallel with a storage capacitor at the output of the rectifier.

4. Performance Evaluation

To better understand how the proposed system has been evaluated, even this section has been divided into two sub-sections. The first one deals with the performance obtained using the dynamic traffic light manager compared to fixed traffic light cycles. In section 4.2 instead will be shown simulation results related to the piezoelectric device for sensors' charge.

4.1. Traffic lights manager evaluation

Our approach has been proved in a normal track crossroad. The simulations have been carried out both in case of fixed and dynamic traffic light cycle. Performance has been evaluated considering that up to 80 vehicles may approach each traffic light. In other words, up to 160 vehicles can be measured on each road. In both cases, the reference cycle was 60 seconds and measurements have been gathered for 60 cycles (1 hour). Figures 7 and 8 show the number of vehicles measured in Road A in case of Fixed Cycle and Dynamic Cycle respectively. The Figure 7 shows how, in case of fixed-cycle, sensors detect on average 23.08 vehicles/minute in transit. Of these, just 10.48 are disposed.

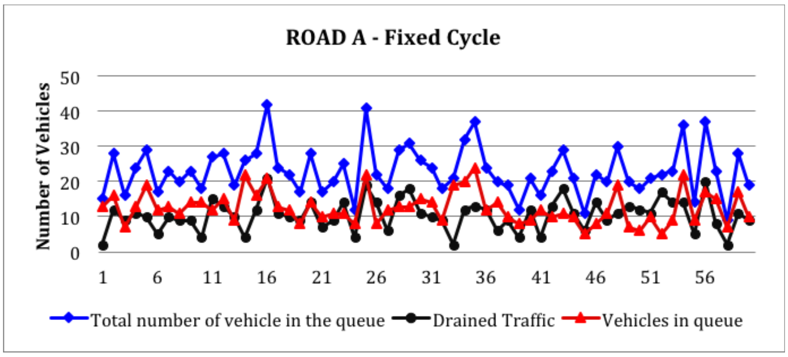

Figure 7. Road A – measures obtained with fixed-cycle

On the contrary, the Figure 8 shows that, in case of dynamic-cycle, on average 20.98 vehicles/minute are disposed, about the 91% of total vehicles transited.

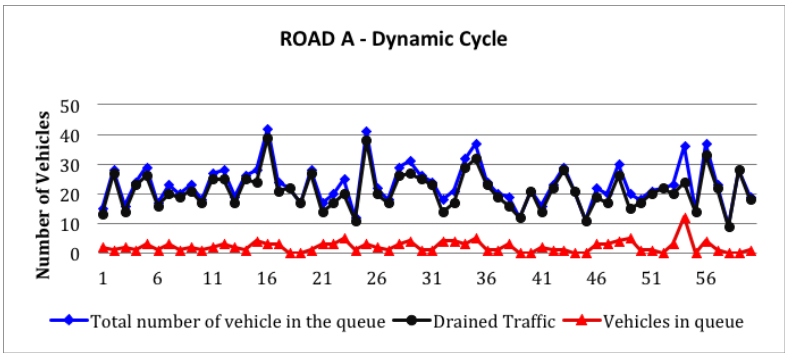

Figure 8. Road A – measures obtained with fixed-cycle

The Figure 9 shows measurements carried out on road B in case of fixed-cycle. In this case, sensors detect on average 21.4 vehicles/min in transit. Of these, just 10.53 are disposed.

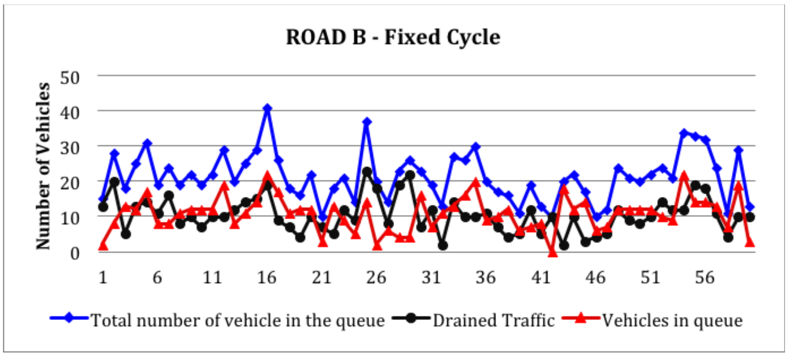

Figure 9. Road B – measures obtained with dynamic-cycle

In case of dynamic-cycle, as shown on Figure 10, on average 10.6 vehicle/minute are drained (about 87% respect to the total number of vehicles transited).

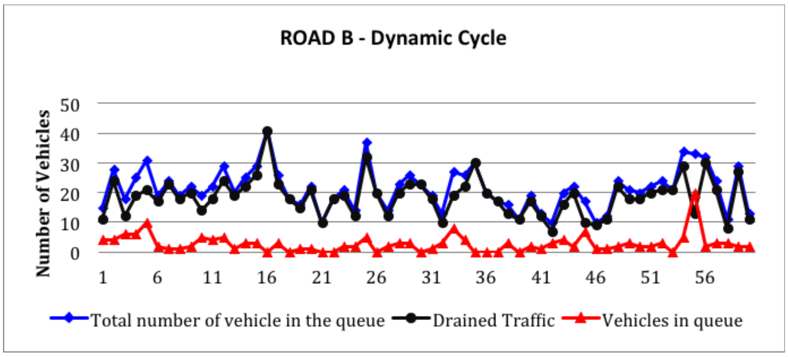

Figure 10. Road B – measures obtained with dynamic-cycle

4.2. Numerical simulations

Two different simulations have been conducted to evaluate the response variation, both in terms of electric potential and electric power generated by electromechanical coupling. The analysis has been conducted through the development of some 3D numerical models using the FEM code "COMSOL MULTIPHYSICS 4.2" [33] and "QUCS 0.0.16"[34] for the electromechanic coupling and the simulation respectively. The FEM model consists of a free tetrahedric mesh made by 14.658 solid elements (90.514 degree of freedom). Firstly, a static analysis was made by applying a displacement imposed to the upper surface of the box, of 10 mm (Figure 6). Then, two dynamical studies were made with and without the circuit respectively. The numerical simulation was performed taking in considerations two different piezo's polarization configurations, [35] with the main aim to evaluate how the model's response changes by changing the polarization direction and resistive load applied [26]. The simulation results show how the increasing of the R2 resistance value (from 100 ohm to 20.000 ohm) produces a more stable load voltage over the time, both for the serial and the parallel configuration (Figure 11). More in detail, in the serial configuration the load voltage varies from 0,0 V to 10,0 V while in the parallel configuration values varies from 0,0 V to 6,0 V as shown on Figure 12.

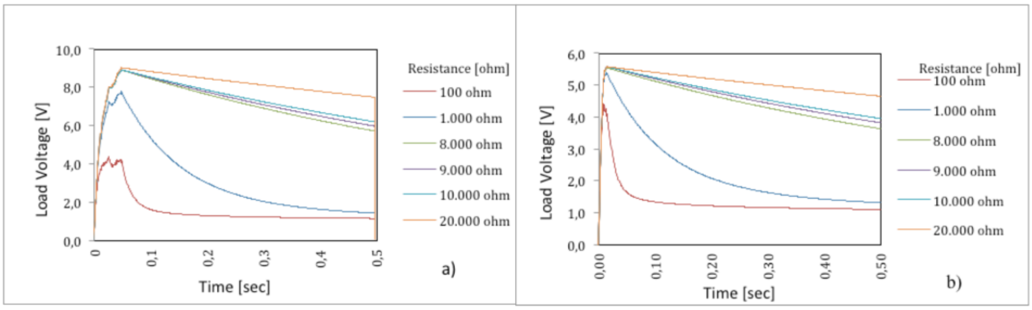

Figure 11. Load Voltage vs Time plotting for different resistance R2 values: a) Serial configuration; b) Parallel configuration

By comparing the peak voltages measured using the parallel and serial polarization respectively as shown in Table 2, it is possible to verify how the serial configuration produces little better performance than the parallel configuration as shown on Figure 12.

Table 2. Average voltage and power harvested from the system vs. load resistance

Serial Configuration	**R load**	[Ω]	1,00E+02	1,00E+03	8,00E+03	9,00E+03	1,00E+04	2,00E+04
	Vm	[V]	0,25	2,20	5,80	6,01	6,20	7,03
	P	[mW]	0,65	4,84	4,21	4,01	3,84	2,47
Parallel Configuration	**R load**	[Ω]	1,00E+02	1,00E+03	8,00E+03	9,00E+03	1,00E+04	2,00E+04
	Vm	[V]	0,35	2,25	4,49	4,66	5,05	5,45
	P	[mW]	1,13	5,06	2,52	2,33	2,17	1,28

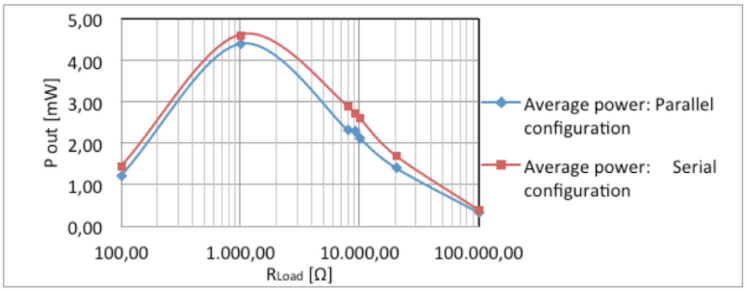

*Figure 12.*Comparison between the average electrical powers harvested from the system depending from the load Resistance

5. Conclusions

The wireless sensor networks are used in several applications, as mentioned above, for several features. The possibility to use real-time information to dynamically manipulate the traffic light cycles is a key aspect of intelligent transportation systems. At the same time, however, the sensor devices are battery powered and, after their normal duration (dependent on the use) must be replaced. In this paper a novel technique for the dynamic management of traffic lights to reduce queues has been presented. This technique is based on information provided by a wireless sensor network powered by energy harvesting devices inserted within a road cavity in order to catch the external vibrations, caused by the passage of vehicles. Obtained results are very promising both in terms of queues management and in terms of the proposed energy harvesting technique. The numerical simulation of the system was performed by applying the 3D numerical modelling techniques through the use of the F.E.M. code "Comsol Multiphysics 4.2", while for the electromechanical coupling and the simulation the program "QUCS 0.0.16" has been used. The positive results obtained from the numerical analysis above, led to experimental applications.

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USING BEES ALGORITHMS FOR SOLUTION OF RADAR PAVEMENT MONITORING INVERSE PROBLEM

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This work has focused on using of Bee Algorithm and Artificial Bee Colony algorithm for solution the inverse problem of subsurface radar probing in frequency domain. Bees Algorithms are used to minimize the aim function. Tree models of road constructions and their characteristics have been used for solution of the subsurface radar probing inverse problem. There has been investigated the convergence of BA and ABC algorithms at minimisation of the aim function of the inverse problem of radar subsurface probing of roadway structures. There has been investigated the impact of free arguments of BA and ABC algorithm, width of the frequency range and width of the searching interval on the error of reconstruction of electro-physical characteristics of layers and duration of algorithm operating. There has been investigated the impact of electro-physical characteristics of roadway structure layers and width of the frequency range on aim function of radar pavement monitoring inverse problem.

Keywords: radar monitoring, inverse problem, electro-physical parameters, Bee Algorithm, Artificial Bee Colony algorithm

1. Introduction

Monitoring and evaluation of pavement condition is important in roadway pavement engineering and management. The in-service performance of the roadway pavement depends on consistent, cost-effective and accurate monitoring of condition for early scheduling of repair and maintenance [1–4]. Modern ground – penetrating radar (GPR) are widely used for monitoring of roadway pavement [1, 3–6]. GPR provide radar profiles of pavement. Radar profiles give only a qualitative picture of the pavement structure and its state usually. It is necessary to perform reconstruction of the pavement electro-physical characteristics with detection and identification of inner zones and objects of pavement. Reconstruction of electro-physical characteristics of the pavement structural elements is in essence identification of electro-physical characteristics of the pavement layers, which can be achieved by solving the inverse problem of radar pavement probing.

In [7] the radar pavement inverse problem has been investigated in the frequency domain. The solution of the inverse problem of radar probing had been received in the frequency domain by method of selection. The aim function Φ is used in the following form:

$$\Phi = \frac{1}{n_{\max}} \sum_{i=0}^{n_{\max}} \left| \dot{S}_e\left(\omega_i, \vec{P}\right) - \dot{S}_t\left(\omega_i, \vec{P}_M\right) \right|^2 , \tag{1}$$

where n_{max} is a number of the spectral component with frequency f_{max}; $\left|\dot{S}_e\left(\omega_i, \vec{P}\right)\right|$ is the complex spectral density from the reflected signal and is function of parameter vector $\vec{P}$ for angular frequency ω_i; $\left|\dot{S}_t\left(\omega_i, \vec{P}_M\right)\right|$ is the complex spectral density, which is derived from the solving of forward problem of GPR probing. $\left|\dot{S}_t\left(\omega_i, \vec{P}_M\right)\right|$ is function of parameter vector $\vec{P}_M$ for angular frequency ω_i. The vector $\vec{P} = \{p_1, p_2, ..., p_n\}$, in which components p_i are electro-physical parameters of layers for n-layered probed roadway pavement. Electro-physical parameters of each layer are: thickness h, conductivity σ and the relative dielectric permittivity ε' of the layer's materials. The solution of the inverse problem was the vector of parameters $\vec{P}_M$, which corresponds to the global minimum of the aim function Φ.

To calculate $B_t\left(\omega_i, \vec{P}_M\right)$ the vector of parameters $\vec{P}_M$ was limited by the set of allowed values of parameters $\vec{P}_{POS}$. An iterative procedure was used to select of electro-physical characteristics values and to find of the aim function Φ global minimum. Results and the duration of the inverse problem solution depends on the algorithm that is used to search the global minimum Φ [5, 7].

Bee Algorithm (BA) [8] and Artificial Bee Colony (ABC) algorithms [9] are the latest multi-agent behavioural methods of global optimisation that are used to solve various practical problems of search and optimisation. In [10] algorithms have been described to solve the inverse problem of the radar pavement monitoring with employment of BA and ABC algorithms.

In this work BA and ABC algorithms have been used to solve the inverse problem of the radar pavement monitoring father. We research the effect of BA and ABC characteristics on the results of inverse problem solution. The peculiarities of aim functions (1), which correspond to the tree electro-physical models of the road structures, are researched too.

2. Forward Modelling of Subsurface Pavement Radar Probing

Generally, any road structure consists of a road surfacing, road foundation and subgrade (subsoil). The roadway surfacing and the road foundation form road pavement of any roadway structure. All pavements are usually subdivided into flexible and rigid on the bending resistance [10].

The flexible pavements: the pavements with layers arranged from different kinds of asphalt concrete (tarmacadam), of materials and soils, stabilized with bitumen, cement, lime and other complex cohesive substances, as well as of weakly granular materials (crushed stone, slag, gravel, etc.). On Figure 1 a generalized the roadway structure with flexible pavement is shown, which consists of three afore-named points [1].

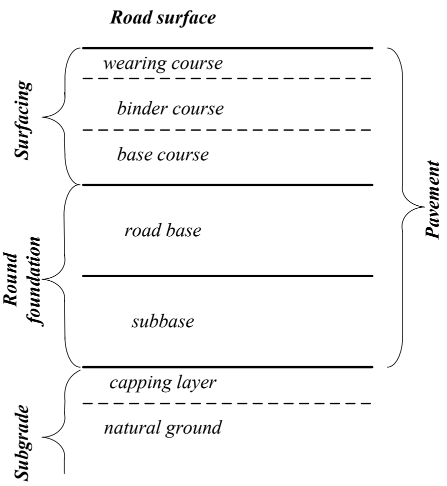


Figure 1. Roadway structure with flexible pavement

Analysis of the types of road constructions shows that their structural elements having the same functionality, either performed from the same material or of materials having similar values of the electro-physical characteristics. The main differences are in the number and thickness of the structural layers of road constructions [10]. The road length, corresponding to SV / I / II / III classes loads, is more than 60% of the total road length in Latvia. Therefore three models were determined for road of SV / I / II / III classes loads. These models were used in the work in investigations of reconstruction electrical parameters of roadway constructions.

The electro-physical parameters of the modelled of the roadway constructions are presented in Tables 1–3. The electro-physical parameters of the roadway constructions has been modelled taking into account that the roadway layers are composed of such materials as asphalt, concrete, crushed stone, crushed slag, sand and others. The number of the layers can vary but the electro-physical characteristics of some layers can be very similar or even equal. Electro-physical parameters of the model partial layers as well as the parameters of two semi-infinite spaces: upper space – air, and low space – subgrade.

Table 1. Electro-physical parameters of the road structure layers (model 1)

Number of layer	Layer material	Electro-physical parameters of layer material		
		ε'	σ, s/m	h, m
1	Air	1	0	∞
2	Dense grated HMA	2,9	0	0,06
3	Coarse-grained asphalt 2 marks	3,6	0	0,08
4	Coarse asphalt 2 marks	5,0	0^{-6}	0,12
5	Crushed stone	7,0	$5*10^{-4}$	0,33
6	Sand	9,0	$5*10^{-3}$	0,65
7	Loam	15,0	$5*10^{-2}$	$\propto$

Table 2. Electro-physical parameters of the road structure layers (model 2)

Number of layer	Layer material	Electro-physical parameters of layer material		
		ε'	σ, s/m	h, m
1	Air	1	0	∞
2	Asphalt-concrete	4,5	0	0,15
3	Crushed stone	7	0,0005	0,33
4	Sand	9	0,005	0,65
5	Loam	15	0,05	$\propto$

Table 3. Electro-physical parameters of the road structure layers (model 3)

Number of layer	Layer material	Electro-physical parameters of layer material		
		ε'	σ, s/m	h, m
1	Air	1	0	∞
2	Asphalt-concrete	4,5	0	0,15
3	Crushed stone	7	0,0005	0,40
4	Loam	15	0,05	$\propto$

Forward problem of the flexible pavement structure GPR probing was solving numerically with the using of the frequency model of signal forming channel for subsurface GPR probing of flexible pavement described in [12]. Calculations were carried out under the following conditions: distance between the antennas – 1 m; antennas high over upper boundary – 0.05 m; half length of linear antennas – 0,25 m; diameter of antennas – 0,0025 m; load resistor of the receiving antenna – 425 Om.

The probing signal was generated by the shock excitation of the transmitting antenna by triangular video, pulse duration of which was equal to 2 ns, and it was equal to 100 V. Complex transfer function $\dot{K}_{RAD}(\omega,\vec{P})$ is calculated according to [12] for vector $\vec{P}$, components of which are corresponded data presented in Table 1-Table 3. The spectrum of receiving signal is computed in the following form:

$$\dot{S}_T(\omega) = \dot{K}_{RAD}(\omega)\cdot\dot{S}_{ex}(\omega)\text{, where } \dot{S}_{ex}(\omega) = \int_{-\infty}^{\infty} u_{ex}(t)\cdot e^{-j\omega t}dt \tag{2}$$

is spectrum of excitation signal $u_{ex}(t)$. $\dot{S}_T(\omega)$ was used in expression (1) to calculate the aim function Φ.

3. Reconstruction of Electro-Physical Characteristics of Roadway Construction Model with Employment of BA and ABC Algorithms

There is investigation of peculiarities of solving the inverse problem of ar subsurface probing of roadway construction model with employment of BA and ABC algorithms [10]. Solution of the inverse problem has been performed with implementation three electro-physical models of roadway construction (Tables 1–3).

The following fundamental values of free arguments of BA algorithm have been employed for searching for the global minimum of aim function Φ: number of bees-scouts – 25; number of selected (the fittest) sites – 7; number of elite sites – 3; number of bees-foragers sent to the elite sites – 5; number of bees-foragers sent to the prospective sites – 2; maximum number of iterations – 100; maximum number of iterations without improvement of the obtained value of aim function – 4; size of sites for local searching – 5% of the width of searching interval for every electro-physical characteristic of roadway construction model. The following basic values of free arguments of BA algorithm have been selected for searching the global minimum of the aim function: number of bees-scouts – 25; maximum number of iterations – 150; maximum number of iterations, not followed by improvement of the aim function value of every bee-scout – 10.

The procedure of investigating the possibilities of BA and ABC algorithms has comprised varying the conditions of solving the inverse structural problem of radar subsurface probing of the road constructions:

- maximum frequency of spectral density $\dot{S}_e(\omega)$ for calculating the aim function of inverse problem (1);
- search intervals for every electro-physical characteristic of modelled roadway construction.

The results of solving the inverse structural problem with employment of BA and ABC algorithms (the vector of the reconstructed parameters of modelled roadway construction $\vec{P}_M^*$ and found minimal values of the aim function) have been employed for assessment of such values as:

- relative error of reconstructing every characteristic of modelled construction; the error is determined as a relative mean square deviation of reconstructed parameter of modelled construction;
- mean number of iterations necessary for completing BA and ABC operations;
- probability of positioning every reconstructed electro-physical characteristic of roadway construction model;
- absolute error of finding the minimum of mean value of specified minimal values of aim function;
- convergence of BA and ABC algorithms.

Solution of the inverse problem with the specified values of free arguments BA and ABC algorithms and conditions of searching for the global minimum of the aim function has been implemented iteratively – 100 times – for excluding the impact of this factor on the research results. The obtained set of independent solutions has been employed for finding the statistical estimations of the values listed above.

Figure 2 demonstrates the results of minimization of aim function Φ for model 1 of roadway construction at different relative values of searching intervals with employment of BA (Fig. 2a) and ABC (Fig. 2b) algorithms. The algorithm operations has completed after accomplishing 150 iterations. Maximum frequency of spectrum for calculating the aim function f_{max} = 500 MHz. These dependencies describe the convergence of BA and ABC algorithms.

The obtained mean values of minimal values of aim function significantly grow at expanding searching intervals. It is seen that the velocity of algorithm convergence gradually goes down with the growth of intervals width. Nevertheless, even at the minimal searching interval the error of finding the minimal value of aim function is far from zero. The BA algorithm allows finding smaller values of aim function at narrowing search range compared with the ABC algorithm.

Table 4 demonstrates the relative errors of reconstruction of the electro-physical characteristics (EPC) of model 1 of roadway structure after accomplishing the 150th iteration of BA and ABC algorithms. Values of relative errors are provided in percent. In case of insufficient a priori information (the relative searching interval width is 50%) the relative error of reconstructing the thickness of layers decreases approaching to 5% excluding the reconstruction error for the fourth layer. In case of smaller relative searching intervals the relative error of reconstructing the thickness of layers does not exceed 3%.

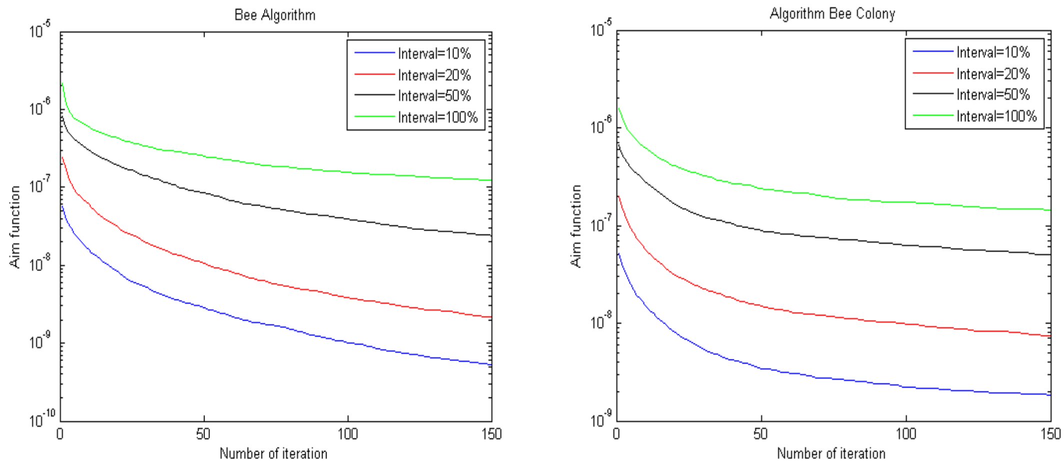


Figure 2. Influence of relative width of electro-physical characteristic search range on convergence of BA (a) and ABC (b) algorithms (model 1 of roadway construction)

Table 4. The relative errors of reconstruction of the electro-physical characteristics of model 1 of roadway construction

Electro-physical characteristics	**BA algorithm** The relative search interval width, %				**ABC algorithm** The relative search interval width, %			
	10	20	50	100	10	20	50	100
h_1	0.8	1.1	4.2	8.3	1.0	2.1	5.0	9.2
h_2	0.4	0. 8	2.7	4.5	0.75	1.6	4.1	6.5
h_3	0.8	1.1	4.9	11.0	1.1	1.8	4.0	6.6
h_4	0.2	0.4	8.0	25.5	0.6	1.0	3.5	22.5
h_5	0.7	0.9	5.7	26.2	0.55	1.4	3.6	18.5
ε_1'	0.03	0.06	0.4	0.6	0.1	0.2	0.5	0.7
ε_2'	0.2	0.6	2.4	4.5	0.6	1.2	3.33	6.5
ε_3'	1.2	2.4	9.2	10.8	1.6	3.4	4.4	23.8
ε_4'	2.1	3.5	12.1	29.0	1.5	4.1	11.3	33.5
ε_5'	2.8	4.2	13.4	23.0	1.8	4.4	10.3	23.5
ε_6'	3.3	5.5	14.9	27.4	2.7	5.0	13.5	27.2
σ_4	3.2	6.4	13.5	31.8	3.0	5.1	13.8	27.1
σ_5	3.2	6.3	15.1	31.8	2.5	5.0	13.4	26.8
σ_6	3.3	6.2	14.8	29.0	2.5	5.1	13.7	28.0

If searching interval of 100% the value of relative errors of reconstructing the thickness of layers indicates that the reconstructed values of thickness are dispensed according to the uniform law in the searching interval. Only the thickness of the second layer can be reconstructed with error close to 5%.

If ABC algorithm is used in case the relative width of the searching interval of layer thickness does not exceed 50%, the reconstruction of thickness of any layer can be completed with relative error of less than 5%. In case of decreasing the relative width of searching interval the relative error of reconstruction of thickness of layer is less than 3%. The ABC algorithm provides reconstruction of the layer thickness with a high accuracy of at least insufficient prior information.

The value of relative dielectric permittivity of the first layer is reconstructed with error less than 1%, and the value of relative dielectric permittivity of the second layer with error less than 5% at any a priori information and does not depend on the algorithm. The relative errors of reconstructing the relative dielectric permittivity and the specific electrical conductivity of lower layers of roadway construction model practically do not depend on the algorithm, and their values are close to root mean square deviation of uniform law of random quantity, in other words the relative error is determined by specified searching interval.

Table 5 presents the results of the aim functions minimization for all models of roadway construction with algorithm BA: the mean and root mean square deviations of the obtained minimal values of aim functions after accomplishing the 150th iteration of BA. These values for model 1 of roadway construction are also presented in Fig. 2.a. Analysis of mean minimal values of aim function reveals that decreasing number of characteristics of the aim function from 14 (model 1 of roadway construction, Table 1) to 10 (model 2, Table 2) and 7 (model 3, Table 3) does not improve the accuracy of aim functions minimization for inverse problem of radar subsurface probing of roadway constructions. The searching intervals width of electro-physical parameters of layers of roadway construction, in other words the degree of a priori information about the roadway construction, presents the principal influence on the aim functions minimisation.

Table 5. The results of the aim functions minimization for all models of roadway construction with BA algorithm

Model of roadway construction	**The mean of aim function**			
	The relative search range width, %			
	10	20	50	100
Model 1	$5.0*10^{-10}$	$2.1*10^{-9}$	$2.4*10^{-8}$	$1.2*10^{-7}$
Model 2	$5.0*10^{-10}$	$1.5*10^{-9}$	$2.5*10^{-8}$	$2.2*10^{-7}$
Model 3	$1.8*10^{-10}$	$7.8*10^{-10}$	$4.3*10^{-9}$	$2.0*10^{-8}$

Table 6 demonstrates the relative errors of reconstruction of the electro-physical characteristics of models 2 and 3 of roadway construction with employment of aim function after accomplishing the 150th iteration of BA.

The comparative analysis of values presented by Table 6 and values of relative errors of reconstruction of the electro-physical characteristics of model 1 of roadway construction (Table 4) shows:

1. Increased thickness of the first layer h_1 in models 2 and 3 of roadway construction results in the situation when the error of reconstructing this parameter significantly depends on a priori information (from relative width of searching interval). The errors of reconstruction of the thickness of lower layers of models 2 and 3 of roadway construction are substantially lower than the errors of reconstruction of the thickness of similar layers of model 1 and do not depend on a priori information. It is explained by high level of signals, reflected from the boundaries of lower layers of models 2 and 3 of roadway construction.
2. The relative dielectric permittivity of two upper layers of roadway construction of models 2 and 3 are reconstructed with rather high accuracy independently from the searching interval width similar to the relative dielectric permittivity of two upper layers of model 1. The error of reconstructing the relative dielectric permittivity of lower layers of models 2 and 3 has the same values as at reconstructing the relative dielectric permittivity of lower layers of model 1 and depends on the searching interval width.
3. The error of reconstruction of the relative dielectric permittivity of layers of models 2 and 3 is only determined by the searching interval width of the corresponding parameter; the same happens for model 1 of roadway covering.

Values of the relative errors of reconstruction of the electro-physical characteristics of all models of roadway construction and the influence on them the search interval widths are explained by to the degree of influence of each the electro-physical characteristic on the aim function (1). Figures 3, 4 and 5 show the cross section of the aim function along all electro-physical characteristics (directions). The cross-sections of the aim function along the relative dielectric permittivity of the all layers of models are asymmetrical (Figure 3). Degree of asymmetry of the cross-sections is different. The cross-section along the relative dielectric permittivity of the second and third layers have the greatest asymmetry. The aim function increases more slowly, if the value of the relative dielectric permittivity of each layer increases with respect to the model value.

Table 6. The relative errors of reconstruction of the electro-physical characteristics of models 2 and 3 of roadway construction

Electro-physical characteristics	Model 2				Model 3			
	The relative search range width, %				The relative search range width, %			
	10	20	50	100	10	20	50	100
h_1	2.3	5.6	12.4	24.8	1.3	2.8	5.8	12.9
h_2	0.4	1.8	3.4	4.4	0.2	0.5	1.1	2.5
h_3	0.4	1.6	2.6	1.6	-	-	-	-
ε_1'	0.4	1.1	2.2	4.2	0.2	0.5	1.1	2.4
ε_2'	0.7	3.6	5.2	18.0	0.4	0.9	2.2	4.4
ε_3'	1.4	5.7	10.6	26.8	1.9	4.4	10.6	22.5
ε_4'	2.4	6.8	13.7	28.6	-	-	-	-
σ_2	2.9	6.7	14.0	30.2	2.9	5.6	15.1	31.2
σ_3	2.8	5.7	14.0	27.7	2.7	6.1	14.2	29.4
σ_4	2.6	5.5	14.0	25.4	-	-	-	-

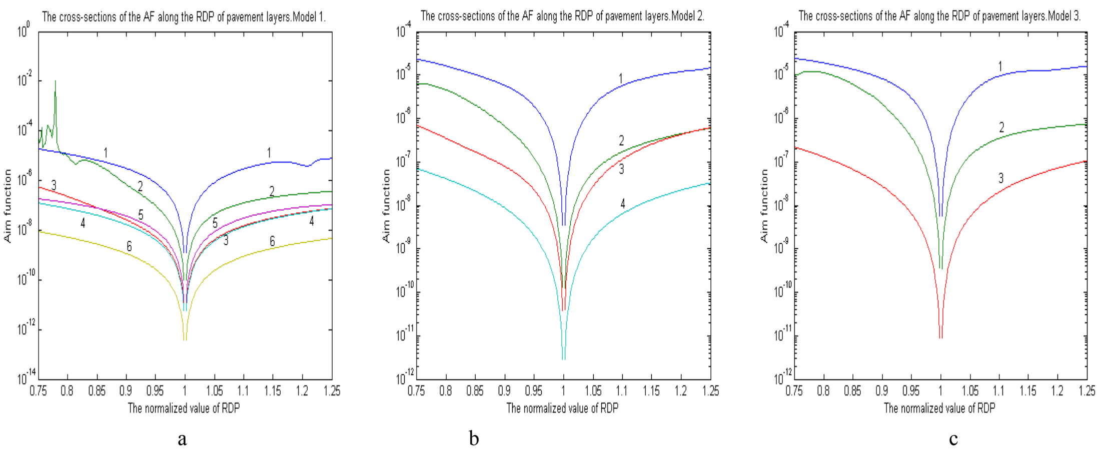
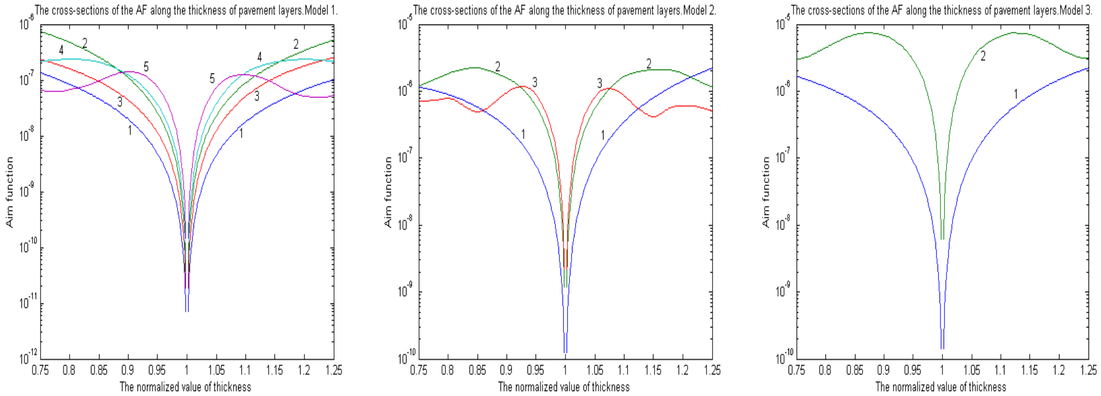


Figure 3. Model-based cross - sections of the aim function along relative dielectric permittivity of pavement layers: a – model 1; b – model 2; c – model 3 (digit near the line is the number of layer)

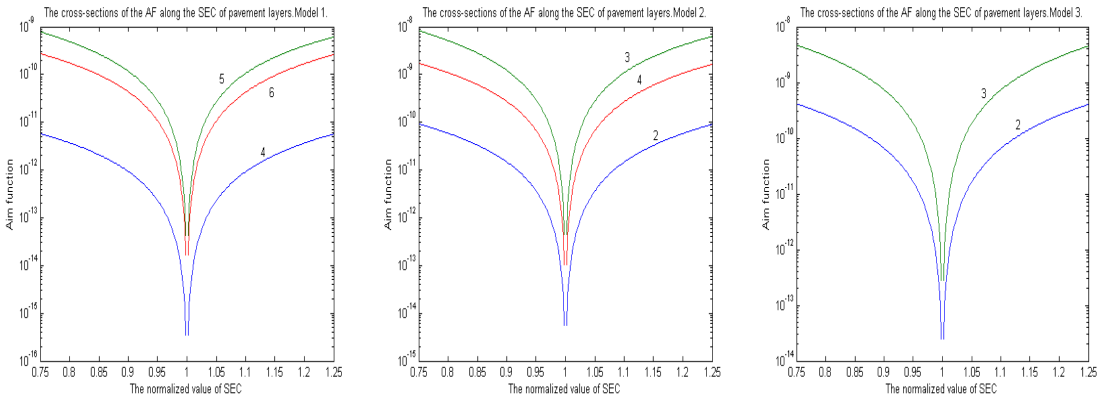
The cross-sections of the aim function along the thickness of the all layers are symmetrical (Figure 4). The local maximums and local minimums are presented at the cross sections of the aim function along the thickness of the bottom layers of every model of roadway construction (the 5th line on Fig. 4a, the 3rd line on Fig. 4b and the 2nd line on Fig. 4c). This can be explained by large thicknesses of these layers. The cross-sections of the aim function along the specific electrical conductivity of the all layers of models are perfectly symmetrical for all layers as it is shown on Figure 5.

The maximum values of the aim function for each section characterize the sensitivity to changes in the aim function of each parameter. The aim function is most sensitive to changes in the relative dielectric permittivity of the first layers (the 1st lines on Fig. 3a, 3b and 3c) of all three models. The aim function has high sensitivity to changes in the relative dielectric permittivity of the second layers and the thickness of the second layers (the 2nd lines on Fig. 4a, 4b and 4c) of all three models, also to changes in the thickness of the lower layers (the 5th line on Fig. 4a, the 3rd line on Fig. 4b) of the first and second models. The aim function has the lowest sensitivity to the changing in specific electrical conductivity of all layers of the tree models (Fig. 5) in comparison to the sensitivity to the changing in relative dielectric permittivity and thickness of layers.



a b c

Figure 4. Model-based cross - sections of the AF along the thickness of pavement layers: a – model 1; b – model 2; c –model 3 (digit near the line is the number of layer)



a b c

Figure 5. Model-based cross - sections of the AF along the specific electrical conductivity of pavement layers: a – model 1; b – model 2; c – model 3 (digit near the line is the number of layer)

Unequal sensitivity of aim function (1) explains the relative errors of reconstruction of the electro-physical characteristics of models of roadway construction and their dependence on the search interval width (Table 4 and Table 6). The higher the sensitivity of aim function Φ to the changing in the electro-physical characteristic of models of roadway construction, the smaller the relative errors of reconstruction of the electro-physical characteristics of models of roadway construction.

The results of reconstruction of similar electro-physical characteristics of layers of roadway constructions for all models coincide, that is why the further research of reconstruction of electro-physical characteristics operates with model 1 of the roadway construction.

Figure 6 demonstrates the dependencies of mean value of obtained minimal values of aim function (the error of finding the global minimum of aim function) from the number of iterations at six values of f_{max} (F_m). In case of decreasing f_{max} the obtained minimum value of aim function diminishes by an order of magnitude. The errors of reconstruction of electro-physical characteristics of layers have bigger values at lower values of f_{max}. Table 6 presents the relative errors of electro-physical characteristics reconstruction of model 1 of roadway construction at different f_{max} after accomplishing the 100th iteration of BA. The width of relative parameters searching interval equals 50%.

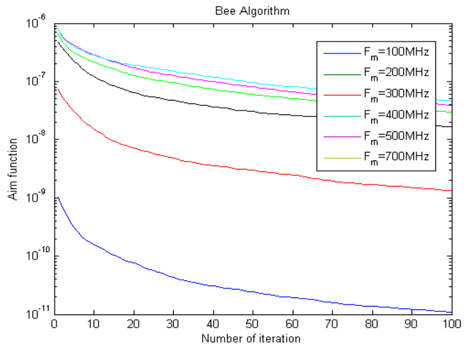


Figure 6. Influence of $f_{\max}$ on convergence of BA (model 1 of roadway construction)

Table 7 presents the relative errors of electro-physical characteristics reconstruction of model 1 of roadway construction at different f_{max} after accomplishing the 100th iteration of BA. It is seen that the relative errors of reconstructing the thickness of three upper layers are less than 5% and relative errors of reconstructing the relative dielectric permittivity of two upper layers are less than 3% at $f_{max} \geq 500$MHz. The expansion of frequency range does not affect the accuracy of reconstruction of the thickness of two lower layers. This is supported by Figure 7 and Figure 8, which show the cross-section of the aim function along the thickness of all layers (Figure 7) and along the relative dielectric permittivity of the upper three layers (Figure 8) of model 1 roadway construction for various f_{max}.

Table 7. Influence of $f_{\max}$ on the relative errors of reconstruction of the electro-physical characteristics of models 1 roadway construction

Electro-physical characteristics	f_{max}, **MHz**					
	100	200	300	400	500	700
h_1	8.8	10.5	13.7	6.2	4.2	4.6
h_2	15.5	17.3	5.7	3.7	2.7	3.2
h_3	14.4	12.2	9.7	8.2	4.9	3.7
h_4	12.3	6.7	6.3	6.1	8.0	8.
h_5	6.6	4.5	5.0	7.1	5.7	7.4
ε_1'	0.7	0.7	0.5	0.5	0.4	0.3
ε_2'	5.9	6.4	2.5	2.8	2.4	2.7
ε_3'	12.3	7.8	10.4	10.8	9.2	8.4
ε_4'	13.2	11.3	12.8	11.0	12.1	12.3
ε_5'	14.4	13.0	13.3	14.3	13.4	13.5
ε_6'	14.3300	15.4100	14.8700	13.7900	14.9	13.3400
σ_4	15.7	16.3	15.5	15.3	13.5	15.4
σ_5	15.1	14.4	15.2	15.3	15.1	14.8
σ_6	15.6	15.3	13.7	14.8	14.8	16.0

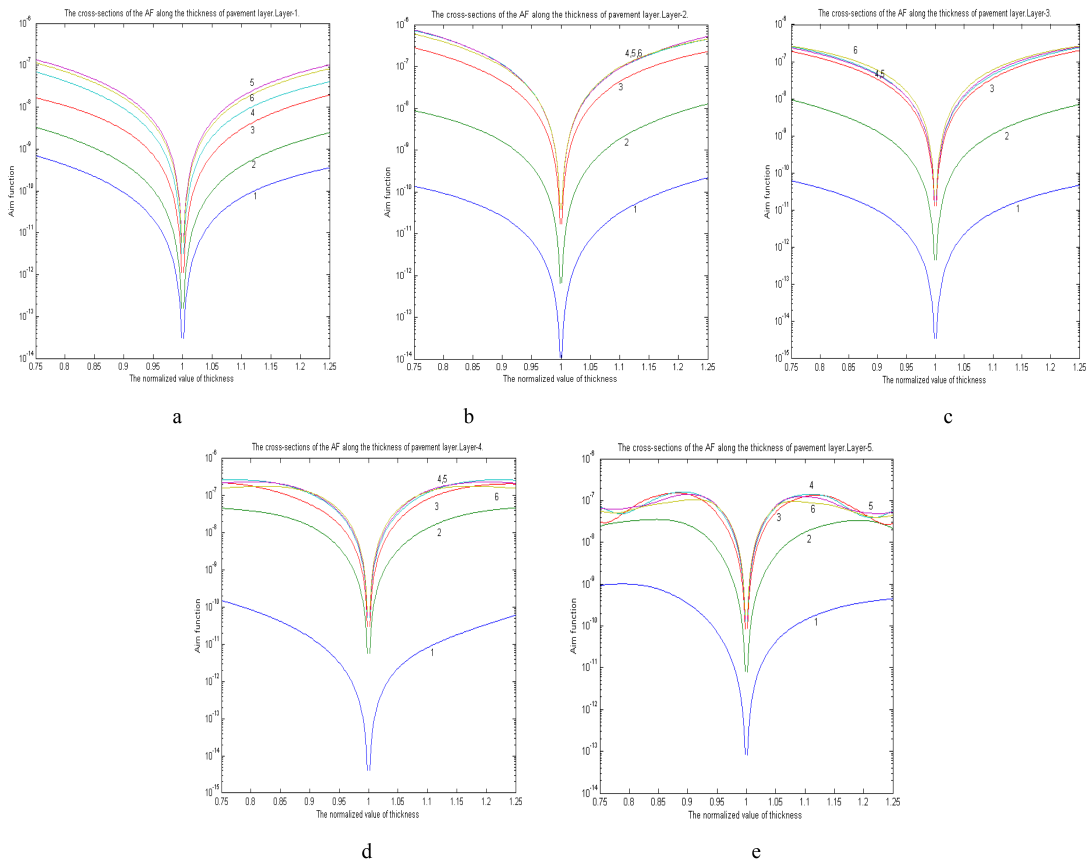


Figure 7. Model-based cross - sections of the aim function along the thickness of pavement layers: a – 1-st layer; b – 2-nd layer; c –3-rd layer; d – 4-th layer; e – 5-th layer; f – 6-th layer (digit near the line: 1 – f_{max} = 100 MHz, 2 – f_{max} = 200 MHz, 3 – f_{max} = 300 MHz, 4 – f_{max} = 400 MHz, 5 – f_{max} = 500 MHz, 6 – f_{max} = 700 MHz)

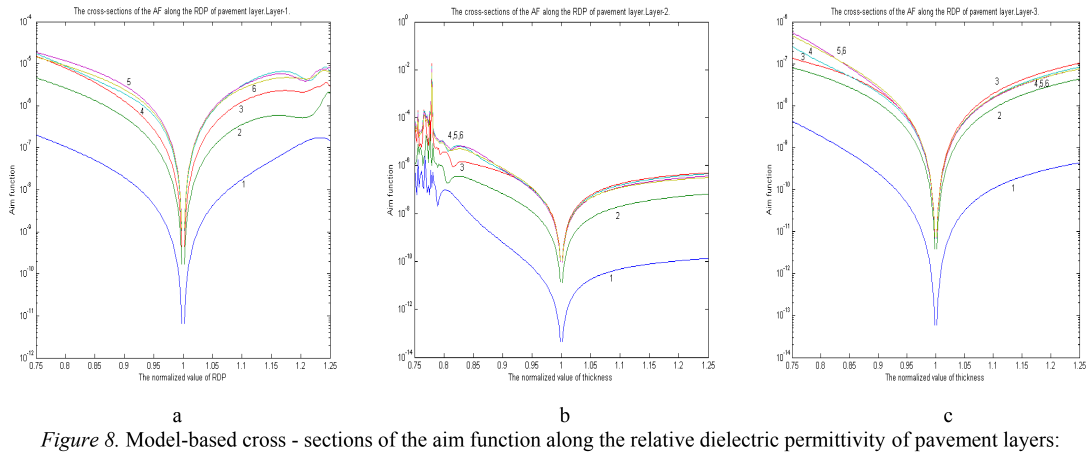
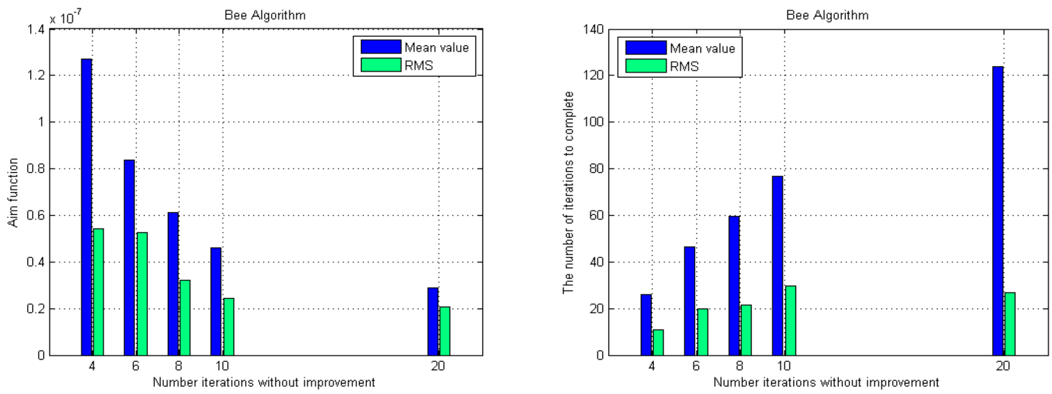


Figure 8. Model-based cross - sections of the aim function along the relative dielectric permittivity of pavement layers: a – 1-st layer; b – 2-nd layer; c – 3-rd layer; (digit near the line: 1 – f_{max} = 100 MHz, 2 – f_{max} = 200 MHz, 3 – f_{max} = 300 MHz, 4 – f_{max} = 400 MHz, 5 – f_{max} = 500 MHz, 6 – f_{max} = 700 MHz)

The aim function Φ (1) increases along each electro-physical characteristics, if the value of f_{max} increases. But when the f_{max} exceeds 400 MHz, aim function Φ increases insignificantly, and the sensitivity of aim function Φ to the changing in the electro-physical characteristic of model of roadway construction. Therefore, the value f_{max} = 500 MHz has been used in the process of employment of BA and ABC algorithms for solving the inverse problem, since the relative errors of reconstruction of characteristics do not diminish significantly at big values of f_{max}, but the number of operations in the process of calculating the AF increases, and accordingly the time of inverse problem solving also increases.

The research has investigated the impact of local searching of BA for an error of finding the minimum of aim function and for relative errors of reconstruction of the electro-physical parameters of model 1 of roadway construction. The relative searching interval at each electro-physical parameter equals 50%. The number of the fittest selected sites and number of elite sites employed for implementation of local searching for global minimum of aim function does not affect the results of solving the inverse problem. In the percentage term the size of the site for local searching must be not less than 3%–5% from the searching interval width according to the corresponding coordinate. Otherwise the efficiency of local searching decreases: the errors of determining the minimal value of aim function increase and the relative errors of reconstruction of electro-physical parameters of roadway layers grow.

Maximum number of last iterations, not followed by improvement of the aim function value employs for algorithm operating accomplishment. The error of finding the global minimum of the aim function and dispersion of values decreases while this parameter is growing (Fig. 9a). Nevertheless, the total number of iterations till the algorithm operating accomplishment grows, consequently the time of the inverse problem solving increases. (Fig.9b) The number of iterations till the algorithm BA operating accomplishment has almost linear dependence with number of iterations, not followed by improvement. The relative root mean square deviation of number of iterations till the algorithm operating accomplishment decreases in case of increasing number of iterations without improvement.



a b

Figure 9. Influence of maximum number of last iterations without improvement of the aim function value on the error minimization of aim function (a) and the total number of iterations BA (b)

Increasing the number of iterations, not followed by improvement of the aim function value also increases the probability of localisation of reconstructed values of thickness. Nevertheless, the relative error of reconstruction decreases only for thickness of the first three layers under the values close to 5%. The errors of reconstruction of thickness of the fourth and the fifth layers also decrease in case of growing number of iterations without the aim function improvement; however the error value is more than 5% (Fig. 10a and 10b).

The probability of localisation of the modelled value of relative dielectric permittivity of the first layer equals to 1 at any number of iterations without the aim function improvement, and the error of reconstruction of electro-physical characteristic is less than 1% (Fig. 10c and 10d). An increase of the number of iterations without the aim function improvement does not decrease the relative error of reconstruction of relative dielectric permittivity of other layers. The probability of localisation of the reconstructed value of relative dielectric permittivity of other layers is several times less than 1 even in case the probability of localisation grows under the condition of increasing the number of iterations without the aim function improvement. The number of iterations without the aim function improvement does not affect the localisation probability and relative errors of reconstruction of relative dielectric permittivity of the layers (Fig. 10e and 10f).

The analysis of impact of number of iterations without the aim function improvement on the results of solving the inverse problem allows concluding that the value of this characteristic must be in the interval 6….12. An increase of the number of bees-scouts of BA has insignificant impact on probability of localisation of the reconstructed values of thickness of the first and the second layers, providing the value of the relative error of reconstruction of thickness of the first two layers less than 5%. The errors of reconstruction of thickness of the lower three layers do not depend on the number of bees-scouts;

the values of errors are more than 5%. The probability of localisation of the modelled value of the relative dielectric permittivity of the first layer equals to 1 at any number of bees-scouts; the error of reconstruction of this electro-physical parameter is less than 1%

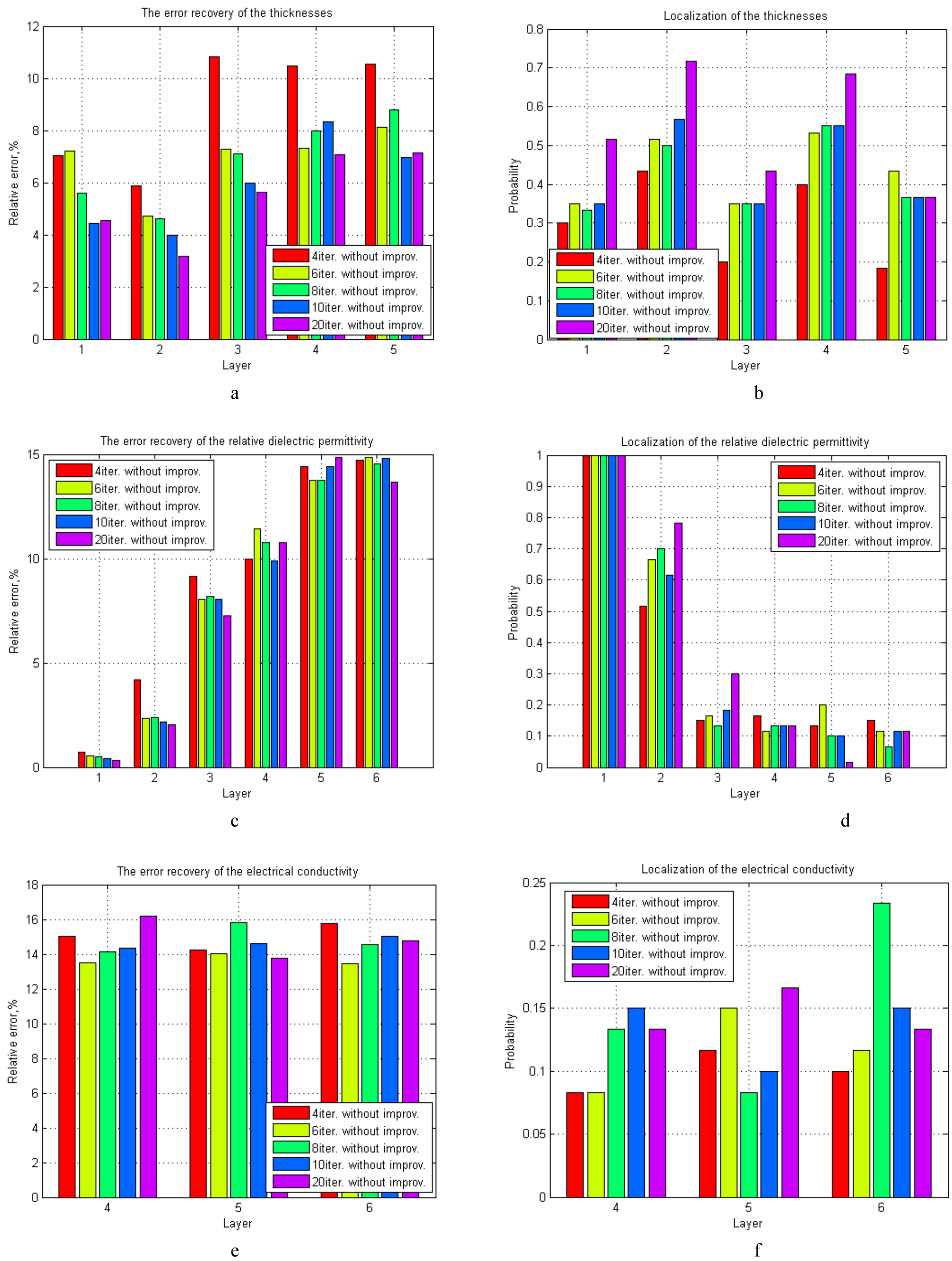


Figure 10. Influence of maximum number of last iterations without improvement of the aim function value on reconstruction by BA the electro-physical parameters of model 1 of roadway

When ABC algorithm is used the impact of the number of bees-scouts on the error of finding the global minimum of the aim function is insignificant. Figure 11 presents the influence of maximum number of iterations without improvement on the solution of the inverse problem with employment ABC algorithm. Increasing the value of this free argument till 20 can decrease the mean value of the obtained minimal values of the aim function by an order of magnitude.

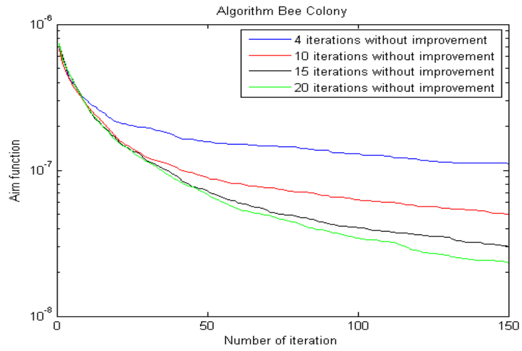


Figure 11. Influence of maximum number of last iterations without improvement of the aim function value on convergence of ABC algorithms (model 1 of roadway construction)

Nevertheless, the impact of this parameter on reconstruction of electro-physical characteristics of layers of model 1 of the roadway construction is different (Fig. 12).

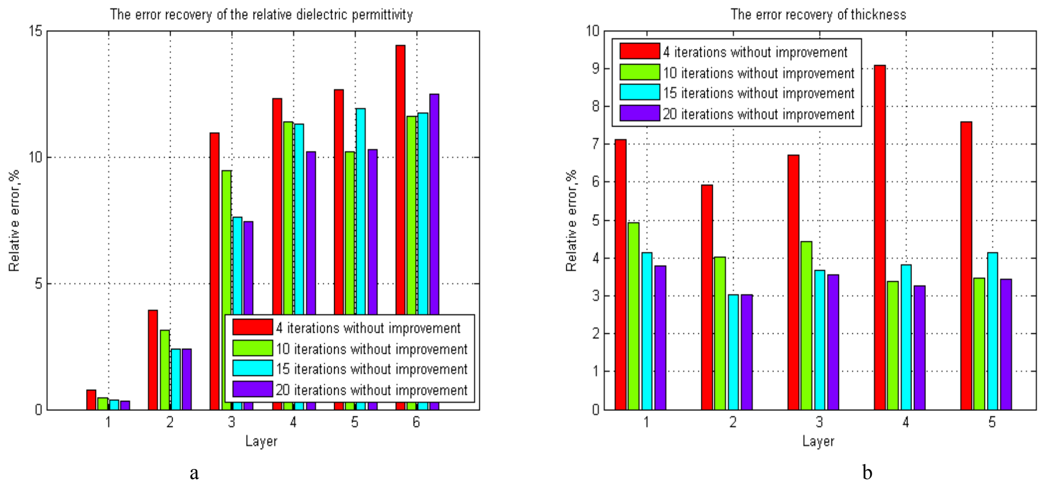


Figure 12. Influence of maximum number of last iterations without improvement of the aim function value on relative errors of reconstruction relative dielectric permittivity and the thickness of roadway construction layers by ABC algorithms (model 1 of roadway construction)

As it has been mentioned above, the errors of reconstruction of relative dielectric permittivity of two upper layers have low values, and increasing the number of iterations without improvement makes them even lower (Fig. 12a). The parameter of ABC algorithm under consideration has no influence on the relative error of reconstruction of relative dielectric permittivity of other layers. Figure 12b demonstrates the impact of number of iterations without improvement on relative errors of reconstruction of thickness of all layers of modelled roadway construction. Increasing the number of iterations without improvement decreases the relative errors of reconstruction of thickness of all layers to the values, which are lower than 4%. The number of iterations without improvement has no impact on relative error of reconstruction of relative dielectric permittivity of all layers.

4. Conclusions

The main results of employment of BA and ABC algorithms are as follows:

- the error of minimisation of the aim function mainly depends on the width of the searching interval of electro-physical characteristics;
- the value of the relative error of reconstruction of electro-physical characteristics depends on the ordinal number of the layer, the type of electro-physical characteristic, and width of the searching interval;
- the maximum number of spectral components must be used for the aim function calculations for decreasing the error of reconstruction of electro-physical characteristics;

- when BA algorithm is used the maximum number of iterations, not followed by improvement of the aim function and size of neighbourhood of local searching are the only factors allowing decreasing the error of reconstruction of thickness and relative dielectric permittivity of layers of roadway construction and permitting growth of probability of localisation of reconstructed value in the specified interval;
- when BA algorithm is used the maximum number of iterations, not followed by improvement of the aim function must be selected from the interval 6–12, the relative size of sites for local searching must be not less than 3%–5% and the number of bees-scouts must be no fewer than 20 for minimising the number of algorithm iterations;
- when BA algorithm is used It has been determined that the number of bees-scouts has no impact on the aim function minimisation and on error of reconstruction of electro-physical characteristics, but the maximum number of iterations, not followed by improvement of the aim function values must be selected from the interval 10–20;
- these values of this parameter of ABC algorithm allow reconstructing the thickness of layers with error less than 5% at any a priori information; this function is not provided by Genetic algorithm and BA.

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WIRELESS ENERGY SUPPLY TO PUBLIC TRANSPORT UNITS WITH HYBRID DRIVE – TRENDS AND CHALLENGES

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This paper describes the initial findings of research project "The Possibilities of Increasing Efficiency of City Bus Hybrid Propulsion Systems by Including Wireless Battery Charging" carried out by „LEO Research Centre" (Competency Centre for Latvian Electrical and Optical Manufacturing Industry).

The project is aimed at developing wireless charging and optimising electric bus propulsion system for modern urban transportation applications. The project runs from the beginning of the 2013 until the end of 2015 and focuses on the sub-theme "Energy and Sustainable Transport".

Keywords: public transport; transport units with hybrid drive; conductive energy transfer; wireless energy transfer

Introduction

Currently the world's growing public focus is on the development of environmentally friendly technologies, including applications in the transport sector. At the same time, public transport, especially buses, is the largest contributor to air pollution in cities.

To stimulate transition from fossil fuels to renewable energy-using engines, especially – electric transport, the European Commission issued in 2011 the White Paper "Roadmap to a Single European Transport Area – towards a Competitive and Resource Efficient Transport System", which encompasses "… by 2030 to reduce by half the usage of 'traditional fuel' cars used for urban transportation; by 2050 to cease stage-by-stage its usage in cities; by 2030 to achieve virtually zero CO_2 emissions in major population centres from city logistics" [1].

Currently well over 50% of all public transportation trips are completed by bus, but, unfortunately, usage of electric buses in the world has been rather symbolic. The main reason for this is electric bus price, which is caused by large volume expensive batteries and currently exceeds any economic efficiency criteria; therefore, battery electric buses have been presented only as separate pilot projects: USA (California), United Kingdom (Nottingham, Coventry), Sweden (Umea) and China; however, in the last years the number of similar projects increased exponentially, showing great interest in the development of new technologies in the city transportation systems.

From the perspective of overall economical reasoning hybrid buses are already economically viable, yet recovered amount of energy so far is very limited – the hybrid electric vehicle (HEV) energy recuperation and replacement technology allows us to recover up to 15% of the energy in the urban cycle, thereby the gain of CO_2 emission reduction is not substantially high. The general industry problem, which is intended to be addressed in this project, is the following – to explore the possibilities of developing the wireless battery charging system for the bus electric drive system that would allow benefiting from opportunities, given by electricity as driving force (power, efficiency, lower costs), while avoiding substantial increase in bus and infrastructure costs.

1. Definition of the Problem

The research problem derives from practical application problem – how to create the most efficient zero emission bus system, which would be economically feasible to implement.

While evaluating this system, city transportation system must be seen as a whole, taking into account all possible transportation modes for compatible particular vehicle application. In case of alternatives to a city bus several options must be evaluated and compared:

a) Ordinary diesel bus;
b) Minibus;
c) LPG/LNG bus;
d) Trolley bus with overhead lines;
e) Electric bus;
f) Hybrid drive bus.

These are just the main groups – in practice there are a lot more: Pierre Ducharme and Simon Ouellette determined six propulsion types of hybrid electric engines with additional six power train configurations [2].

This research will compare three main groups – classical ordinary diesel bus, electric bus with trolley as electrical energy supply system, and electric bus with hybrid/accumulator as energy supply system.

In general, when seeking how to minimize total costs of ownership (TCO) for environmentally clean city transport one must compare TCO for each vehicle system.

$$TCO_{system} = TCO_{vehicle\ type} + TCO_{infrastructure}. \tag{1}$$

Each of these parts in turn will consist of three main components: purchase price (P), residual value (V) and cost of operation (C).

$$TCO_{vehicle\ type} = \frac{P_{vehicle} - V_{residual}}{years_{service}} + C_{operaton}. \tag{2}$$

When comparing electric busses with their counterparts, we see still quite a lot unknown values, which moreover are inter-dependable (Table 1).

Table1. Some variables for TCO estimation

Type of vehicle	Vehicle				Infrastructure			
	Purchase costs	Residual value	Costs of operation	Years of service	Purchase costs	Residual value	Costs of operation	Years of service
Ordinary bus	Low	Moderate/Low	High	7-12 [3] / 20 + [4]	Assumptions that there are no additional costs, as other vehicles use the roads as well			
Trolley bus	High	Moderate/Low	Low	12/20 +	High	Low	High	25 +
Electric bus	High	Unknown	Low	Unknown battery life	Low to High	Low	None to High	Unknown to 25

Apart from these objective variables, one must include subjective factors that in practice are included in the process of decision on vehicle system, like aesthetics of the system (some cities will pay more to avoid the ugly looking overhead lines), willingness to pay more for environmentally friendly energy, etc.

This particular project will address the problem how the on-board battery capacity affects the TCO of electric or hybrid electric bus.

The main chains of effects are presented in the Table 2.

Table 2. Main chains of effects of on-board battery size

Batteries	↑	Drive distance	↑	Charging infrastructure costs	↓		
				Alternative charging infrastructure	?	Charging infrastructure costs	?
				Useful drive time	↑	Income	↑
Batteries	↑	Vehicle costs	↑				
Batteries	↑	Lifetime	?	Residual value	?		
Batteries	↑	Vehicle weight	↑	Energy consumed	↑		
				Passengers on board	↓	Income	↓

As it's shown in the Table 2, the relationships are by no means straightforward. So, increasing battery size would increase the costs of the vehicle. Additionally it would add to its weight and it has been determined that if the 14 ton bus' mass increases per 1000 kg, the corresponding power consumption increases by 0.03–0.04 kWh/km at constant speed, which corresponds to 3–4% of power consumption [5]. On the other hand, larger battery size would give additional driving distance, thus decreasing charging infrastructure costs for wireless charging.

Furthermore, the particular practical implementation of various alternatives available on the market can lead to opposite results, especially when looking at battery lifetime and residual values of the vehicle. Thus there is a wide area for research in optimisation of on-board battery parameters.

2. Description of the Research

2.1. Background information on hybrid busses

Hybrid bus production is the leading trend in public transportation. Major bus producers all over the world are involved in the production and tests. The most active players in this market are North American companies, which have strong cooperation with large energy producing companies and national research laboratories like EPRI, General Electric, NREL, INEEL, ISE Research. Development of hybrid busses in this region started on 1997, and currently several thousands of hybrid busses driven by internal combustion engine driven or fuel cells driven hybrid systems are operating in the market of public transportation.

Hybrid transport's economic and environmental performance improvement is determined by qualitatively different "ID" operation conditions. The diesel engine will run steady state, which is the optimal from the fuel economy and harmful emissions point of view.

Diesel with less power usage in hybrid bus, compared with a serial produced type, braking energy recuperation options, overrun time and deceleration time allow us to save up to 50% of fuel. Hybrid bus handling and comfort are ensured by drive systems and the electric driver response time to the driver's speed. Electrical system significantly increases the mechanical and hydro-mechanical system speed. Traction equipment noisiness is reduced due to the elimination of mechanical connection between the engine and the wheels. The traction drive control electronics will allow fulfilling the control and service functions that are not available in ordinary vehicle.

USA and Canada are between the largest hybrid busses, at most part diesel electric, consumers. Research projects of public transportation with LPG or fuel cells elements are not topical there because of questionable commercialization and business development possibilities. As an example one could mention the case of New Your city, which denied the idea of 200 LPG (LNG) driven busses purchases, buying the same amount of hybrid busses. Finally the government decided to switch to hybrid transportation as main public transportation principle, stressing on the facts, that diesel electric busses with very similar ecologic impact on environment, are more economically viable, they have also substantial strengths in comfort and daily use and management, they do not require additional investments in infrastructure, but the price difference (125,000 USD to 200,000 USD in prices of year 2000) allows us to have substantially shorter investment repayment time.

Despite of some slowness in the hybrid busses commercial application, several companies in the Asia region, mainly in Japan, South Core, and China, are working intensively in this direction as well.

First hybrid busses were produced in Japan on 1991, by Toyota subsidiary company Hino Motors. The largest producer from China, Shanghai Automotive Industrial Corp. has developed hybrid busses production unit together with General Motors. Another producer from China – FAW, which is the second largest according to the turnover, started production of hybrid busses named Jiefang on 2005, using technology designed by the company Enova from USA. The characteristics of bus – fuel economy 38%, emission decrease by 30%, in comparison with traditional diesel engine driven bus. NiMH accumulators are used as the main energy storage unit in this bus. Company FAW had decided to produce at least 1000 hybrid busses by 2010. Company China Yuchai International Ltd. (China) presented the hybrid bus engine system designed by their engineers and researchers on 2008. The system is based on the parallel hybrid principle with integrated starter – generator.

European producers are rather behind their American and Asian colleagues despites the fact that they started the research of hybrid systems a while ago. United Kingdom is the current leader in the Europe in hybrid systems use, and especially the capital – London, where the municipality decided to purchase only hybrid technologies based new public transportation units starting with 2012.

All large European transportation means producers like Mercedes, MAN, Scania, VOLVO, are preparing their production facilities for hybrid busses production and commercial production of electric power units of public transportation. Financial support for these activities is being received from their home countries government budgets. MAN in cooperation with Siemens A&D, using series hybrid drive system with super capacitors as energy storage units, re-designed bus MAN Lion's City production line, but Scania is working on their bus OmniLInk modification using hybrid system designed by company Voith from Austria, and using Maxwell (USA) super capacitors.

DesignLine International Holdings from New Zealand should be mentioned between the serious players in the hybrid buss production segment. First diesel electric hybrid busses were presented by the company already on 1998, and starting with 2000 they introduced Capstone MicroTurbine microturbines, different types of energy storage units including NiMH, LiIon accumulator batteries, and super capacitors, and intellectual power modules SKAI designed by company Semikron. The busses called DesignLineEcoSaver are delivered to USA, United Kingdom, and Japan.

The main hybrid system developers are presented in the Table 3.

Table 3. Leading world hybrid system developers

Series hybrid systems	**Parallel hybrid system**	**Combined hybrid system**
BAE Systems (UK). System HybriDrive®	GM/Allison (USA). System – EP40, EP50 Systems – EP40, EP50 (mixed parallel system Split modified for long vehicles)	Enova (USA). Using both series and parallel hybrid systems
ISE/Siemens (USA). System Elfa® (Siemens A&D, Germany)	Eaton (USA). System with automatic transmission Fuller®	
Voith (Austria). System ELVO®		

2.2. Comparative analysis of energy storage principles

The latest hybrid bus design includes different energy storage systems – starting with flywheel as mechanical energy storage and recuperation device, and in the electrical energy storage side – from lead-acid batteries as the oldest device up to NiMH or LiIon batteries designed especially for transportation units, and electro chemical super capacitors as the latest energy storage modules.

NiMH andLiIon accumulator batteries are good alternative because of their light weight and high specific power. The main drawbacks are limitations of charging and discharging speed, and substantially shorter lifetime in comparison with super capacitors. Typical lifetime of accumulator batteries is around 6 years, at the same time the lifetime of the bus is more than 10 years. This means that at least two packages of accumulator batteries must be used during the bus application as a public transportation mean. Super capacitor producers are offering their product lifetime longer than 10…12 years, which could mean that there will be no additional expenses for replacement of this type of energy storage devices.

3. Electric Energy Transfer Technologies to Moving Objects

3.1. Conductive energy transfer

3.1.1. Overhead wire grid

The basic, widely known electric energy transfer principles to the transportation units are based on electric grid and pantograph (moving contact system). This allowed developing specific electricity driven transportation units – trolley busses and trams use this system all over the world.

The main drawbacks are electric grid development and maintenance expenses, fixed lines and fast wear out of the contact systems, which asked for solutions as to wider electric transportation system development.

3.1.2. Plug-in charging

Along with electronic components and energy storage development hybrid vehicles and pure electric vehicles appeared. As one of the ideas that is expected to significantly alter electrified transport, the charging station placement throughout the vehicle journey to provide additional accumulator charging. At present there are several competing charging technologies: some of them are already in the testing and implementation phase, while others are still being developed.

The simplest transfer of power from the charging station the vehicle is a direct connection to the vehicle using power cable. Currently, there are several standards for road station to charge the batteries, which uses both DC and AC power.

Positive features of this system are: high system efficiency (more than 99.5%), the transferred power is limited only by the cable cross-section, the implementation simplicity, absence of electromagnetic interference generation. Weaknesses of the system are: the need for a cable connection, capture and transfer equipment mechanical contact necessity, electrical contact between the reception and transmission equipment necessity, complicate to use during short stops, cannot be used while moving.

Direct connection system is suitable for high capacity accumulator charging, while the vehicle has long stops through the journey, and is not suitable for charging during short time stops.

3.1.3. Trolley systems

Trolley system provides electrical contact between the power transmitter and receiver using specific devices – trolleys, located at the stop spot. This system has the following advantages: high efficiency (more than 99.5%), the possibility of a fast automatic bonding opportunity, absence of electromagnetic interference generation. Weaknesses of the system are: substantial number of mechanical moving part, necessity of capture and transfer equipment mechanical contact, necessity of electrical contact between the reception and transmission equipment, power transmission system contacts pollution impact on system performance, the need to accurately position the vehicle with respect to the charging equipment.

There are different types of trolley system. Company ABB is offering contact plates system positioned on the bus stops [6]. Power receiver is equipped with an automatic positioning system, which allows changing the current location of the receiver relative to the contact plates. ABB Group has also developed a 400 kW electric buses particularly fast-charging system, which is being tested in Switzerland. The system called TOSA (Trolleybus Optimisation System Alimentation) [7] lets to charge the bus accumulators during the short, just 15 seconds long stop.

Currently, under the pilot project a number of charging stations are installed on the route from Geneva airport, which connects the city to the international exhibition centre. When the bus arrives at the stop, mechanic alarm from the power charger is automatically connected to the bus for charging. While the passengers disembark and are picked up, the battery is charged. At the final destinations it is enough to charge the battery just for 3–4 minutes, and the bus is ready to ride again on the route. Bus length is 19 m, the maximum number of passengers – 135 [8].

Company SIEMENS is offering the trolley system [9], which differs substantially – it allows to charge during the driving. Two parallel positioned power wires and pantograph system, very similar to the one which is being used in current trolley bus system, is being used there. The system is being tested in the pilot project in Vienne, Austria [10].

3.2. Wireless energy transfer

3.2.1. Electromagnetic induction system

The system, which uses electromagnetic induction method, is considered the best prospects direction as it allows transmitting electric energy without direct contact between the receiver and transmitter. The transmission takes place between two adjacent solenoids forming a transformer with linked magnetic field of mutual induction. Alternating current, which flows through the primary winding, is creating a variable magnetic field that creates the alternating electric current in the secondary winding due to induction. The transformer may be with core or coreless, and the transformer primary and secondary winding turns out to be non- electrically connected to each other. Depending on the design of the transformer the energy losses can occur in windings, core, and through the dispersion of electromagnetic field in the environment. Transformer efficiency can reach 98%. Wireless transmission method main disadvantage is its short operating distance. The receiver must be located close to the receiver. With the distance increase the inductive link efficiency decreases substantially.

The resonance transformer principle is being used in order to increase efficiency and the distance between the transmitter and the receiver. Resonance transformer primary winding and secondary winding are having the same oscillating frequencies.

Another way is to increase the efficiency is the non-sinusoidal excitation pulse oscillation circuit use. Energy impulse transmission occurs due to a circuit oscillation cycle. Transmission and perception of the coils is made as single layer solenoids or flat spirals with capacitors, which allows tuning the necessary resonance frequency of the circuit.

The main advantages of this system are as follows: no electrical contact between the electrical power receiver and transmitter, always ready for use, able to use during a short stop, the opportunity to use on moving systems. Weaknesses of the system: short-distance transmission, low efficiency if compared to the contact system, generates high levels of electromagnetic disturbances, design complexity.

3.2.2. Induction system with joint core

Classic transformer transmits energy in the form of a variable magnetic field in the magnetic circuit (rod), besides there is no electrical contact between the primary and secondary windings. When establishing a core consisting of two quickly separable parts, one of which is a primary winding, the other secondary, it is possible to increase the no-contact power transmission efficiency by more than 96%. Another advantage of this method worth to mention is small device dimensions. The disadvantage of this method is the need for mechanical contact to join both core parts during charging.

3.2.3. Resonance induction system

The system consists of two contours which are tuned to the same frequency. Classically it was suggested to recognize the two circuits as a resonant transformer, however, the contour of the coil can be realized as a beam antenna, but the entire power transmission system – as the interaction between the two antennas, which are located near each other within the radiating area [11]. In this case, the combination of receivers and antennas in the transmitting side can be researched as the phased-array antenna grid. Current stage of research has very limited knowledge about the interaction between the two antennas with very close the radiating area, however, other researchers raised assumptions about the possibility of concentrating energy within the radiating area with a phased-array antenna grid [12]. It is likely that phased-array antenna grid usage could reduce or eliminate the energy dissipation in the surrounding objects and decrease adjacent radiation in the environment, which are the main drawbacks for the traditional induction method [13].

3.3. Observed transportation line research

Since the recuperation principle-based hybrid buses are most effective on routes, on which they often have to stop, slow down and change the speed, it is expected that the greatest demand for them, first of all, will be at inner-town routes in Riga, in case of Latvia. At the same time, in order to fully appreciate the application of technical and economic parameters of this bus, ideally, pilot route is expected to be partly in-town and partly out-of-town. Another important requirement would be to obtain sufficient electrical connections for extra recharge at bus stops and final stops without significant additional investment.

Recognising those requirements, the most convenient route would be from Riga centre to airport “Riga”, allowing to assess bus efficiency on different route stages and generated requirements that could be efficient on various Riga routes, as well as other Latvian cities’ and inter-cities’ routes.

For similar reasons, many countries select direct routes between major city centres and airports as pilot projects sites (e.g., ABB project in Geneva).

Reviewing the above mentioned route (Abrenes street – „Riga” airport), it is 11.5 km long, with many stops in city centre and long distances between bus stops outside the city, allowing to precisely assess bus functioning and amount of used electricity during different driving conditions. Infrastructure available at the route final stops and stops complies with pilot project requirements.

Currently, bus total journey time from one final stop to another is 34 minutes, of which 19 minutes are consumed in driving, while 15 minutes are the summary stopping time at the bus stops and parking in the final stop. Depending on what type of wireless charging is chosen, how many stops have extra charging equipment, and how fast is to be the charging process, then these time parameters would remain unchanged or slightly increase. If we compare the above mentioned ABB prototype bus route in Geneva and its flash charging technology, which provides charging at bus stops within 15 seconds, but at the bust final stops within 2 minutes, in case of Riga expected route time could be unchanged.

Feasibility study was carried for the route Airport “Riga” – Riga (current bus route No. 22) to carry out theoretical calculations and to determine the suitability of electric bus and determine if the electric bus could be used for such route and what would be the theoretical limiting requirements for the charging system.

During the feasibility study, it was concluded:

- the total length of the route in one direction is 11,500 meters;
- the total power consumption of the electric bus on the route: 10.72 kWh (calculated from the assumption that specific energy consumption of the bus is 0,93 kWh/km);
- the total charging time depends on the installed capacity of the charger (not considering the actual characteristics of the battery pack and rechargeable power acceptation capabilities).

The total driving time on the route is 34 minutes, from which:

- the actual driving time: 19 minutes;
- idle time at the stops: 15 minutes.

Thus, in theory, the minimum charger's power requirements are 55.94 kW. Project estimated wireless charging system’s amount of power is planned to be 30 kW, therefore the prospective charger configuration is shown in the Table 4.

Table 4. Charger configuration for public transportation line

Final destination point 1	**Busstop1...N**	**...**	**Busstop X**	**....**	**Final destination point 2**
Super-fast charging (conductive)	Quick charging (inductive)		Quick charge for the necessary adjustments along the route (inductive / conductive)		Super-fast charging (conductive)
Charging power: 100 + kW	Charging power: 30 kW		Charging power: 100 + kW		Charging power:100 + kW

Stop X might require a power adjustment based on the actual bus route, because it is not known at how many bus stops on each route bus actually stops. Additionally, the total charging scheme can be represented by the following linear programming optimization task:

Minimising C, with the variables N and P, where

$$\begin{cases} P(sum) = P * t(final\ destination) + \sum_0^{N=23} P(N) * t(N)(wireless) \\ C = 2C(final\ destination) + \sum_0^{N=23} C(n)(wireless) + C(bus) \\ C(each\ position) = f(Px * X) \\ P(bus) = 1.2y * P(nominal) \\ N(number\ of\ busstops), 0 < N < 23 \\ dP(compensation), 0 < dP < P \\ dP = P(busstop\ X) + auxiliary\ P\ (bus) \\ t = f(C) \end{cases} \quad (3)$$

where

P – installed charging power, kW;
C – cost, EUR;

The cost is a function of the power C = P (x) * X, which is not necessarily linear, and must be determined in the research;

t – charging time dependent on the route and the technology used (expense) (a limiting speed of charge batteries super capacitors, etc.) – a particular function should be determined in the study;

dP – required compensatory reserve at the stop X, depending on the actual trip, which ranges from 0 (ideally) to P – in the worst case, if there are no stops between start and final destination, and it is needed to travel the entire route on a single charge;

y – charge reserve in the accumulator or super capacity, %.

As a concrete solution to the system, in the event of bus stopping at all the stops (thus dP = 0) is following:

- Number of busstops: 23, charging (wireless) power 30kW, charging time at the stop is 30 seconds, charge capacity at each stop = 0.25 kWh.
- Final stops = charge power of 75 kW, charging time 4 min, charged energy of 4.97 kWh.
- Minimum On-board battery capacity: 7 kWh, assuming discharge reserve y = 40% (battery is charged at 20–80%).
- Charging speed: 10C (super capacitors are used).

The other extreme charging scenario, in case the bus drives the whole distance without a single stop (dP = P):

- Number of bus stops: 0, wireless charger power 0 kW, charging time in bus stops 0 seconds = charged capacity in each bus stop = 0 kWh.
- Final stops = charging power 160 kW, charging time 4 min, charged energy 10.72 kWh.
- Minimum On-board battery capacity: 20 kWh, assuming discharge reserve y = 40%. (battery is charged 20–80% SoC).
- Charging speed: 23C (super capacitors should be used).

Conclusions

Initial investigation carried during the reporting period leads to the following conclusions:

- Hybrid transportation systems have a permanent place in the public transportation system, especially in view of fossil fuel prices, and the environmental conditions worsening.
- Serious studies and pilot production of small series hybrid transportation units are taking place worldwide. Recently more and more widespread research of use of hybrid system in the public transport states the economical and environmentally friendly viability of electricity driven city transportation systems.
- Rather limited research results are available about the hybrid busses using super capacitors, and about the automatic control principles and electrical wiring principles of combined systems including electric motors, diesel-generator systems, accumulator batteries and super capacitors.

- Research data about medium power (above 20 kW) wireless energy transfer systems and their application for transportation units energy supply are unavailable. Also the technical requirements of such systems are not developed yet.
- The main activities of hybrid vehicles developers are oriented on the vehicle technical development, very limited interest devoted to power supply system. The power grid specialists are not acquainted with the impulse wireless energy transfer, because of no demand for these systems.

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, volume 15, no. 1, 2014 (Abstracts)

Collotta, M., Pau, G., Scatà, G., Campisi, T. A Dynamic Traffic Light Management System Based on Wireless Sensor Networks for the Reduction of the Red-Light Running Phenomenon, *Transport and Telecommunication*, vol. 15, no. 1, 2014, pp. 1–11.

The real-time knowledge of information concerning traffic light junctions represents a valid solution to congestion problems with the main aim to reduce, as much as possible, accidents. The Red Light Running (RLR) is a behavioural phenomenon that occurs when the driver must to choose to cross (or not) the road when the traffic light changes from green to yellow. Most of the time the drivers cross even during transitions from yellow to red and, as a consequence, the possibility of accidents increases. This often occurs because the drivers wait too much in the traffic light queue as a consequence of the fact that the traffic light is not well balanced. In this paper we propose a technique that, based on information gathered through a wireless sensor network, dynamically processes green times in a traffic light of an isolated intersection. The main aim is to optimise the waiting time in the queue and, as a consequence, reduce the RLR phenomenon occurrence.

Keywords: wireless sensor networks, RLR, traffic lights, real-time; intelligent transportation systems

Runyoro, A.-A., K., Zlotnikova, I., Ko, J. Towards Automated Road Information Framework a Case Study of Tanzania, *Transport and Telecommunication*, vol. 15, no. 1, 2014, pp. 12–19.

Traffic congestion problem has been noticed to have a serious impact on the economy of the country in terms of time wastage, energy consumption costs, human loss and environmental effects. Different strategies have been used so far all over the world as shown in the literature review. Intelligent Transportation System (ITS) is a multi-technology approach that can help to handle the issues and create a complete congestion reduction framework. This paper presents a case study for implementing automated road management system using networks in Tanzania, where three cities highly affected by traffic congestion have been studied. Study results show that these cities have not yet implemented new technologies in road traffic management; instead the traffic is controlled using traffic police officers and traffic lights only. The traffic lights use an old technology that cannot manage traffic in relation to the real-time situations. This study proposes components for a framework, which will assist automation in road traffic management. From the review of various existing ITS of which Advanced Traffic Management System (ATMS) and Advanced Travel Information System (ATIS) are subsystems, we have identified the possibility to integrate the two sub-systems within the framework. Three-phase traffic theory has been referred, FOTO and ASDA models are applied to the automatic recognition and tracking of congested spatiotemporal traffic patterns on roads.

Keywords: traffic congestion, urban transportation, Intelligent Transportation Systems (ITS)

Pavlyuk, D. Spatial Aspects of European Airports' Partial Factor Productivity**,** *Transport and Telecommunication,* vol. 15, no. 1, 2014, pp. 20–26.

This research is devoted to discovering of spatial effects in European airports' partial factor productivity (PFP). A set of study PFP indicators includes infrastructural (air transport movements per runway), labour (workload units per employee), and financial (revenue and profit per workload unit) ratios. We utilised a number of appropriate statistical tests (Moran's I., Geary's C., Mantel test, and spatial auto-regression) for revelation of spatial relationships between PFP indicator's values. The tests were separately applied to samples of Spanish (2009–2010) and UK airports (2011–2012) and provided evidences of significant spatial effects in data.

Keywords: airport, partial factor productivity, spatial heterogeneity, spatial dependency, spatial statistics

Orlov, S., Vishnyakov, A. Pattern-Oriented Architecture Design of Software for Logistics and Transport Applications**,** *Transport and Telecommunication,* vol. 15, no. 1, 2014, pp. 27–41.

Software architecture design plays the key role for logistics and transport software engineering. One of the design approaches is to reuse the architectural patterns, which express a fundamental structural organization of software systems and its behaviour. The usage of the proven and tested solutions allows us to increase the software quality and reduce potential risks.

In this paper the technique that allows selecting and evaluating suite of architectural patterns is proposed. It can be used for logistics and transportation software, which is constructed using Multi-tier architecture. The technique allows us to consistently evaluate the impact of specific patterns to software characteristics with a given functionality. Effectiveness and efficiency of the described method is confirmed by a case study.

Keywords: multi-tier architecture, pattern, functional points, coupling and cohesion, logistics and transport software, optimisation, decision

Collotta, M., Denaro, M., Scatà, G., Messineo, A., Nicolosi, G. A Self-Powered Wireless Sensor Network for Dynamic Management of Queues at Traffic Lights, *Transport and Telecommunication,* vol. 15, no. 1, 2014, pp. 42–52.

The dynamic management of traffic light cycles is a really interesting research issue considering modern technologies, which can be used in order to optimise road junctions and then improve living conditions of the roads. Wireless sensor networks represent the most suitable technology, as they are easy to deploy and manage. The data relating to road traffic flows can be detected by the sensor network and then processed through the innovative approach, proposed in this work, in order to determine the right green times at traffic lights. Although wireless sensor networks are characterized by very low consumption devices, the continuous information transmission reduces the life cycle of the whole network. To this end, the proposed architecture provides a technique to power the sensor nodes based on piezoelectric materials, which allow producing potential energy taking advantage of the vibration produced by the passage of vehicles on the road.

Keywords: wireless sensor networks; piezoelectric; traffic lights; intelligent transportation systems

Krainyukov, A., Kutev, V., Andreeva, E. Using Bees Algorithms for Solution of Radar Pavement Monitoring Inverse Problem, *Transport and Telecommunication,* vol. 15, no. 1, 2014, pp. 53–66.

This work has focused on using of Bee Algorithm and Artificial Bee Colony algorithm for solution the inverse problem of subsurface radar probing in frequency domain. Bees Algorithms are used to minimize the aim function. Tree models of road constructions and their characteristics have been used for solution of the subsurface radar probing inverse problem. There has been investigated the convergence of BA and ABC algorithms at minimisation of the aim function of the inverse problem of radar subsurface probing of roadway structures. There has been investigated the impact of free arguments of BA and ABC algorithm, width of the frequency range and width of the searching interval on the error of reconstruction of electro-physical characteristics of layers and duration of algorithm operating. There has been investigated the impact of electro-physical characteristics of roadway structure layers and width of the frequency range on aim function of radar pavement monitoring inverse problem.

Keywords: radar monitoring, inverse problem, electro-physical parameters, Bee Algorithm, Artificial Bee Colony algorithm

Graurs, I., Vizulis, A., Rubenis, A., Laizāns, A. Wireless Energy Supply to Public Transport Units with Hybrid Drive – Trends and Challenges, *Transport and Telecommunication,* vol. 15, no. 1, 2014, pp. 67–76.

This paper describes the initial findings of research project "The Possibilities of Increasing Efficiency of City Bus Hybrid Propulsion Systems by Including Wireless Battery Charging" carried out by „LEO Research Centre" (Competency Centre for Latvian Electrical and Optical Manufacturing Industry).

The project is aimed at developing wireless charging and optimising electric bus propulsion system for modern urban transportation applications. The project runs from the beginning of the 2013 until the end of 2015 and focuses on the sub-theme "Energy and Sustainable Transport".

Keywords: public transport; transport units with hybrid drive; conductive energy transfer; wireless energy transfer

TRANSPORT and TELECOMMUNICATION, 15. sējums, Nr. 1, 2014 (Anotācijas)

Kolota, M., Pau, G., Skata, G., Kampisi, T. Dinamiska luksoforu vadības sistēma, kas balstās uz bezvadu sensoru tīkliem sarkanās gaismas nepārtrauktības fenomena mazināšanai, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2014, 1.–11. lpp.

Reāllaika zināšanas par informāciju, kas attiecas uz luksoforu krustojumiem, ir par sastrēgumu problēmas derīgu risinājumu ar galveno mērķi, cik vien iespējams, samazināt negadījumus. Sarkanās gaismas nepārtrauktība ir uzvedības fenomens, kas notiek tad, kad vadītājam ir jāizvēlas šķērsot (vai nē), ceļu, kad luksofora gaismas signāls mainās no zaļā uz dzelteno. Lielāko daļu vadītāji šķērso krustojumu pat pie dzeltenā pārejas uz sarkano, kā rezultātā, negadījumu iespēju risks palielinās. Tas bieži notiek, jo autovadītāji gaida pārāk ilgi luksofora rindā, un kā sekas tam, luksofora gaismas nav labi sabalansētas. Šajā rakstā mēs ierosinām tehniku, kas, pamatojoties uz informāciju, kas iegūta, izmantojot bezvadu sensoru tīklu, dinamiski apstrādā zaļās gaismas biežumu izolētas krustošanās luksoforā. Galvenais mērķis ir optimizēt gaidīšanas laiku rindā, kā rezultātā, samazinot sarkanās gaismas nepārtrauktības fenomena parādīšanos.

Atslēgvārdi: bezvadu sensoru tīkli, sarkanās gaismas nepārtraukība, luksofors, inteliģentās transporta sistēmas

Ranjoro, A.-A., K., Zlotnikova, I., Ko, Dž. Par ceļu automatizēto informatīvo sistēmu Tanzānijas gadījumā, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2014, 12.–19. lpp.

Satiksmes sastrēgumu problēma tiek atzīmēta kā nopietna ietekme uz valsts ekonomiku, ņemot vērā laika zudumus, enerģijas patēriņa izmaksas, cilvēku zaudējumu un ietekmi uz vidi. Līdz šim ir izmantotas dažādas stratēģijas visā pasaulē, kā tas ir redzams literatūras apskatā. Inteliģentās transporta sistēmas (ITS) ir multi tehnoloģiju pieeja, kas var palīdzēt risināt šos jautājumus un izveidot pilnīgu sastrēgumu samazināšanas sistēmu. Šis raksts sniedz gadījumu izpēti automatizētās ceļu vadības sistēmas īstenošanai, izmantojot tīklus Tanzānijā, kur trīs pilsētas ļoti ietekmē satiksmes sastrēgumi. Pētījuma rezultāti parāda, ka šīs pilsētas vēl nav ieviesušas jaunās tehnoloģijas ceļu satiksmes vadībā, tā vietā satiksme tiek kontrolēta, izmantojot tikai satiksmes policistus un luksoforus. Luksofori izmanto veco tehnoloģiju, kas nespēj vadīt satiksmi attiecībā uz reāllaika situāciju. Šis pētījums piedāvā komponentes pamatu, kas palīdzēs automatizēt ceļu satiksmes vadību.

Atslēgvārdi: satiksmes sastrēgumi, pilsētas pārvadājumi, inteliģentā transporta sistēma (ITS)

Pavļuks, D. Eiropas lidostu daļēja faktoru ražīguma telpiskie aspekti, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2014, 20.–26. lpp

Šis pētījums ir saistīts ar telpisko efektu atrašanu Eiropas lidostu daļēja faktoru ražīguma (DFR) indikatoru lielumos. Pētījuma DFR indikatoru kopumā ir iekļauti infrastruktūras (gaisa transporta kustība uz starta ceļu), darba (gaisa transporta slodzes vienība uz lidostas darbinieku) un finansu (ienākums un peļņa uz gaisa transporta slodzes vienības) koeficienti. Mēs izmantojām piemērotu statistikas testu kopumu (Morana I., Gierija C. un Mantela testu un telpisko auto-regresiju) telpisko attiecību atklāsmei starp DFR indikatoru lielumiem. Statistikas testi tika pielietoti četrām nolasēm – Spānijas (2009–2010) un Lielbritānijas (2011-2012) lidostām. un pierāda nozīmīgu telpisko efektu klātbūtni datos.

Atslēgvārdi: lidosta, daļējs faktoru ražīgums, telpiskais neviendabīgums, telpiskā atkarība, telpiskā statistika

Orlovs, S., Višņakovs. Programmatūras uz modeli orientēts arhitektūras dizains loģistikai un transporta pielietojumiem, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2014, 27.–41. lpp

Programmatūras arhitektūras dizainam ir galvenā loma loģistikas un transporta programmatūras inženierijā. Viena no projekta pieejām ir atkārtoti lietot arhitektūras modeļus, kas izsaka būtisku programmatūras sistēmas strukturālo organizāciju un to uzvedību. Pierādītu un pārbaudītu risinājumu izmantošana ļauj palielināt programmatūras kvalitāti un samazināt iespējamos riskus.

Šajā rakstā tiek piedāvāta tehnika, kas ļauj arhitektūras modeļu komplekta atlasīšanu un novērtēšanu.

Atslēgvārdi: daudzlīmeņu arhitektūra, modelis, funkcionālie punkti, savienojums un kohēzija, loģistikas un transporta programmatūra, optimizācija, lēmums

Kolota, M., Denaro, M., Skata, G., Mesineo, A., Nikolosi, G. Pašdarbojošamies bezvadu sensoru tīkls dinamiskai vadībai rindām pie luksofora, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2014, 42.–52. lpp.

Luksoforu ciklu dinamiska vadība ir ļoti interesants pētījumu jautājums, ņemot vērā mūsdienu tehnoloģijas, ko var izmantot, lai optimizētu ceļu krustojumus un arī uzlabotu dzīves apstākļus uz ceļiem. Bezvadu sensoru tīkli ir vispiemērotākā tehnoloģija, jo tie ir viegli izmantojami un pārvaldāmi. Datus, kas attiecas uz ceļu satiksmes plūsmām, var noteikt ar sensoru tīklu un pēc tam apstrādāt, izmantojot inovatīvu pieeju, kas arī tiek ierosināts šajā darbā, lai noteiktu pareizu zaļās gaismas biežumu luksoforiem. Kaut arī bezvadu sensoru tīkli ir raksturoti kā ļoti zema patēriņa ierīces, nepārtraukta informācijas pārraide samazina dzīves ciklu visā tīklā. Lai to panāktu, ierosinātā arhitektūra nodrošina metodes, lai darbinātu sensoru mezglus, pamatojoties uz pjezoelektriskiem materiāliem, kas ļauj ražot potenciālo enerģiju, izmantojot vibrācijas priekšrocības, ko rada transportlīdzekļu braukšana pa ceļu.

Atslēgvārdi: bezvadu sensoru tīkli; pjezoelektriskie; luksofori; viedās transporta sistēmas

Kraiņukovs, A., Kutevs, V., Andrejeva, E. Bites algoritmu izmantošana radara seguma monitoringa inversās problēmas risināšanai, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2014, 53.–66. lpp.

Šis pētījums ir vērsts uz Bišu Algoritma un Mākslīgās Bišu Kolonijas algoritma izmantošanu pazemes radara zondēšanas frekvenču domēnā inversās problēmas risināšanā. Bites algoritmi tiek izmantoti, lai samazinātu mērķa funkciju. Ceļu konstrukciju kokmodeļi un to īpašības ir izmantotas pazemes radara zondēšanas inversās problēmas risinājumam. Ir pētīta BA un ABC algoritmu konverģence ceļa struktūras pazemes radara zondēšanas inversās problēmas mērķa funkcijas samazināšanā. Ir pētīta ceļa struktūras slāņu elektro-fizikālo īpašību ietekme un frekvenču diapazona platums uz radara seguma monitoringa inversās problēmas mērķa funkciju.

Atslēgvārdi: radara monitorings, inversā problēma, elektro-fizikālie parametri, Bišu Algoritms, Mākslīgās Bišu Kolonijas algoritms

Graurs, I., Vizulis, A., Rubenis, A., Laizāns, A. Bezvadu energoapgāde sabiedriskā transporta vienībām ar hibrīda piedziņu – tendences un izaicinājumi, *Transport and Telecommunication,* 15. sēj., Nr. 1, 2013, 67.–76. lpp.

Šajā rakstā tiek parādīti sākotnējie atklājumi pētniecības projektā „Par efektivitātes palielināšanu pilsētas autobusu hibrīda piedziņas sistēmām, iekļaujot bezvadu akumulatoru uzlādes iespējas", ko veic „LEO pētījumu centrs" (Kompetences centrs Latvijas elektrisko un optisko ierīču ražošanas rūpniecībā).

Projekta mērķis ir attīstīt bezvadu uzlādi, kā arī elektrisko autobusu dzinējspēka sistēmu optimizācija mūsdienu pilsētas transporta pielietojumos. Projekts ilgst no 2013. gada sākuma līdz 2015. gada beigām, un ir vērsts uz apakštēmu „Enerģētika un ilgtspējīgs transports".

Atslēgvārdi: sabiedriskais transports, transporta vienības ar hibrīda piedziņu; bezvadu enerģijas pārnesums

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

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1. Gibson, E.J. (1977) The performance concept in building. In: *Proceedings of the 7th CIB Triennial Congress*, Edinburgh, September 1977. London: Construction Research International, pp. 129-136.
2. Kayston, M. and Fried, W. R. (1969) *Avionic Navigation Systems.* New York: John Wiley and Sons Inc.
3. Ministerial Council on Drug Strategy. (1997) *The national drug strategy: Mapping the future*. Canberra: Australian Government Publishing Service.
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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