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CONSTRUCTION AND INVESTIGATION OF ONE CONTINUOUS NONSTATIONARY 3D MATHEMATICAL MODEL FOR MONITORING OF NOISE POLLUTION IN THE AREA SURROUNDING AN AIRPORT

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This report is based on a scientific work which is dedicated to the development and research of an unsteady 3D mathematical model for the constant monitoring of the environmental situation of air and water in areas near an airport (airport 'RIX', City of Riga is used as an example). Mainly noise (acoustic) pollution is considered – the anthropogenic noise which interferes with the activities of humans and other living organisms. The report proposes a mathematical model, consisting of a system of two differential equations in partial derivatives with small parameters of the initial and mixed boundary conditions and the relevant consistency conditions. In addition, using monotone difference approximation, the proposed mathematical model is sampled, and the resulting second-order discrete model is solved numerically.

Keywords*:* noise pollution, dynamics of sound-wave propagation, system of PDE with small parameters, continuous mathematical model, finite-difference approximation

1. Introduction

In modern cities vehicles are a major source of noise (acoustic) pollution. Near airports the prevailing source of acoustic noise is, of course, aircraft. The need to increase the capacity of aircraft and the speed of their flight has led to increases in the thrust of their power systems, resulting in dramatic increases in the level of sound they generate. Increasing the level of use of civil aircraft, in particular operating aircraft in the 'jump' mode, with the corresponding increase in the number f takeoffs and landings, has lead to adverse effects on high noise levels experienced by residents in areas surrounding airports. Noise abatement in the aviation industry has become a part of the general struggle for cleaner environment.

Aviation acoustics problems' solving can be achieved by an integrated implementation of a number of activities, taking into consideration technical limitations and economic costs. Emphasis is placed on reducing noise at source; specifically considering the acoustic impact in the design of equipment, and the application of methods to reduce noise along its path of dissemination.

The main noise sources of aircraft are aero-gas-dynamics flows in propulsion systems, air flow around the apparatus, and the gas flow of on-board equipment systems. Aeroacoustics mostly deals with sound created by aerodynamic forces and disturbances that occur in the air stream itself. Since the formation of aerodynamic noise is the result of the transfer of energy from vortex perturbations to acoustic vibrations, the successful solution of aeroacoustics problems is largely achieved by the aerodynamic encompassment of unsteady flows, particularly turbulent flows.

With intensive 24-hour operation, airport noise levels reach 80 dBA in the daytime and 78 dBA at night time, with maximum levels ranging from 92 till 108 dBA. This is considered an unacceptable level of acoustic noise.

The increase of the sound level in summer time is due to the increased number of flights. However, this can be decreased in some locations due to the screening effect of dense green plantation. Therefore, the noise level depends on the season, the weather conditions in the area of the airport and other factors.

Physiological-hygienic studies in France showed that the noise of passing aircraft, depending on the type of person, may have different, but similarly irritating effects on different people. To determine the reactions of people to the effects of aircraft noise, about 3000 people in 34 urban settlements and rural settlements, located within a radius of 30 km from an airport were interviewed using a special questionnaire. Interviewees noted that aircraft noise was annoying, tiring, caused headaches, palpitations, disturbed sleep and rest, and obstructed concentration on any work. People in urban areas were more likely than people in rural areas to complain about aircraft noise (20-25%).This apparently can be explained by citizens' increased sensitivity to noise, due to the impact it has on them, despite their being accustomed to industrial, transport and municipal noise. The biggest concerns were experienced by people suffering from diseases of the nervous and cardiovascular systems and the gastrointestinal tract. The percentage of complaints from this part of the population (64-90%) was much greater than that from healthy people (39-52%).

The possibility of 24-hour monitoring and control of noise levels at airports using permanent measuring equipment has existed for some time. Airport authorities have shown increasing interest in the installation and use of such equipment. Factors determining the loudness of sound are so complex, that in the relevant field of acoustics important theoretical work and experimental research is still being carried out. One such factor is the frequency dependence of the sensitivity of human hearing (the maximum sensitivity of $2 \div 5$ kHz and the minimum in the high and low frequencies).

The airport acoustic passport is a static model of noise distribution in the airport area (zonal distribution of the noise). It is created as a result of a special commission (a one-time measurement of marginal and average daily noise levels, its projection onto the map and topography of the area, and the designation of aircraft noise contours). However, as a result of intensive development of airport infrastructure and of the aviation industry as a whole, certain tools for the monitoring and analysis of the dynamics of noise are required. The model should be flexible and be able to take many factors into account. Discrete sound meter values can only serve as a tool to control zones 'of local acoustic pollution', not provide a picture of the dynamics of the pollution.

For a comprehensive solution for the environmental monitoring of the dynamics of the noise, there is a need to develop adequate mathematical models that can take into account different sets of environmental factors / parameters and their own complex relationships.

2. Mathematical Model of Noise Propagation

Before proceeding to the construction of a mathematical model to determine the dynamics of noise pollution in the 'parallelepiped' area of the airport, it should be pointed out that in almost all theoretical studies of acoustic waves held to date (acoustic-gravity waves, inwardly-gravity waves, etc), none have developed mathematical models which consider together (i.e. in relationships) the fundamental factors of the dissipative medium, such as the nonlinearity and viscosity of the environment, the stratification of geophysical environments, zonal winds and other factors which must be considered. In these studies, internal relationships and the resulting impact on the distribution of acoustic waves in the developed mathematical models were considered in isolation from each other. As a result, none of the existing mathematical models so far can explain the full range of atmospheric wave perturbations generated by different anthropogenic sources. However, in the 1990s, due to the increase in the speed of computers, as well as the revolutionary development of computational hydrodynamics and gas dynamics in the late 20th century, new separate theoretical and experimental trends in atmospheric physics were explored, including the theory of propagation of atmospheric waves with the help of the numerical solutions of nonlinear equations of geophysical hydrodynamics and gas dynamics. This theory was further developed into a powerful apparatus of numerical methods, allowing the majority of the fundamental factors of a dissipative environment to be considered together. These significantly affect the distribution of acoustic-gravity waves with finite amplitude in the Earth's atmosphere. It is important to note that despite the huge amount of experimental data, only a relatively small number of scientific studies have attempted to explain from a theoretical perspective the observed acoustic disturbances in the atmosphere generated by both terrestrial and atmospheric sources. These efforts have played a significant role in understanding the mechanisms of the complex relationships in the lithosphere-atmosphere-ionosphere system, but the full interpretation of observational data is so far unavailable.

In this thesis, to solve the problem of non-stationary ecological monitoring of the effect of noise, it is proposed to use mathematical modelling of acoustic wave emissions, with the subsequent construction of the contour of propagation of aircraft noise in real time. Sound meters installed at airports record discrete values of noise levels at the control points (usually the noisiest locations). By processing the data using mathematical tools, with a priori data about the topography of the airport zone, we can obtain a detailed model of the spread of noise.

The following is a continuous non-stationary mathematical model describing the spread of noise while considering some of the major factors of the dissipative medium. The proposed model is based on the system of Maxwell equations and telegraph equations, given the fact, that the force of gravity and stratification of geophysical environments strongly modify sound waves propagating through them.

The system of equations with small parameters $\varepsilon_i \ (i=1,2)$; initial conditions and boundary conditions of mixed type:

$$\begin{cases} \begin{cases} \dfrac{\partial^2 u(t,x)}{\partial t^2} + \varepsilon_1 \cdot \dfrac{\partial u(t,x)}{\partial t} = \Delta u(t,x) + \rho(t,x), \ x \in D, \ t \in [0,T], \\ \dfrac{\partial^2 \rho(t,x)}{\partial t^2} + \varepsilon_2 \cdot \dfrac{\partial \rho(t,x)}{\partial t} = \Delta \rho(t,x) + u(t,x) + F(t,x), \ x \in D, \ t \in [0,T], \end{cases} \\ \begin{cases} u(t,x)\big|_{t=0+0} = u_0(x), \ x \in \overline{D}, \\ \rho(t,x)\big|_{t=0+0} = \rho_0(x), \ x \in \overline{D}, \end{cases} \\ \begin{cases} u(t,x)\big|_{x_i=l_1^{\{i\}}+0} = u_1^{\{i\}}(t; x/\{x_i\}), \ x/\{x_i\} \in \overline{D}/[l_1^{\{i\}}, l_2^{\{i\}}], i=\overline{1,3}, \ t \in [0,T], \\ u(t,x)\big|_{x_i=l_2^{\{i\}}-0} = u_2^{\{i\}}(t; x/\{x_i\}), \ x/\{x_i\} \in \overline{D}/[l_1^{\{i\}}, l_2^{\{i\}}], i=\overline{1,3}, \ t \in [0,T], \end{cases} \\ \begin{cases} \left.\dfrac{\partial \rho(t,x)}{\partial x_i}\right|_{x_i=l_1^{\{i\}}+0} = \rho_1^{\{i\}}(t; x/\{x_i\}), \ x/\{x_i\} \in \overline{D}/[l_1^{\{i\}}, l_2^{\{i\}}], i=\overline{1,3}, \ t \in [0,T], \\ \left.\dfrac{\partial \rho(t,x)}{\partial x_i}\right|_{x_i=l_2^{\{i\}}-0} = \rho_2^{\{i\}}(t; x/\{x_i\}), \ x/\{x_i\} \in \overline{D}/[l_1^{\{i\}}, l_2^{\{i\}}], i=\overline{1,3}, \ t \in [0,T], \end{cases} \end{cases} \tag{1}$$

Consistency conditions of initial and boundary functions:

$$\begin{aligned} & u_1^{\{1\}}(t, l_1^{\{2\}}+0, x_3) = u_1^{\{2\}}(t, l_1^{\{1\}}+0, x_3), \ t \in [0, T], \ x_3 \in \left[l_1^{\{3\}}, l_2^{\{3\}} \right]; \\ & u_1^{\{1\}}(t, x_2, l_1^{\{3\}}+0,) = u_1^{\{3\}}(t, l_1^{\{1\}}+0, x_2), \ t \in [0, T], \ x_2 \in \left[l_1^{\{2\}}, l_2^{\{2\}} \right]; \\ & u_1^{\{2\}}(t, x_1, l_1^{\{3\}}+0,) = u_1^{\{3\}}(t, x_1, l_1^{\{1\}}+0), \ t \in [0, T], \ x_1 \in \left[l_1^{\{1\}}, l_2^{\{1\}} \right]; \\ & u_2^{\{1\}}(t, l_2^{\{2\}}-0, x_3) = u_2^{\{2\}}(t, l_2^{\{1\}}-0, x_3), \ t \in [0, T], \ x_3 \in \left[l_1^{\{3\}}, l_2^{\{3\}} \right]; \\ & u_2^{\{1\}}(t, x_2, l_2^{\{3\}}-0,) = u_2^{\{3\}}(t, l_2^{\{1\}}-0, x_2), \ t \in [0, T], \ x_2 \in \left[l_1^{\{2\}}, l_2^{\{2\}} \right]; \\ & u_2^{\{2\}}(t, x_1, l_2^{\{3\}}-0,) = u_2^{\{3\}}(t, x_1, l_2^{\{1\}}-0), \ t \in [0, T], \ x_1 \in \left[l_1^{\{1\}}, l_2^{\{1\}} \right]; \end{aligned} \tag{2}$$

$$\begin{aligned} & u_0(l_1^{\{1\}}+0, x_2, x_3) = u_1^{\{1\}}(0+0, x_2, x_3), \ x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], i=2,3; \\ & u_0(x_1, l_1^{\{2\}}+0, x_3) = u_1^{\{2\}}(0+0, x_1, x_3), \ x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], i=1,3; \\ & u_0(x_1, x_2, l_1^{\{3\}}+0) = u_1^{\{3\}}(0+0, x_1, x_2), \ x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], i=1,2; \\ & u_0(l_2^{\{1\}}+0, x_2, x_3) = u_2^{\{1\}}(0+0, x_2, x_3), \ x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], i=2,3; \\ & u_0(x_1, l_2^{\{2\}}+0, x_3) = u_2^{\{2\}}(0+0, x_1, x_3), \ x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], i=1,3; \\ & u_0(x_1, x_2, l_2^{\{3\}}+0) = u_2^{\{3\}}(0+0, x_1, x_2), \ x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], i=1,2; \end{aligned}$$

$$\frac{\partial \rho_0 (l_1^{\{1\}} + 0, x_2, x_3)}{\partial x_1} = \rho_1^{\{1\}} (0 + 0, x_2, x_3), \; x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], \; i = 2,3;$$
$$\frac{\partial \rho_0 (x_1, l_1^{\{2\}} + 0, x_3)}{\partial x_2} = \rho_1^{\{2\}} (0 + 0, x_1, x_3), \; x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], \; i = 1,3;$$
$$\frac{\partial \rho_0 (x_1, x_2, l_1^{\{3\}} + 0)}{\partial x_3} = \rho_1^{\{3\}} (0 + 0, x_1, x_2), \; x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], \; i = 1,2;$$
$$\frac{\partial \rho_0 (l_2^{\{1\}} + 0, x_2, x_3)}{\partial x_1} = \rho_2^{\{1\}} (0 + 0, x_2, x_3), \; x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], \; i = 2,3; \tag{3}$$
$$\frac{\partial \rho_0 (x_1, l_2^{\{2\}} + 0, x_3)}{\partial x_2} = \rho_2^{\{2\}} (0 + 0, x_1, x_3), \; x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], \; i = 1,3;$$
$$\frac{\partial \rho_0 (x_1, x_2, l_2^{\{3\}} + 0)}{\partial x_3} = \rho_2^{\{3\}} (0 + 0, x_1, x_2), \; x_i \in \left[l_1^{\{i\}}, l_2^{\{i\}} \right], \; i = 1,2;$$

where

- $x = (x_1, x_2, x_3) \in \overline{D} \overset{def}{\equiv} \left[l_1^{\{1\}}, l_2^{\{1\}} \right] \times \left[l_1^{\{2\}}, l_2^{\{2\}} \right] \times \left[l_1^{\{3\}}, l_2^{\{3\}} \right], \; D = \overline{D} / \partial D;$
- $l_1^{\{i\}} \; \left(i = \overline{1,3} \right)$ and $l_1^{\{i\}} \; \left(i = \overline{1,3} \right)$ are respectively original and finitesimal coordinates for edges of the 3D 'parallelepiped' airport area/zone $\overline{D}$, where the expansion of noise pollution is investigated;
- $t \in [0, T]$, T is the end of the time segment during which the process is investigated;
- numeric parameters $\varepsilon_i \; (i = 1,2)$ are relaxation coefficients;
- the function $u(t,x) = u(t, x_1, x_2, x_3) \in C^{2,2} \left\{ [0,T] \times \overline{D} \right\}$ characterizes the "quantity" of acoustic pollution (i.e. weighted-noise power) in the spatial point $x \in \overline{D}$ at the time point $t \in [0, T]$, and this function is unknown;
- the function $\rho(t,x) = \rho(t, x_1, x_2, x_3) \in C^{2,2} \left\{ [0,T] \times \overline{D} \right\}$ characterizes environment density (i.e. density of the 'parallelepiped' area $\overline{D}$) in the spatial point $x \in \overline{D}$ at the time point $t \in [0, T]$, and this function is also unknown;
- the initial functions $u_0(x), \; x \in \overline{D}$ and $\rho_0(x), \; x \in \overline{D}$ are assumed to be specified, moreover $u_0(x) \in C\left\{ \overline{D} \right\}, \; \rho_0(x) \in C\left\{ \overline{D} \right\};$
- the boundary functions $u_j^{\{i\}}(t) \in C\{[0,T]\} \; \left(i = \overline{1,3}; \; j = 1,2 \right), \; \rho_j^{\{i\}}(t) \in C\{[0,T]\} \; \left(i = \overline{1,3}; \; j = 1,2 \right)$ are also assumed to be a priori prescribed functions;
- the given function $F(t,x)$ describes the intensity of external sources that have an impact on the environment density $\rho(t,x)$ at $(t,x) \in [0,T] \times \overline{D}$.

It is required to determine uniquely the sought functions $u(t,x) \in C^{2,2}\{[0,T] \times \overline{D}\}$ and $\rho(t,x) \in C^{2,2}\{[0,T] \times \overline{D}\}$ from the model (1)-(3).

This thesis does not study the question of the analytical solution of the proposed continuous non-stationary model (1)-(3) However, in this section, with the simplifying assumption that the density $\rho(t,x) = \rho(t, x_1, x_2, x_3) \in C^{2,2} \left\{ [0,T] \times \overline{D} \right\}$ of a dissipative medium $\overline{D}$ is known a priori, we will investigate the possibility of an analytical solution of the corresponding simplified model in reference to only one unknown function $u(t,x) = u(t, x_1, x_2, x_3) \in C^{2,2} \left\{ [0,T] \times \overline{D} \right\}$. This can be easily obtained from (1)-(3) under the above simplifying assumptions.

On the assumption that in model (1)-(3) function $\rho(t,x)=\rho(t,x_1,x_2,x_3)\in C^{2,2}\left\{[0,T]\times\overline{D}\right\}$ is somehow defined, instead of model (1)-(3), we shall have the following statement of the initial-boundary problem for the unknown function $u(t,x)=u(t,x_1,x_2,x_3)\in C^{2,2}\left\{[0,T]\times\overline{D}\right\}$, which describes the 'amount' of noise pollution at any moment of time $t\in[0,T]$ at the arbitrary point x of the dissipative medium $\overline{D}$, which can be identified with a segment $[0,l]$ (i.e. $\overline{D}=[0,l]$) for simplification of mathematical calculations (without any prejudice to the main idea) only:

$$\frac{\partial u(x,t)}{\partial t}+\tau_r\cdot\frac{\partial^2 u(x,t)}{\partial t^2}=a^2\cdot\frac{\partial^2 u(x,t)}{\partial x^2}+f(x,t), \tag{4}$$
$$0<x<l<\infty,\ 0<t\le T<\infty,$$

$$u(x,t)\big|_{t=0}=u_0(x),\ 0\le x\le l, \tag{5}$$

$$\left.\frac{\partial u(x,t)}{\partial t}\right|_{t=0}=u_1(x),\ 0\le x\le l, \tag{6}$$

$$\left.\frac{\partial u(x,t)}{\partial x}\right|_{x=l}=0,\ 0\le t\le T, \tag{7}$$

$$-k\cdot\left.\frac{\partial u(x,t)}{\partial x}\right|_{x=0}+\beta^m\cdot\left\{u(x,t)\big|_{x=0}-\theta(t)\right\}^m=0, \tag{8}$$

where

$$0\le t\le T,\ m,\beta=const>0$$

$$\left.\begin{aligned}&u_0'(l)=u_1'(l)=0,\\&-k\cdot u_0'(0)+\beta^m\cdot\{u_0(0)-\theta(0)\}^m=0,\\&m\cdot u_0'(0)\cdot\{u_1(0)-\theta'(0)\}=u_1'(0)\cdot\{u_0(0)-\theta(0)\}.\end{aligned}\right\} \tag{9}$$

It is not difficult to show that (see [7-10]) the problem (4)-(9) can be reduced to the problem of finding the unknown function $h(\varphi)$ from the following nonlinear integral equation:

$$h(\varphi)=g(\varphi)\cdot\left\{1-\int_0^{\varphi}G(\varphi,\psi)\cdot h(\psi)\,d\psi\right\}^m, \tag{10}$$

where the functions $h(\varphi)$, $g(\varphi)$, $G(\varphi,\psi)$ and the variables φ, ψ have the following significances if we consider the corresponding problem for equation (4):

$$h(\varphi)\overset{def}{\equiv}k\cdot\beta^{-m}\cdot\vartheta_2\left(\frac{k\cdot\tau_r}{\beta^m\cdot a^2}\cdot\varphi\right),$$

$$g(\varphi)\overset{def}{\equiv}\overline{g}\left(\frac{k\cdot\tau_r}{\beta^m\cdot a^2}\cdot\varphi\right),$$

$$G(\varphi,\psi)\overset{def}{\equiv}\overline{G}\left(0,0,\frac{k\cdot\tau_r}{\beta^m\cdot a^2}\cdot(\varphi-\psi)\right),$$

$$\overline{g}(t)\overset{def}{\equiv}e^{-\frac{m-1}{2\tau_r}t}V^m(t),$$

$$\vartheta_2(t)\overset{def}{\equiv}\left.\frac{\partial\vartheta(x,t)}{\partial x}\right|_{x=0},$$

$$\vartheta(x,t)\overset{def}{\equiv}e^{\frac{t}{2\tau_r}}\{u(x,t)-\theta(t)\},\ 0\le x\le l,\ 0\le t\le T,$$

$$V(t)\overset{def}{\equiv}\int_0^l\left.\frac{\partial G(x,\xi,t)}{\partial t}\right|_{x=0}\vartheta_0(\xi)\,d\xi+\int_0^l G(x,\xi,t)\big|_{x=0}\vartheta_1(\xi)\,d\xi+\int_0^t d\tau\int_0^l G(x,\xi,t-\tau)\big|_{x=0}F(\xi,\tau)\,d\xi,$$

$$F(x,t)\overset{def}{\equiv}e^{\frac{t}{2\tau_r}}\left\{\frac{1}{\tau_r}f(x,t)-\frac{1}{\tau_r}\theta'(t)-\theta''(t)\right\},$$

$$\overline{G}(x,\xi,t-\tau)\big|_{\xi=0,x=0}\overset{def}{\equiv}\frac{G(x,\xi,t-\tau)\big|_{\xi=0,x=0}}{V(t)},\ V(t)\ne 0,$$

$$G(x,\xi,t)\overset{def}{\equiv}4\tau_r\sum_{n=1}^{N}\cos\left(\frac{\pi nx}{l}\right)\cos\left(\frac{\pi n\xi}{l}\right)\frac{\sinh\left(t\frac{\sqrt{\left|\left(2a\pi n\sqrt{\tau_r}\right)^2-l^2\right|}}{2l\tau_r}\right)}{\sqrt{\left|\left(2a\pi n\sqrt{\tau_r}\right)^2-l^2\right|}}+$$

$$+4\tau_r\sum_{n=N+1}^{\infty}\cos\left(\frac{\pi nx}{l}\right)\cos\left(\frac{\pi n\xi}{l}\right)\frac{\sin\left(t\frac{\sqrt{\left(2a\pi n\sqrt{\tau_r}\right)^2-l^2}}{2l\tau_r}\right)}{\sqrt{\left(2a\pi n\sqrt{\tau_r}\right)^2-l^2}}+\frac{2\tau_r}{l}\sinh\left(\frac{t}{2\tau_r}\right),$$

where

$$\varphi=\frac{\beta^m a^2}{k\tau_r}t,$$

$$\psi=\frac{\beta^m a^2}{k\tau_r}\tau.$$

Without loss of generality in the expression for the Green function $G(x,\xi,t)$ we have assumed the existence of such a natural number N that for all $n=\overline{1,N}$ the following inequality is valid: $\tau_r\le\left(\frac{l}{2a\pi n}\right)^2$, and for the natural numbers $n=N+1,N+2,\ldots$ the following inequality is valid: $\tau_r>\left(\frac{l}{2a\pi n}\right)^2$.

Having designated the solution of the nonlinear integral equation (10) as $h_{exact}^{hyp.heat}(\varphi)$, then the solution of the original problem (4)-(9) is the function

$$u(x,t) = \theta(t) + e^{-\frac{t}{2\tau_r}}\left\{\int_0^l \frac{\partial G(x,\xi,t)}{\partial t}\left[u_0(\xi)-\theta(0)\right]d\xi + \int_0^l G(x,\xi,t)\left[\frac{u_0(\xi)}{2\tau_r} + u_1(\xi) - \frac{\theta(0)}{2\tau_r} - \theta'(0)\right]d\xi + \right.$$

$$\left. + \int_0^t e^{\frac{\tau}{2\tau_r}}d\tau \int_0^l G(x,\xi,t-\tau)\left[\frac{f(\xi,\tau)}{\tau_r} - \frac{\theta'(\tau)}{\tau_r} - \theta''(\tau)\right]d\xi - \frac{a^2\beta^m}{\tau_r k}\int_0^t G(x,\xi,t-\tau)\Big|_{\xi=0} h_{exact}^{hyp.heat}\left(\frac{a^2\beta^m}{\tau_r k}\tau\right)d\tau\right\}.$$

Thus, the last formula determines a desired solution of the general problem (4)-(9) if the integral equation (10) can be solved. For solving the nonlinear Volterra integral equation of the second kind (10) we will introduce the following definition:

Definition. *The functional* $H(\varphi,h)\ (\varphi>0)$ *we will be said to be Volterra functional if* H *is a number which depends on parameter values and depends on values of function* $h(\psi)$ *in the half-open interval* $0 \le \psi < \varphi$.

Now let us consider the functional equation:

$$h(\varphi) = H(\varphi,h). \tag{11}$$

It is obvious that our integral equation (10) belongs to the type of functional equation, where

$$H(\varphi,h) \overset{def}{\equiv} g(\varphi)\left\{1-\int_0^\varphi G(\varphi,\psi)h(\psi)d\psi\right\}^m . \tag{12}$$

Let us assume that the above-defined functional $H(\varphi,h)$ satisfies the following conditions:

A. If $h(\psi)\in C[0,\varphi)$ then the functional $H(\varphi,h)$ is well defined and $H(\varphi,h)$ is a continuous function on variable φ;

B. If $h_1(\psi)$ and $h_2(\psi)$ are continuous functions on variable ψ and if $|h_1(\psi)|<M$, $|h_2(\psi)|<M$ for $0 \le \psi \le \varphi_0$ then the following inequality is valid:

$$|H(\varphi,h_1)-H(\varphi,h_2)| \le \int_0^\varphi K(\varphi,\psi;M,\varphi_0)\cdot|h_1(\psi)-h_2(\psi)|d\psi \quad \text{for } \forall\varphi\in[0,\varphi_0],$$

where

$$K(\varphi,\psi;M,\varphi_0) \overset{def}{\equiv} \frac{K_1(M,\varphi_0)}{K_2(\varphi,\psi)};$$

$K_1(M,\varphi_0)$ is a constant dependent on M and φ_0 ;

$$K_2(\varphi,\psi) \overset{def}{\equiv} (\phi-\psi)^\alpha,\ \alpha\in[0,1)\cdot$$

Remark 1.*Through immediate verification it is possible to ensure that these two propositions are valid for our functional* $H(\varphi,h)$ *defined by formula (10).*

Theorem. *Should some functional (not merely our functional (12))* $H(\varphi,h)$ *satisfies the above-enumerated conditions A and B. Then the functional equation (11) has a unique solution in some segment* $0 \le \varphi \le \varphi_0$.

Theorem proof

We will prove this theorem using a step-by-step method. For this purpose, consider the functional transformation $S(\varphi)=H(\varphi,h)$, which transforms the function $h(\varphi)$ to $S(\varphi)$. Our main task is following: we must determine such φ_0 in order that the continuous function $h(\varphi)$ with the property $|h(\psi)|<M$, $0\le\psi\le\varphi_0$ is transformed to a function possessing the same property. This can be achieved in the following way: we assume $\overline{H}(\varphi)\overset{def}{\equiv}H(\varphi,h)\big|_{h=0}$. Evidently $\overline{H}(\varphi)$ is a continuous function (by the property A). We assume $L\overset{def}{\equiv}\max\limits_{0\le\varphi\le\varphi_0}\left|\overline{H}(\varphi)\right|$. Then for the function $h(\varphi)$, where $|h(\varphi)|<M$ and $M>L$, we have the following inequality:

$$\left|H(\varphi,h)-H(\varphi,h)\big|_{h=0}\right|\le M\cdot\int_0^{\varphi}K(\varphi,\psi;M,\varphi_0)\,d\psi=M\cdot K_1(M,\varphi_0)\cdot\frac{\varphi^{1-\alpha}}{1-\alpha}.$$

From here

$$|S(\varphi)|=|H(\varphi,h)|\le L+M\cdot K_1(M,\varphi_0)\cdot\frac{\varphi^{1-\alpha}}{1-\alpha}.$$

It is clear that for $\forall M>L$ it is possible to find such φ_1 $(\varphi_1<\varphi_0)$ that

$$L+M\cdot K_1(M,\varphi_0)\cdot\frac{\varphi_1^{1-\alpha}}{1-\alpha}=M.$$

From here we obtain the final value of the unknown number φ_1 as

$$\varphi_1=\left(\frac{(M-L)\cdot(1-\alpha)}{M\cdot K_1(M,\varphi_0)}\right)^{\frac{1}{1-\alpha}}. \tag{13}$$

Thus, we establish the following fact: if $|h(\varphi)|<M$ for $0\le\varphi\le\varphi_1$ then $|S(\varphi)|<M$ for $0\le\varphi\le\varphi_1$. Now let us take any function $h_0(\varphi)$ that $|h_0(\varphi)|<M$ in the segment $0\le\varphi\le\varphi_1$. For the sake of definiteness we can take as an example, $h_0(\varphi)=0$. Then we can construct the successive approximations $h_1(\varphi),h_2(\varphi),\ldots,h_n(\varphi),\ldots$ by principle

$$h_n(\varphi)=H(\varphi,h_{n-1}). \tag{14}$$

Then, owing to (13) it is clear that $|h_n(\varphi)|<M$ for $\forall n\in N$.

From here we can write

$$|h_n(\varphi)-h_{n-1}(\varphi)|=|H(\varphi,h_{n-1})-H(\varphi,h_{n-2})|\le K_1(M,\varphi_0)\cdot\int_0^{\varphi}\frac{h_{n-1}(\psi)-h_{n-2}(\psi)}{K_2(\varphi,\psi)}\,d\psi. \tag{15}$$

Here it is significant that in the inequality (15) the constant $K_1(M,\varphi_0)$ is identical for all $n\in N$.

Thus, we receive the following estimations:

$$h_0(\varphi)=0,$$

$$|h_1(\varphi)-h_0(\varphi)|=\left|H(\varphi,h)\big|_{h=0}\right|\le L,$$

$$\left|h_2(\varphi)-h_1(\varphi)\right| \le L\cdot K_1(M,\varphi_0)\cdot\int_0^{\varphi}\frac{d\psi}{K_2(\varphi,\psi)} = L\cdot K_1(M,\varphi_0)\cdot\varphi^{1-\alpha}\cdot\int_0^{1}\frac{d\psi}{(1-\psi)^{\alpha}} =$$

$$=\left\{\begin{matrix}\int_0^1 (1-\psi)^{\beta-1}\cdot\psi^{\gamma-1}d\psi = \dfrac{\Gamma(\beta)\cdot\Gamma(\gamma)}{\Gamma(\beta+\gamma)}, \\ where\ \ \Gamma(\bullet)\ is\ \ the\ 2nd\ kind\ Euler\ integral\end{matrix}\right\} = L\cdot K_1(M,\varphi_0)\cdot\frac{\Gamma(1-\alpha)}{\Gamma(2-\alpha)}\cdot\varphi^{1-\alpha},$$

$$\left|h_3(\varphi)-h_2(\varphi)\right| \le L\cdot K_1^2(M,\varphi_0)\cdot\frac{\Gamma(1-\alpha)}{\Gamma(2-\alpha)}\cdot\int_0^{\varphi}\frac{\psi^{1-\alpha}d\psi}{K_2(\varphi,\psi)} = L\cdot K_1^2(M,\varphi_0)\cdot\frac{\Gamma(1-\alpha)}{\Gamma(2-\alpha)}\cdot\varphi^{2\cdot(1-\alpha)}\cdot\int_0^1\frac{\psi^{\alpha}d\psi}{(1-\psi)^{\alpha}} =$$

$$= L\cdot K_1^2(M,\varphi_0)\cdot\frac{\Gamma^2(1-\alpha)}{\Gamma\left(1+2\cdot(1-\alpha)\right)}\cdot\varphi^{2\cdot(1-\alpha)},\ \ldots,$$

$$\left|h_n(\varphi)-h_{n-1}(\varphi)\right| \le L\cdot K_1^{n-1}(M,\varphi_0)\cdot\frac{\Gamma^{n-1}(1-\alpha)}{\Gamma\left(1+(n-1)\cdot(1-\alpha)\right)}\cdot\varphi^{(n-1)\cdot(1-\alpha)}. \tag{16}$$

Using the so-called Stirling formula

$$\Gamma(\beta) = \sqrt{\frac{2\cdot\pi}{\beta}}\cdot\left(\frac{\beta}{e}\right)^{\beta}\cdot\left(1+O\left(\frac{1}{\beta}\right)\right) > \sqrt{\frac{2\cdot\pi}{\beta}}\cdot\left(\frac{\beta}{e}\right)^{\beta}$$

from (16) we will obtain

$$\left|h_n(\varphi)-h_{n-1}(\varphi)\right| \le L\left\{K_1(M,\varphi_0)\Gamma(1-\alpha)\right\}^{n-1}\cdot\left(\frac{e}{1+(n-1)(1-\alpha)}\right)^{(n-1)\cdot(1-\alpha)}\sqrt{\frac{1+(n-1)(1-\alpha)}{2\pi}}\varphi^{(n-1)\cdot(1-\alpha)}. \tag{17}$$

From (17) it follows that the successive approximations $h_1(\varphi), h_2(\varphi),\ldots,h_n(\varphi),\ldots$ are uniformly convergent to some function $h(\varphi)$ in the open-interval $(0,\varphi_1)$, at that $\left|h(\varphi)\right| < M$. On the other hand we have

$$\left|H(\varphi,h)-H(\varphi,h_n)\right| < \int_0^{\varphi}\frac{\left|h(\psi)-h_n(\psi)\right|}{K_2^n(\varphi,\psi)}d\psi.$$

Consequently,

$$H(\varphi,h_n)\overset{n\to\infty}{\Rightarrow} H(\varphi,h).$$

From here we obtain the final result (11):

$$h(\varphi) = H(\varphi,h),\ 0\le\varphi\le\varphi_1.$$

The theorem is proved.

Thus, we offer the following recurrence formula for solving nonlinear integral equation (10):

$$h_0(\varphi)=0,\ h_n(\varphi)=g(\varphi)\left\{1-\int_0^{\varphi}G(\varphi,\psi)h_{n-1}(\psi)d\psi\right\}^m,\ n=1,2,3,\ldots \tag{18}$$

Moreover, having designated the exact solution of the equation (10) as the function $h_{exact}(\varphi)$, then we have

$$g(\varphi)\left\{1-\int_0^{\varphi} G(\varphi,\psi)\cdot h_n(\psi)\,d\psi\right\}^m \overset{n\to\infty}{\Rightarrow} g(\varphi)\left\{1-\int_0^{\varphi} G(\varphi,\psi)\cdot h_{exact}(\varphi)\,d\psi\right\}^m,$$

i.e. the functional sequence $h_n(\varphi)$ defined by recurrence formula (18) converges uniformly to the desired solution

$$h_{exact}(\varphi):\ h_n(\varphi)\overset{n\to\infty}{\Rightarrow} h_{exact}(\varphi).$$

Remark 2. *In the proof of Theorem we have used the constraint* $0 \le \varphi \le \varphi_1$ *only for proof the fact* $|h_n(\varphi)| < M \ \forall\ \varphi$. *If the successive approximations* $h_1(\varphi), h_2(\varphi), ..., h_n(\varphi), ...$ *are uniformly bounded in some segment* $[0,\varphi_2]$ *or in the semi-infinite interval* $[0,\infty)$ *then these successive approximations* $h_1(\varphi), h_2(\varphi), ..., h_n(\varphi), ...$ *will converge in all area and give us the solution of the functional equation (11).*

3. Approximation of the Second-Order Model (1)-(3)

This section shows the discrete model (special case of model (1)-(3)) of acoustic noise emission, resulting from the continuous model (1)-(3) by its finite-difference approximation of second order.

$$\begin{cases} \dfrac{U_{i,j,k}^{m+2}+2U_{i,j,k}^{m+1}+U_{i,j,k}^{m}}{\tau^2}=a_{i,j,k}\cdot\left\{\dfrac{U_{i+2,j,k}^{m}-2U_{i+1,j,k}^{m}+U_{i,j,k}^{m}}{h_1^2}+\dfrac{U_{i,j+2,k}^{m}-2U_{i,j+1,k}^{m}+U_{i,j,k}^{m}}{h_2^2}+\dfrac{U_{i,j,k+2}^{m}-2U_{i+1,j,k+}^{m}+U_{i,j,k}^{m}}{h_3^2}\right\}+ \\ +\rho_{i,j,k}^{m}+\overline{f}_{i,j,k}^{m}\ , \\ \dfrac{\rho_{i,j,k}^{m+2}+2\rho_{i,j,k}^{m+1}+\rho_{i,j,k}^{m}}{\tau^2}=b_{i,j,k}\cdot\left\{\dfrac{\rho_{i+2,j,k}^{m}-2\rho_{i+1,j,k}^{m}+\rho_{i,j,k}^{m}}{h_1^2}+\dfrac{\rho_{i,j+2,k}^{m}-2\rho_{i,j+1,k}^{m}+\rho_{i,j,k}^{m}}{h_2^2}+\dfrac{\rho_{i,j,k+2}^{m}-2\rho_{i+1,j,k+}^{m}+\rho_{i,j,k}^{m}}{h_3^2}\right\}+ \\ +U_{i,j,k}^{m}+\overline{\overline{f}}_{i,j,k}^{m}\ ; \end{cases} \tag{19}$$

where

$U(x_1, x_2, x_3, t)=U_{i,j,k}^{m}$, $\rho(x_1, x_2, x_3, t)=\rho_{i,j,k}^{m}$ $(i=\overline{0,N};\ j=\overline{0,N};\ k=\overline{0,N};\ m=\overline{0,T})$;

$h_1=\dfrac{\Delta x_1}{N};\ h_2=\dfrac{\Delta x_2}{N};\ h_3=\dfrac{\Delta x_3}{N};\ \tau=\dfrac{\Delta t}{N}$;– grid choice for the three spatial coordinates and time respectively.

Discrete model (19) is a clear and monotonic differential scheme and it can be solved numerically, given initial and boundary functions, as well as given certain known $\overline{f}_{i,j,k}^{m}$ и $\overline{\overline{f}}_{i,j,k}^{m}$ $(i=\overline{0,N};\ j=\overline{0,N};\ k=\overline{0,N};\ m=\overline{0,T})$.

4. Conclusions

- A continuous non-stationary mathematical model for determining the dynamics of acoustic noise propagation near airports is proposed.
- We show, that under the assumption that the density of the dissipative ‘parallelepiped’ area of the airport is known a priori, the proposed mathematical model is somewhat simplified, and an analytical method for the solution of this simplified model is developed and justified.
- A discrete second-order mathematical model, which describes the ‘amount’ of noise in discrete time moments in given spatial nodes of 3D ‘parallelepiped’ area / zone near the airport, is obtained.

Looking forward, we plan to develop software applications for calculating the propagation of noise, with a subsequent analysis of the effectiveness of the model, the approximation of data and the determination of aircraft noise exposure contours, based on this model. It is assumed as a series of field measurements of noise in the area of the airport of Riga is to be taken in order to obtain the statistical data and compare them with the values obtained by modelling. The model and the data analysis will help in creating a dynamic system of monitoring the noise levels in the airport area and its surroundings, identifying violations of noise pollution levels for aircraft during take-off and landing modes.

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RELIABILITY AND REPLACEMENT OF VEHICLE FLEET

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Reliability of any product is an integral part of its quality. Depending on the phase of the product lifecycle, certain types of reliability analysis are appropriate. The operational reliability takes into account operational conditions. It can be specified by evaluating the operational data gained during the operation of the object. In the area of operation of road vehicles, it is possible to evaluate records of failures, repairs, maintenance, operation costs, etc. These are stored in an information system or in another digital evidence system and are usable for operation reliability evaluation. The operational data can be also used to prognosticate the development of some reliability parameters. Most of SMEs in the area of transport do not use special software for the monitoring and evaluating of the operational reliability of road vehicles. This article refers to the possibility to acquire some variables of operation reliability from a commonly used Information Systems and to the possibility to create simple programming tool for decision-making and management support in the area of maintenance and replacement of road vehicles by means of common used office software.

Keywords: evaluation, reliability, replacement, road vehicles, software, Excel

1. A Term of Reliability

Reliability is a term which has undergone a long development. It has various interpretations and it is used with many different connotations. In the last three decades the research in the theory of reliability has been intensified and new methods of analysis of reliability, new computational models, methods of reliability test as well as other tools enabling to deliberately influence reliability have been developed.

Reliability of any product is understood as an integral part of a sum of attributes influencing its ability to satisfy the anticipated needs of the user. This ability is called quality. It includes not only reliability, but also many other partial characteristics of the product, e.g. functionality, accuracy, manageability, safety, ecological soundness, aesthetics etc.

In the European norm International Electronical Vocabulary, Chapter 191: Dependability and quality of service, dependability is defined as the collective term used to describe the availability performance and its factors: reliability performance, maintainability performance and maintenance support performance. Dependability is used only for general descriptions in non-quantitative terms. Reliability is the ability of an item to perform a required function under given conditions for a given time interval [1].

There are some attributes of reliability that are commonly used but are not defined in current technical norms. These types of reliability are the following:

- Inherent reliability that originates in the phase of the development of the product and does therefore not include influences by operational conditions, maintenance etc.
- Operational reliability that takes into account operational conditions and can be evaluated after the object has been put in use.

There are different methods to evaluate reliability in every phase.

The reliability evaluation of a product or process can include a number of different reliability analyses. Depending on the phase of the product lifecycle, certain types of analysis are appropriate. As the reliability analyses are being performed, it is possible to anticipate the reliability effects of design changes and corrections. The different reliability analyses are all related, and examine the reliability of the product or system from different perspectives, in order to determine possible problems and assist in analysing corrections and improvements.

Reliability engineering can be done by a variety of engineers, including reliability engineers, quality engineers, test engineers, systems engineers or design engineers. In highly evolved teams, all key engineers are aware of their responsibilities in regards to reliability and work together to help improve the product.

The reliability engineering activity should be an ongoing process starting at the conceptual phase of a product design and continuing throughout all phases of a product lifecycle. The goal always needs to be to identify potential reliability problems as early as possible in the product lifecycle. While it may never be too late to improve the reliability of a product, changes to a design are orders of magnitude less expensive in the early part of a design phase rather than once the product is manufactured and in service.

The methods for monitoring and evaluating system reliability used most often are Procedure for failure mode and effects analysis (FMEA, FMECA), Fault tree analysis (FTA) and Reliability Block Diagram method (RBD). These are used in the development stage and can evaluate inherent reliability [5].

Failure mode and effects analysis (FMEA) is one of the formal techniques for effective product development. Its main purpose is to avoid as many potential failures as possible by identifying actions in the early stages of design and development [8].

FMEA is an engineering technique used to define, identify and eliminate known and potential failures, problems and errors. Effective FMEA system is basically realized through the system engineering process, research and product development. The focus, in this stage, is to:

- Transform an operational need into a description of system performance parameters through the use of an interactive process of functional analysis, synthesis, optimisation, definition, test and evaluation;
- Integrate related technical parameters and assure compatibility of all physical, functional and program interfaces in a manner that optimises total system definition and design;
- Integrate reliability, maintainability, engineering support, human factors, safety, security, structural integrity, productivity and other related specialities into the total engineering effort.

The goal of the FMEA system is to define and demonstrate a proper balance among operational and economic factors. To accomplish the objective, the FMEA system must base its requirement on solid needs, wants, and expectations of the customer.

Fault Tree Analysis (FTA) attempts to model and analyse failure processes of engineering and biological systems. FTA is basically composed of logic diagrams that display the state of the system and is constructed using graphical design techniques. Originally, engineers were responsible for the development of Fault Tree Analysis, as a deep knowledge of the system under analysis is required. Often, FTA is defined as another part, or technique, of reliability engineering. Although both model the same major aspect, they have arisen from two different perspectives. Reliability engineering was, for the most part, developed by mathematicians, while FTA, as stated above, was developed by engineers.

FTA can be used as a valuable design tool, can identify potential accidents, and can eliminate costly design changes. It can also be used as a diagnostic tool, predicting the most likely system failure in a system breakdown. FTA is used in safety engineering and in all major fields of engineering.

In this technique, an undesired effect is taken as the root ('top event') of a tree of logic. There should be only one Top Event and all concerns must tree down from it.

Another known method of analysis of reliability is the Reliability Block Diagram (RBD). It is designed mostly for systems where no repairs are carried out and for systems where sequence of failures is of no relevance. On the other hand, if the nature of the system requires to take into account the sequence of failures or to carry out repairs, the Markov's analysis is more appropriate.

All the analytical methods mentioned above are described in European norms and they are used in the phase of development of the product or system. Evaluation of the operational reliability is more complicated. As already stated, the operation reliability takes into account operational conditions. It can be specified by evaluating the operational data gained during the operation of the object.

2. Operational Reliability in the Maintenance and Reconditioning Management

The general development of the road transport, especially achieving high transportation capacity, depends on the effective use, organization and management of the road transport. The European Union protects the rights of the users of means of transportation and enhances the quality and security in transport.

Because of the current competitive environment, monitoring and managing the quality and reliability requires systematic approach, which has to focus on use of information and communication technologies.

The situation can be characterized as heavily influenced by extensive knowledge and multiple models of reliability based on the theory of reliability. This process is also influenced by some ISO norms that deal with building systems of quality. Fulfilling the transportation tasks requires securing the most stable reliability of the road vehicle in operation. This is achievable thanks to series of measures and activities, as maintenance, repairs, replacement, etc.

This is the time of important changes in the area of the replacement of vehicle fleet. Vehicles that were manufactured with the idea of pre-planned periodical operational maintenance are approaching the end of their service life. They are being replaced by vehicles manufactured with regard to the service life of individual spare parts as well as the vehicle as a whole.

Using the computer management of maintenance offers basic information documenting the system of maintenance management. It allows to create and access a plan of preventive maintenance of any vehicle, or to retroactively check maintenance of any vehicle, including such details as when, how, by whom, with what costs and what material the vehicle was repaired, and what was the cause for maintenance or repairs in any particular case. The system is also able to offer much additional information, such as the sum of monthly costs of repairs and maintenance or downtime according to the code of failure or of vehicle type, and the trend in their developments, the hours worked on the maintenance, indexes of efficiency and many others.

The management of operation reliability of a vehicle fleet is one of the most important tasks of the technical operation. It is important to know and be able to quantify necessary variables of operation reliability as it is an inseparable part of quality.

Reliability variables may be classified into three groups.

- technical variables, i.e. those characterizing service life, non-fault rate etc., e.g. the duration of service life, duration of operation, malfunction probability, malfunction intensity and the like;
- time variables, i.e. those characterizing time operation parameters, e.g. maintenance duration, repair duration, down time duration etc;
- costs variables, i.e. those characterizing vehicle operation reliability costs parameters, e.g. average costs of replacement per unit of drive output and the like.

Costs items related to the technical state of the respective object, or more precisely to the changes in the technical state of the respective object, which can be continuously observed while the respective object (road vehicle) is used, may be exploited as costs parameters. Changes in the technical state provoke changes in selected kinds of operation costs.

There are three significant forms of costs parameters related to operation of road vehicle: cumulative costs, average costs and immediate costs [7].

- Cumulative costs represent a function of operation duration; in a given time t reflect the total sum of costs since the beginning of the operation until the given time t. They inform about the total sum expended on operation through the time.
- Average unit costs express the average sum imposed on the unit of operation duration since the beginning of observation.
- Immediate unit costs express elementary increase in costs for elementary increase in operation duration. These are those most closely connected with changes in the technical state of a vehicle.

Costs parameters are characteristic not only of their dependence on the changes in the technical state, but on the current prize level as well. This can be perceived as a disadvantage as well as an advantage, as it is the prize level that influences the weight or the importance of any kind of interference in the area of maintenance and reconditioning in given operation conditions in given time [3].

3. Computer Support of Operational Reliability Evaluation

Observation and evaluation of operation reliability of road vehicles as well as acquisition and evaluation of other parameters, that could be helpful in decision-making and managing of the technological maintenance and reconditioning of road vehicles, can be integrated as a part of Information System.

Even if there are special information systems for the maintenance management, they are usually too expensive for smaller enterprises.

Currently, the most of the enterprises use centralized information system, which is usually modularly formed. Its only module is sometimes equal to a maintenance management module. However, IS are usually oriented on economics and logistics (accountancy, HR, storage, invoices, etc.) and there is minimal benefit for the maintenance management (if there are used for that purpose at all).

Available net applications aimed at maintenance management are suitable for that purpose regarding their utility characteristics and satisfaction of the needs of the management maintenance system, but their prize is not acceptable for SMEs. Therefore, many small enterprises prefer to order bespoke software of lesser scope. The analysis and designing phase of an appropriate model of IS as well as the creation of a database (i.e. supplying the input parameters phase) is lengthy and there are many potential pitfalls for both partners – enterprise and programmers as well. If the designed system is too large-scale and relatively complex, its creation and initiation takes too long, not less than two years, and costs are too high for a small enterprise as well. Therefore, it is very common that an enterprise use a commercial system for accountancy, wages, logistics and the like. Then, the workers of maintenance use smaller-scale software, whose creation and initiation they supported themselves.

Even in the case of absence of any software for management maintenance, it is possible to acquire data which can be used e.g. for the evaluation of operation reliability or for the prognosis of the development of some observed parameters from a “classical” Information System. There is an appropriate and often used programming tool: commonly used office software – database or spreadsheet calculator.

Owing to the nature of transport activities, the questions of maintenance, repairs, reliability monitoring etc. are handled together with logistics and transport services. In reality, monitoring and evaluating of reliability is often of secondary importance, or, eventually, there is no computer support for reliability monitoring at all. On the other hand, it may be expected that there is an evidence of failures and repairs in some form in any company. Moreover, it may also be expected that any company uses a spreadsheet calculator, usually the MS Excel. Among its more advanced tools are pivot tables and charts that can be successfully used to create outputs, overviews and calculations in the form of tables and charts regarding the maintenance, repairs, failure rare, reliability etc. The presented software is based on the very same pivot tables, which are simple and of great information value.

The system is based on a register of spare parts used and work done in maintenance and repairs of a road vehicle kept continuously in a database. Consequently, it offers an overview of some reliability variables displayed as tables or charts and it enables to check the logistics development trend for any component group or for the vehicle as a whole [4].

The software consists of a package of templates and books in MS Excel, named Evidence, Time, Cost and Replacement and a special program in Visual Basic named Prognosis [6].

It was generated by using the tools of the spreadsheet calculator MS Excel, especially pivot tables, charts and macro programming in Visual Basic for Applications.

The following pictures illustrate the whole software and the Evidence file that serves also to run the Time, Costs and Replacement modules [5].

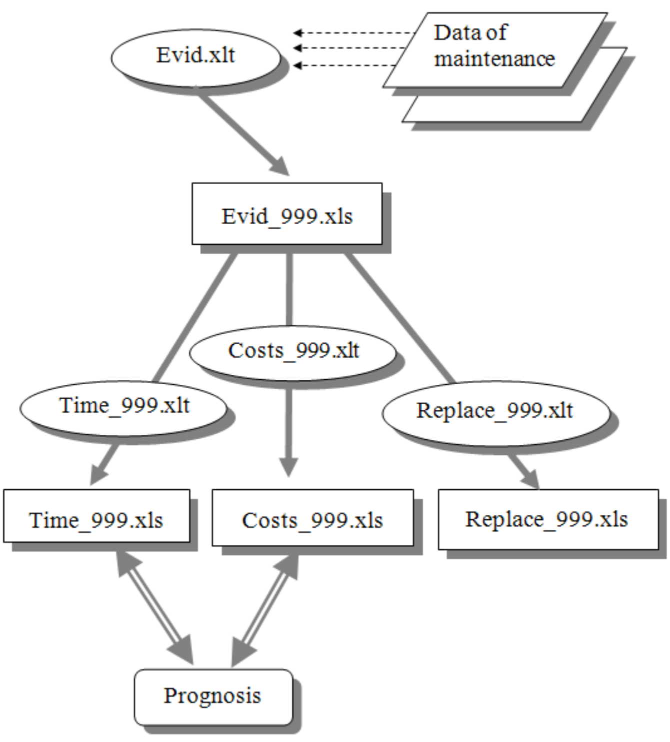
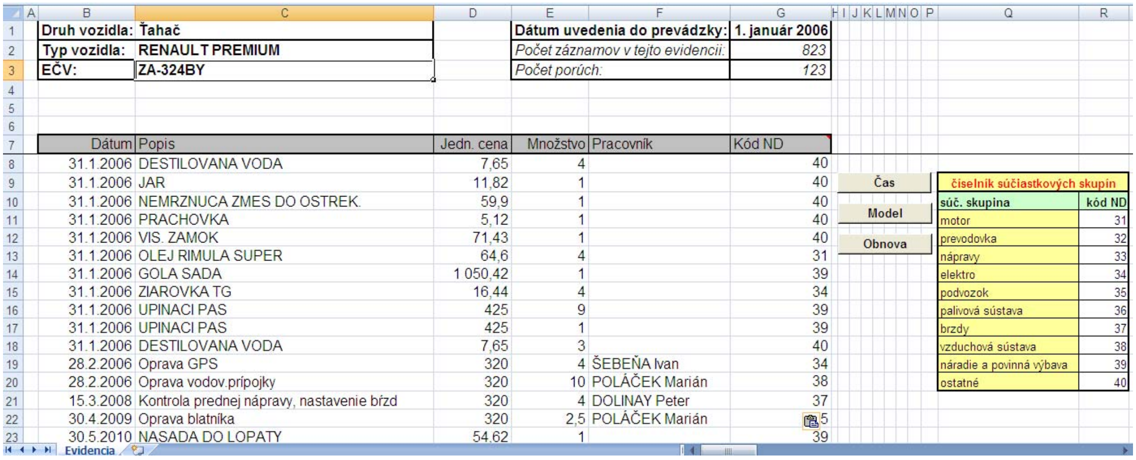


Figure 1. Scheme of the software

The Evidence file (Evid_999.xls) represents the basis of the whole processing. This book has a single sheet containing the evidence of individual spare parts and additional material used and work done in repairs of a specific road vehicle in the course of its service.

There are identification data of a vehicle, the date of the start of its service, the number of records in a given time and the number of registered failures. (Cells G1 to G3).



Druh vozidla:	Ťahač		Dátum uvedenia do prevádzky:		1. január 2006
Typ vozidla:	RENAULT PREMIUM		Počet záznamov v tejto evidencii:		823
EČV:	ZA-324BY		Počet porúch:		123
Dátum	Popis	Jedn. cena	Množstvo	Pracovník	Kód ND
31.1.2006	DESTILOVANA VODA	7,65	4		40
31.1.2006	JAR	11,82	1		40
31.1.2006	NEMRZNUCA ZMES DO OSTREK.	59,9	1		40
31.1.2006	PRACHOVKA	5,12	1		40
31.1.2006	VIS. ZAMOK	71,43	1		40
31.1.2006	OLEJ RIMULA SUPER	64,6	4		31
31.1.2006	GOLA SADA	1 050,42	1		39
31.1.2006	ZIAROVKA TG	16,44	4		34
31.1.2006	UPINACI PAS	425	9		39
31.1.2006	UPINACI PAS	425	1		39
31.1.2006	DESTILOVANA VODA	7,65	3		40
28.2.2006	Oprava GPS	320	4	ŠEBEŇA Ivan	34
28.2.2006	Oprava vodov.prípojky	320	10	POLÁČEK Marián	38
15.3.2008	Kontrola prednej nápravy, nastavenie bŕzd	320	4	DOLINAY Peter	37
30.4.2009	Oprava blatníka	320	2,5	POLÁČEK Marián	5
30.5.2010	NASADA DO LOPATY	54,62	1		39

Čas

Model

Obnova

číselník súčiastkových skupín	
súč. skupina	kód ND
motor	31
prevodovka	32
nápravy	33
elektro	34
podvozok	35
palivová sústava	36
brzdy	37
vzduchová sústava	38
náradie a povinná výbava	39
ostatné	40

Evidencia

Figure 2. Example of data in the Evidence sheet

The specific records consist of the data: Date, Description, Unit price, Amount, Worker, ND Code (Cells B7 to G7). These records are created gradually in the course of service of the road vehicle and are ranged in accordance to date. The "Worker" data contains the name of a worker in the case of work done in repairing the vehicle; in the case of spare parts used the column rests empty. An example of input data can be seen on Figure 2.

Evidence file serves as the source of data for consecutive processing the Costs, Time and Replacement books, that are activated by macro buttons (Čas, Model, Obnova), as seen on Figure 2. The data in the Evidence can be acquired also by exporting and adjusting the data from the business information system into an Excel table, if the system used contains such data but does not monitor the reliability. The ND code is assigned to the records according to the encoding contained in the Table 1.

Table 1. Encoding

Spare parts groups encoding	
Spare parts group	**Code**
motor	31
gear	32
axles	33
electronics	34
chassis	35
fuel system	36
brakes	37
air system	38
tools and compulsory equipment	39
other	40

To enable a successful use of this book, continuous evidence including the correct ND codes is required. Moreover, the data from the book are to be used as the single common data source for the Costs.xls (button "Model"), Time.xls (button "Čas"), and Replacement.xls (button "Obnova") books.

The Costs.xls and Time.xls books allow acquiring various overviews and values concerning the reliability indexes by using the pivot tables and charts. These books can be created by running macro directly from the Evidence book. The macro copies the records on evidence into the Costs.xlt and Time.xlt templates and so the prepared pivot tables, pivot charts and calculations of reliability indexes are updated [6].

The module Prognosis is a program to search for Logistic Curve ("Logkrivka" button) variables that can be run on some sheets of Costs and Time books. This enables to prognosticate the development of monitored indicators in the future [5].

Logistic function or logistic curve is the most common sigmoid curve. It models the S-shape of growth or decreasing. These functions find applications in a range of fields, e.g. neural networks, ecology, biology, medicine, economics and reliability, too.

A logistic function is defined by the mathematical formula:

$$y(x) = \frac{a}{1 + c.e^{-b.x}} \,. \tag{1}$$

Parameters a, b, c >0 in the case of increasing function.

This program uses the smallest square method to search the parameters a, b, c on the bases of data from the evidence book. Idea of this method is minimalizing the sum of squares of expressions:

$$\sum_{i=1}^{n} \left(y_i - \overline{y}_i \right)^2 , \tag{2}$$

where $[x_1,y_1]$, $[x_2,y_2]$,…, $[x_n,y_n]$ are in our case the data from the Evidence file exported to the Cost and Time books. This module computes the values of logistic function on the basis of data from the pivot table, and prognosticates the trend.

Pivot table with the rate of occurrence of failures of spare parts group 37-brakes for a specific road vehicle complemented by output from the module Prognosis (Logistic curve/Logkrivka) is on Figure 3 [6].

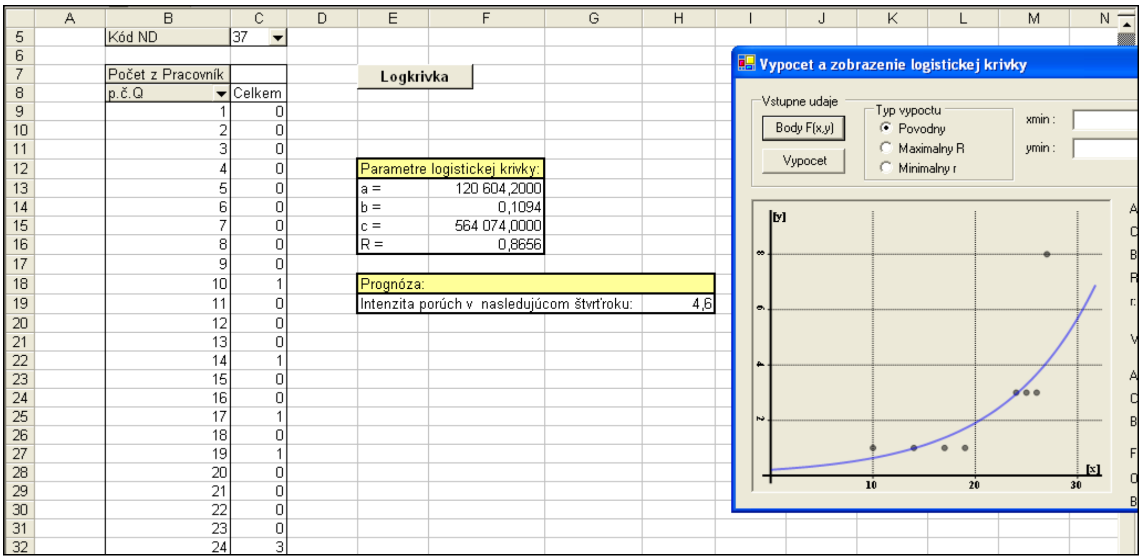


Figure 3. Rate of occurrence of failure complemented by logistic curve and prognosis

The book Costs has some other sheets with various outputs. They can be used for managers to show rather overviews of development of number and costs of maintenance, spare parts and work done in all spare parts groups during the operation of road vehicle. Here is some another of them:

Figure 4 illustrates review of price of work done in maintenance in accordance with spare parts groups (ND codes 31-40) by quarters of years in operation duration.

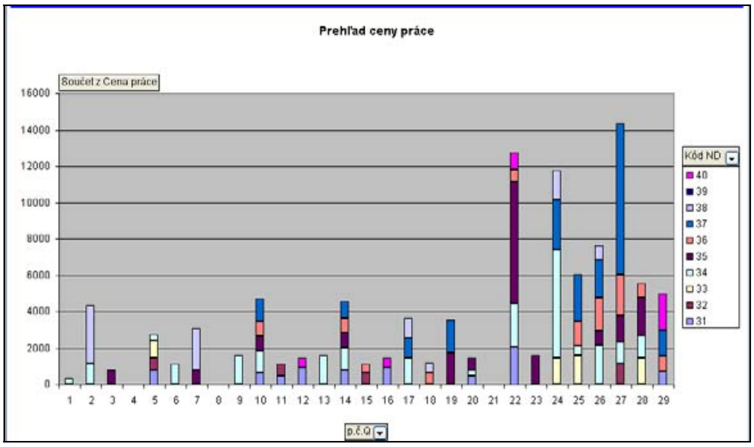


Figure 4. Pivot chart - price of work in maintenance

Another sheet contains the chart based on the same data as the last one. But this is created not as pivot, and it is complemented with trend lines and equations of regression polynomial functions. This sheet is designed more for students of informatics and road transport than for managers.

Figure 5. Chart with trend lines

There is an output with development of all costs of maintenance according to spare parts groups by quarters of years in operation of road vehicle at another figure. It is a pivot table complemented with output from the Prognosis (Logkrivka) module.

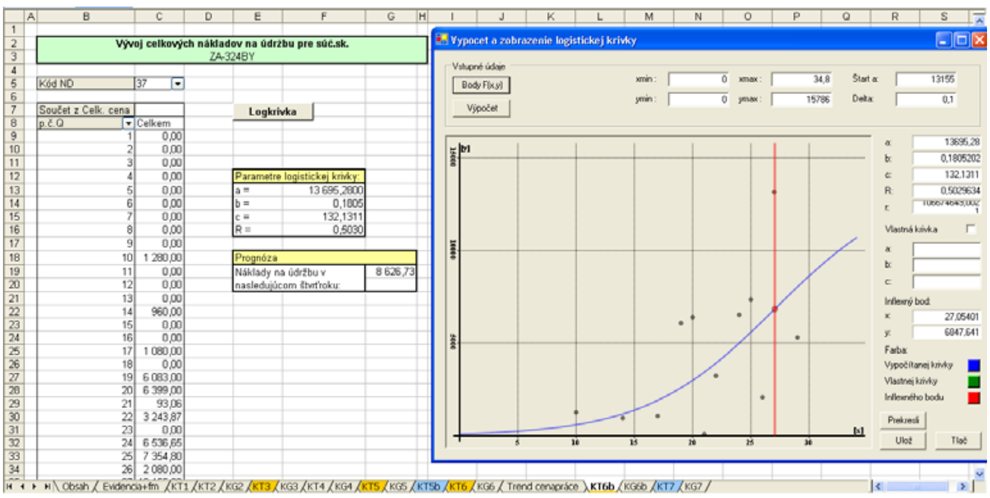


Figure 6. Development of all costs of maintenance

Time indicators are contained in the Time.xls book. Pivot table and pivot chart offering the information on gradually decreasing time between failures of the spare parts groups 37-brakes are seen on Figures 7 and 8.

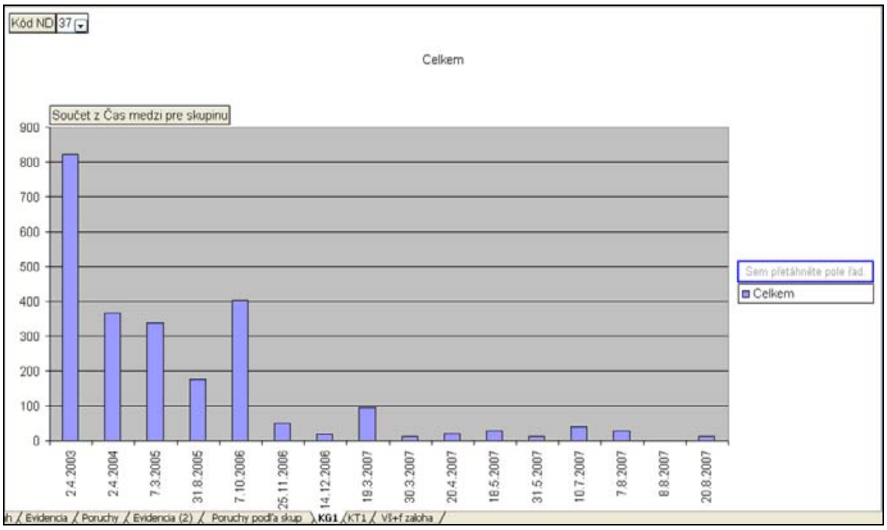


Figure 7. Pivot chart – decreasing time between failures

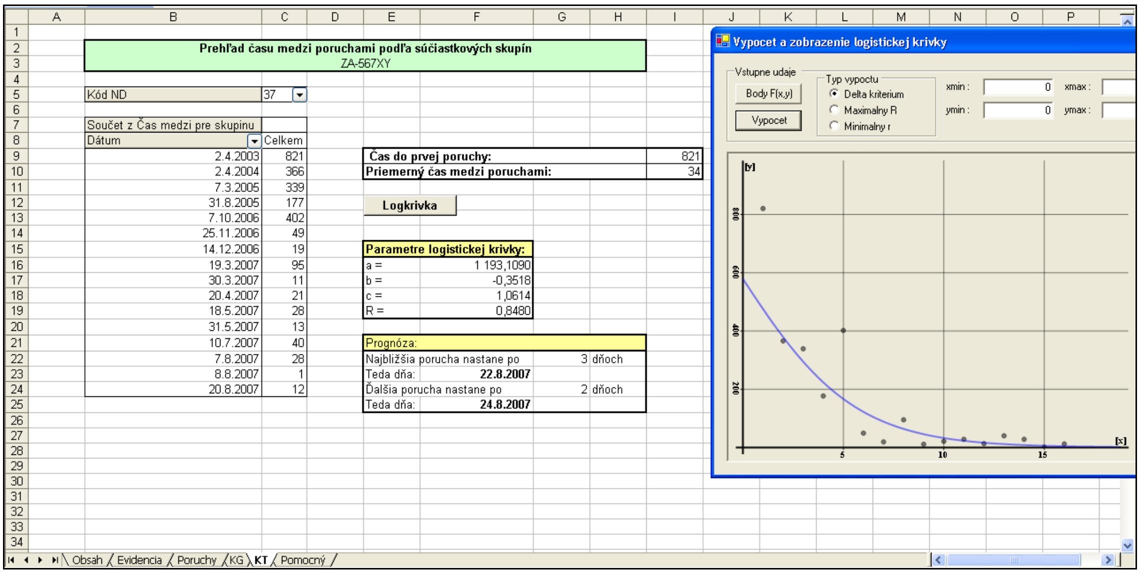


Figure 8. Output of the Time book with prognosis the next failure

The macro ran from Evidence book can also activate the Replacement template and create the Replacement book, aimed to calculate the time for optimal replacement of the object. by using the function of immediate costs of replacement with the help of the Excel function to add a trend line to the chart and get corresponding equation of regression function. While applying the regression function for a few periods ahead, we acquire some prognosis of development of the observed variable.

4. Determining Optimal Time for Replacement

Various methods of determining optimal time for replacement of a machine to be based on information on costs of replacement of the machine and history of costs related to the operation of the machine.

The value of costs of replacement N_0 can be for each object (a vehicle, a machine or its part) easily calculated basing on actual market price of the machine C_P and qualified estimate of costs related to machine's installation C_I, transport C_T, necessary downtime due to replacement C_{DT} and salvage value of the machine C_{SV}:

$$N_O = C_P + C_I + C_T + C_{DT} + C_{SV} \,. \tag{3}$$

The operational costs $N_P(t)$ represent the financial amount that must be expended in order to ensure the desired machine's operation. The value of operational costs is typically a function of machine's time of operation and for a complex of the following items [2]:

$$N_P(t) = N_b(t) + N_e(t) + N_z(t) + N_u(t) \,, \tag{4}$$

where

N_b – costs of labour (wages of operating staff)
N_e – costs related to energy (fuel) consumption
N_Z – costs related to loss or deterioration of working material, scraps, etc.
N_u – costs of maintenance

The method used in this software is based on the cumulative operational costs function, from which, by derivation, the function of instantaneous unit costs $v_p(t)$ is obtained. Then the value of t_o is found by measuring the area above the curve of $v_p(t)$ according to Figure 9. At the time of t_o the shaded area equals N_o:

$$N_0 = t.v_p(t) - \int_0^t v_p(t) \,. \tag{5}$$

Basing on the indicated equation, the formula for direct calculation of t_o can be determined (this formula is specific for different types of approximation functions).

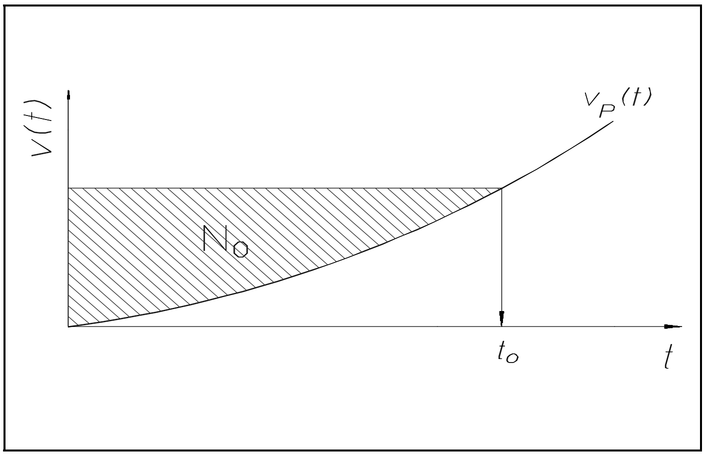


Figure 9. Function of instantaneous unit costs

This algorithm is implemented into the Replacement module by using the following MS Excel tools and functions:

- The operational costs during the operation are summed
- The chart of cumulative costs is created
- The trend line in this chart is added and the analytical expression of regression function is shown
- The derivation of this function is obtained – it is the function of instantaneous unit costs $v_p(t)$
- The time for optimal replacement is calculated

All this steps are full automatically by using prepared macros. There are two types of approximation function used in this module:

- Polynomial function
- Power function

In the case of approximating of polynomial function $y = a.t^2 + b.t + c$ its derivation is the function of instantaneous unit costs $v_p(t) = 2.a.t + b$.

If N_0 is the value of costs of replacement, the formula for calculating of optimal time to replacement is

$$t = \sqrt{\frac{N_0}{a}} \,. \tag{6}$$

In the case of approximating of power function $y = a.t^b$ is the function of instantaneous unit costs $v_p(t) = a.b.t^{b-1}$ and the formula to calculating of optimal time t for replacement is as follows:

$$t = \sqrt[b]{\frac{N_0}{a.(b-1)}} \,. \tag{7}$$

These formulas are used in cells of Excel and the optimal time for replacement is calculated. Output of the Replacement book is shown on Figure 10.

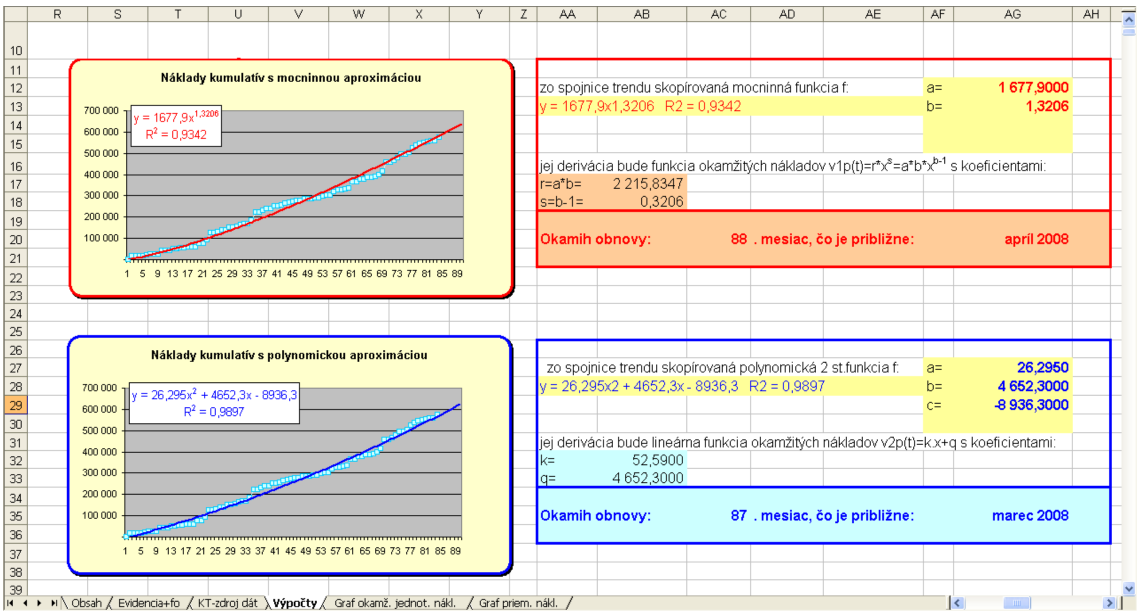


Figure 10. Charts of cumulative costs with trend lines and optimal time for replacement in case of power and polynomial function (optimal time is 88th or 87th month of operation of road vehicle)

After running macro "Replacement" from the Evidence book the user needs to enter or update the values in the "Costs of replacement" field for the actualised value of optimal time for replacement of the vehicle to be calculated.

A situation can occur, when none of the trend lines offered by the spreadsheet (MS EXCEL in our case) for the chart design is appropriate for the regression of development. Then it is possible to use its complementary part Solver or to create a simple application using e.g. searching for a regression function by the smallest squares method. Of course, many activities may be automated even in Excel by using macros.

5. Conclusions

This software support of decision-making in the maintenance and repair process has been created on the basis of an analysis of the use of an IS for maintenance in a few firms providing cargo transportation. The survey was carried out in three firms in the Žilina region. All deal with national and international cargo transportation; each has around 80 vehicles and the firms are comparable also in terms of amount of number of employees, transport capacity, and outputs.

The first firm has not yet implemented an IS. The firm has opted for creation of its own, relatively complex and massive system that is being developed by an external IS firm. The overall conception and some modules are already finished, but the user firm has realized that there is a human-resources related problem with inputting data into databases. The data processing needed for operational management is not carried out systematically and it's done mostly via MS Excel. The software presented in this paper has not yet been tested in the firm.

The second firm does not implement a complex IS and it uses only the software for specific tasks such as dispatching or accounting. This firm decided to test our software even if it does not keep appropriate digital data from past operation of road vehicles. Since January 2009, it has been keeping evidence for 5 selected vehicles. It is too soon to evaluate the results.

The third firm uses two independent information systems, one for accounting and the other for other agendas. The second system includes databases Stock and Repair. By importing data from these databases, a file with the evidence of maintenance and repairs needed for testing our software. The testing has been carried out for six vehicles and further evidence and data-processing are ongoing. The management of this firm is aware of possible assets of the software for maintenance management support and they intend to start keeping evidence for each vehicle.

As the processing is automatic and supported by various macros, this software product can be also used by a not very skilled MS Excel user. This tool has a potential to be used in information system of operation reliability of road vehicles for the needs of managing the technological process of maintenance and repairs. After a little adjustment, this software support for monitoring and evaluating the reliability can be also used for other objects of maintenance than road vehicles.

Similar approach is appropriate if there is an SME not using any special Information System for the maintenance management, that would offer suitable ground for decision-making and managing in the technological process of maintenance and reconditioning of road vehicles.

The software is simple and user-friendly, with low hardware requirements and it's easily compatible with other platforms of business information systems or maintenance management systems. Thanks to these qualities, as well as its low cost, it is especially suitable for SMEs in the transport business that could find the purchase of a complex information system with an integrated support for the operation, maintenance and repairs of road vehicles beyond their needs and means.

Given example can provide a basis for special software, which, if being developed with knowledge of the given enterprise and not expected to be grand and universal, can provide higher quality in the process of maintenance management, while costs are kept low and design period short. This can profoundly influence the operation reliability of the enterprise's vehicle fleet, lower the costs of reconditioning, and lower the inventory level in the spare part warehouse and the like. In this way, the total costs can be lowered and the profit increased.

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THE PRESENTATION OF PRODUCTION LINE AND WAREHOUSE MANAGEMENT BASED ON RFID TECHNOLOGY THROUGH 3D MODELLING AND ANIMATION

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The RFID technology is complex, combining a number of different computing and communications technologies to achieve desired objectives. This article primarily deals with the simulation of production line and warehouse management based on RFID technology, through 3D modelling and animation. It describes the various components of a RFID lab (a laboratory for the automatic identification of goods and services), which consist of a production line and a warehouse management system based on RFID technology.

This paper characterizes and describes the processes that take place in the laboratory as well as the technologies which are used. Moreover it describes production line processes and warehouse management. 3D models and animations created to capture the whole process in the laboratory are set up and described.

Keywords: RFID technology, 3D models, warehouse management, simulation

1. Introduction

RFID technology is complex, combining a number of different computing and communication technologies to achieve desired objectives. Each object, which has to be identified, has a small object called a RFID tag stuck to it. Each RFID tag has a unique identifier that enables additional information about each object to be stored. Devices known as RFID readers wirelessly communicate with RFID tags, with a view to identifying the attached RFID tags, as well as enabling information stored in the RFID label to be read and updated. Our department has focused on research in the field of automatic identification and data collection. The established RFID lab (laboratory for the automatic identification of goods and services), which consists of a production line and a warehouse management system based on RFID technology, acts as a model in the article, depicting the process of automatic identification in a conditions similar to operational conditions.

2. About the RFID Lab

RFID lab means laboratory for the automatic identification of goods and services. The core of the system for the identification of goods and services through RFID technology is known as SAP. It is therefore a real system that is used in practice and through logistics processes can be simulated in the laboratory. The data format conforms to GS1 standards. The formats in this specification are defined, and are available for use. Resolution of the data involves AI application identifiers, while tags are the format used by EPC – Electronic Product Code. An Electronic Product Code can be characterized as a number encoded in electronic form and stored in a storage medium such as a chip. EPC is an internationally standardized system that is used to identify objects and goods uniquely throughout the supply chain. The laboratory for the automatic identification of goods and services is designed to present RFID technology in various parts of distribution chain and provide a platform for partner companies to test applications for their customers. RFID lab is also intended to cooperate with universities to enable the project's own research and development, as well as to create space for joint projects. As has been already mentioned above, the University of Zilina, Faculty of Operation and Economics of Transport and Communications is one of the partners of the laboratory and is represented by members of the Department of Communications.

The main goals of the laboratory are:

- to show the utilization of radio frequency identification in various parts of the supply chain (in manufacture, distribution, warehousing, retail). Laboratory demonstrates the advantages delivered by radio frequency identification, i.e. no line of sight scanning, multiple scanning etc.,
- to provide partner companies with an opportunity to test their applications for their clients. Laboratory enables its partners to use the installed equipment for developing pilot projects and applications,
- to cooperate with universities on solving projects of research and development as well as creating space for joint projects,
- to introduce the key standards of GS1, i.e. barcodes, eCom – electronic exchange of data and GDSN – global data synchronisation network on real examples.

Laboratory is divided into 5 sectors:

- design and verification of barcodes,
- manufacture,
- packaging and distribution,
- warehouse,
- retail outlet.

2.1. Description of the Processes and Equipment

In this section we characterize production line and warehouse management processes simulated through 3D models and animations.

The main objective of the laboratory for the automatic identification of goods and services is to present RFID technology in the following processes:

- Receipt of material – entered from SAP.
- Application of RFID labels to the desired material.
- Simulation of production (SAP applicator gate) and finished products.
- Labelling of pallets and crates through Smart Labels.
- Palletising and packaging.
- Warehousing.
- Simulation of the store with RFID support [1].

2.1.1. Entering the Production and Application of Labels

The process of the identification of goods begins with selecting the quantity and type of material from SAP. It is possible to enter:

- EAN product number (a product serial number will be generated from SAP ERP).
- Batch number.
- Number of boxes (representing products).

After all transactions are done, all information about content and label design is sent to be printed. This is done on the bottom side of the RFID tag. This has an adhesive surface. The upper side has a backup bar code and other necessary information.

Design ‘template’ label boxes include:

- in text form:
  - Product name (20 alphanumeric characters).
  - Batch Number (10 alphanumeric characters).
  - Date of manufacture (YYMMDD – 6 numeric characters).
  - Serial number of the box (four numeric characters).
- Bar code EAN13 (the product number assigned in SAP ERP) (the bar code must be in accordance with ISO/IEC 15420).
- RFID tag – EPC 96-bit format (GTIN (product number) + serial number) [1].

Before sending data to a ZEBRA printer, it is necessary to configure the parameters for RFID printing and set the printer for network printing. This allows the printer to print a label (the label) and encode the EPC number onto the tag. The conveyor belt is up and running. Figure 1. shows two conveyors, the applicator of labels produced on the Zebra printer and two RFID gates.

Figure 1. Simulation of production

2.1.2. Presentation of Production, Entry into the Warehouse

Entry into production:

At the end of the first belt, on which there is the printer and the label applicator, is a RFID gate. This is tasked with reading all smart labels or RFID tags located on boxes. Scanned data from each unique tag is transferred to the SAP system by requesting a Web service, then taking the number and batch and comparing them with required number to be produced. The SAP report shows which product is in production.

Output of the production:

In the laboratory, the production process is not simulated. The actual process of production should be located in the same place as the two associated conveyors. At the beginning of the second conveyor is the next RFID gateway. This reads information about the product coming from the production line; in our case the box.

The finished products fall into a pallet fence, which is located at the end of the second belt. In this range, the tag is placed on pre-recorded data Datamax printer. This printer is not involved in the system, and the system knows which products (boxes) contain a tag.

Palletising:

Pallets containing finished products are hand-labelled with pallet tag numbers. A forklift truck is used to transport the goods to the warehouse through the door "KODYS / Vectra [2], where the contents are assigned to the pallet tag. A situation may arise in which the number of products scanned at the production exit gate (second gate) does not match to the number of products scanned at the KODYS / Vectra gate. If this happens we recommend turning on the puttee range and the gate area will try to read all tags. The process continues only with the number that was loaded by the gate. "Here we get the answer to the question: 'Are there any products that get lost?' [2]. In this way we obtain a unique identification needed for the storage of goods.

Figure 2 shows RFID gate and puttee [2].

Figure 2. RFID gate and puttee

2.1.3. Warehouse Management

This process occurs in the laboratory to simulate inventory control, warehouse management, automated storage management and unloading, inventory stocks, and orientation in the warehouse using RFID in conjunction with reading the barcode label on the shelves.

Figure 3 shows a mobile terminal being used in a RFID lab.

Figure 3. Mobile terminal

The mobile application was created with SAP ITS Mobile Technology. Operations in mobile applications are as follows:

Storing:

The terminal of storage operation is selected. Subsequently, the RFID sensor will load the number of pallets to be stored. At the destination site the bar codes will be scanned. The location of the pallets in the goods reception area will be controlled. The SAP ERP is based on data which has been entered. It creates a storage command and a menu with the goods which are stored in the new storage location.

Bin transferring:

The terminal selects the bin transfer operation. The RFID reader will load the number of the pallet intended for storing and warehousing, and at the destination site the bar code will be scanned. The SAP ERP is based on data which has been entered and creates a warehouse order together with a list of goods stored in the new storage location.

Removal – issue of cost centre:

The terminal selects the removal operation. Pallets are loaded via the RFID reader and then selected the number or type a number of cost centre. The SAP ERP is based on data which has been entered and creates a warehouse order and material evidence, the range of material on it is removed and the pallet in the system disappears [1].

3. RFID Technology

Identification processes that rely on AIDC technologies are significantly more reliable and less expensive than those that are not automated. The most common AIDC technology is bar code technology, which uses optical scanners to read labels. Most people have direct experience with bar codes because they have seen cashiers scan items at supermarkets and retail stores. Bar codes are an enormous improvement over ordinary text labels because personnel are no longer required to read numbers or letters on each label or manually enter data into an IT system; they just have to scan the label. The innovation of bar codes greatly improved the speed and accuracy of the identification process and facilitated better management of inventory and pricing when coupled with information systems.

Radio frequency identification is a wireless data collection technology that uses electronic tags which store data, and tag readers which remotely retrieve data. It is a method of identifying objects and transferring information about the object's status via radio frequency waves to a host database. RFID is not necessarily a direct replacement for bar codes, but as the costs of RFID systems continue to decrease, the functional utility of RFID will greatly surpass that of bar codes [7].

RFID represents a significant technological advancement in AIDC because it offers advantages that are not available in other AIDC systems such as barcodes. RFID offers these advantages because it relies on radio frequencies to transmit information rather than light, which is required for optical AIDC technologies.

Like bar codes in an earlier time, RFID is the next revolution in AIDC technology. Most of the advantages of RFID are derived from the reliance on radio frequencies rather than light (as is required in optical technology) to transmit information. This characteristic means that RFID communication can occur:

- Without optical line of sight, because radio waves can penetrate many opaque materials,
- At greater speeds, because many tags can be read quickly, whereas optical technology often requires time to manually reposition objects to make their bar codes visible, and
- Over greater distances, because many radio technologies can transmit and receive signals more effectively than optical technology under most operating conditions.

The ability of RFID technology to communicate without optical line of sight and over greater distances than other AIDC technology further reduces the need for human involvement in the identification process. For example, several retail firms have pilot RFID programs to determine the contents of a shopping cart without removing each item and placing it near a scanner, as is typical at most stores today. In this case, the ability to scan a cart without removing its contents could speed up the checkout process, thereby decreasing transaction costs for the retailers. This application of RFID also has the potential to significantly decrease checkout time for consumers.

3.1. Components of an RFID System

An RFID system is a set of components that work together to capture, integrate, and utilize data and information. This section describes some of them. The components are as follows:

- Sensors, Tags, Antennas, Readers.
- Connectors, Cables, Networks, Controllers.
- Data, Software, Information Services.

RFID systems can be very complex, and implementations vary greatly across industries and sectors. RFID system is composed of up to three subsystems:

- An RF subsystem, which performs identification and related transactions using wireless communication,
- An enterprise subsystem, which contains computers running specialized software that can store, process, and analyse data acquired from RF subsystem transactions to make the data useful to a supported business process, and
- An inter-enterprise subsystem, which connects enterprise subsystems when information needs to be shared across geographic or organizational boundaries.

Every RFID system contains an RF subsystem, and most RFID systems also contain an enterprise subsystem. An RFID systems supporting a supply chain is a common example of an RFID system with an inter-enterprise. In a supply chain application, a tagged product is tracked throughout its life cycle, from manufacture to final purchase, and sometimes even afterwards (e.g., to support service agreements or specialized user applications).

3.1.1. RFID Tags and Frequencies

An RFID tag is a small device that can be attached to an item, case, container, or pallet, so it can be identified and tracked. It is also called a transponder. The tag is composed of microchip and antenna. These elements are attached to a material called a substrate in order to create an inlay [8].

Tags are categorized into three types based on the power source for communication and other functionality.

- A passive tag uses the electromagnetic energy it receives from an interrogator’s transmission to reply to the interrogator. The reply signal from a passive tag, which is also known as the backscattered signal, has only a fraction of the power of the interrogator’s signal. This limited power significantly restricts the operating range of the tag. Since passive tags are low power devices, they can only support data processing of limited complexity. On the other hand, passive tags typically are cheaper, smaller, and lighter than other types of tags, which are compelling advantages for many RFID applications.

- An active tag relies on an internal battery for power. The battery is used to communicate to the interrogator, to power on-board circuitry, and to perform other functions. Active tags can communicate over greater distance than other types of tags, but they have a finite battery life and are generally larger and more expensive. Since these tags have internal power, they can respond to lower power signals than passive tags.
- A semi-active tag is an active tag that remains dormant until it receives a signal from the interrogator to wake up. Then the tag can use its battery to communicate with the interrogator. Like active tags, semi-active tags can communicate over a longer distance than passive tags. Their main advantage relative to active tags is that they have a longer battery life. The waking process, however, sometimes causes an unacceptable time delay when tags pass interrogators very quickly or when many tags need to be read within a very short period of time.
- A semi-passive tag is a passive tag that uses a battery to power on-board circuitry, but not to produce return signals. When the battery is used to power a sensor, they are often called sensor tags. They typically are smaller and cheaper than active tags, but have greater functionality than passive tags because more power is available for other purposes. Some literature uses the terms "semi-passive" and "semi-active" interchangeably.

Carrier frequencies

Today, there are four carrier frequencies implemented for RFID that are popular globally: 125 KHz, 13.56 MHz, UHF ranging from 866 to 950 MHz depending on national radio regulations, and microwave frequencies of 2.45 GHz and 5.8 GHz. There is also the frequency range 430-440 MHz, which is allocated to amateur radio usage around the world. The ISM band 433.05-434.790 MHz is located near the middle of the amateur radio band. The amateur radio band has emerged as an RFID channel in a number of applications. The frequency range has been called the 'optimal frequency for global use of Active RFID'.

Functionality

The primary function of a tag is to provide an identifier to an interrogator, but many types of tags support additional capabilities that are valuable for certain business processes. These include:

- Memory – memory enables data to be stored on tags and retrieved at a later time. Memory is either write once, read many (WORM) memory or re-writeable memory, which can be modified after initialisation. Memory enables more flexibility in the design of RFID systems because RFID data transactions can occur without concurrent access to data stored in an enterprise subsystem. However, adding memory to a tag increases its cost and power requirements.
- Environmental sensors. The integration of environmental sensors with tags is an example of the benefit of local memory. The sensors can record temperature, humidity, vibration, or other phenomena to the tag's memory, which can later be retrieved by an interrogator. The integration of sensors significantly increases the cost and complexity of the tags. Moreover, while many tag operations can be powered using the electromagnetic energy from an interrogator, this approach is not workable for sensors, which must rely on battery power. Tags typically are only integrated with sensors for high-value, environmentally sensitive, or perishable objects worthy of the additional expense.
- Security functionality, such as password protection and cryptography. Tags with on-board memory are often coupled with security mechanisms to protect the data stored in that memory. For example, some tags support a lock command that, depending on its implementation, can prevent further modification of data in the tag's memory or can prevent access to data in the tag's memory. In some cases, the lock command is permanent and in other cases, an interrogator can "unlock" the memory. EPCglobal standards, International Organization for Standardization (ISO) standards, and many proprietary tag designs support this feature. Some RFID systems support advanced cryptographic algorithms that enable authentication

mechanisms and data confidentiality features, although these functions are most commonly found on RFID-based contactless smart cards and not tags used for item management. Some tags offer tamper protection as a physical security feature.

- Privacy protection mechanisms. EPC tags support a feature called the kill command that permanently disables the ability of the tag to respond to subsequent commands. Unlike the lock command, the kill command is irreversible. The kill command also prevents access to a tag's identifier, in addition to any memory that may be on the tag. While the lock command provides security, the primary objective of the kill command is personal privacy. RFID tags could be used to track individuals that carry tagged items or wear tagged articles of clothing when the tags are no longer required for their intended use, such as to expedite checkout or inventory. The ability to disable a tag with the kill command provides a mechanism to prevent such tracking.

3.1.2. RFID Reader

The second component in a basic RFID system is the *interrogator* or *reader* (see Figure 4). Readers can have an integrated antenna, or the antenna can be separate. The antenna can be an integral part of the reader, or it can be a separate device. Handheld units are a combination reader/antenna, while larger systems usually separate the antennae from the readers. The reader retrieves the information from the RFID tag. The reader may be self-contained and record the information internally; however, it may also be a part of localized system such as a POS cash register, a large Local Area Network (LAN), or a Wide Area Network (WAN) [6].

There is also Middleware, software that controls the reader and the data coming from the tags and moves them to other database systems. It carries out basic functions, such as filtering, integration and control of the reader.

RFID systems work, if the reader antenna transmits radio signals. These signals are captured tag, which corresponds to the corresponding radio signal.

Figure 4. Mobile Handheld Interrogator

4. The Presentation of Production Line and Warehouse Management with RFID Technology through Multimedia Application

This chapter describes how the processes of the product line and warehouse management were presented in the laboratory for the automatic identification of goods and services through multimedia application.

Multimedia is a term frequently heard and discussed among educational technologists today. Unless clearly defined, the term can alternately mean .a judicious mix of various mass media such as print, audio and video. Or it may mean the development of computer-based hardware and software packages produced on a mass scale and yet allow individualized use and learning. In essence, multimedia merges multiple levels of learning into an educational tool that allows for diversity in curricula presentation.

Multimedia is the exciting combination of computer hardware and software that allows you to integrate video, animation, audio, graphics, and test resources to develop effective presentations on an affordable desktop computer (Fenrich, 1997).

Multimedia is characterized by the presence of text, pictures, sound, animation and video; some or all of which are organized into some coherent program (Phillips, 1997).

Today's multimedia is a carefully woven combination of text, graphic art, sound, animation, and video elements. When you allow an end user, i.e. the viewer of a multimedia project, to control 'what' and 'when' and 'how' of the elements that are delivered and presented, it becomes interactive multimedia.

Why use multimedia at all? Of what use is multimedia in education? The answers to these questions could be sought through an understanding of the capabilities and limitations of the medium.

Besides being a powerful tool for making presentations, multimedia offers unique advantages in the field of education. For instance, text alone simply does not allow students to get a feel of any of Shakespeare's plays. In teaching biology, an instructor cannot make a killer whale come alive in a classroom. Multimedia enables us to provide a way by which learners can experience their subject in a vicarious manner. The key to providing this experience is having simultaneous graphic, video and audio, rather than in a sequential manner. The appeal of multimedia learning is best illustrated by the popularity of the video games currently available in the market. These are multimedia programs combining text, audio, video, and animated graphics in an easy-to-use fashion.

Moreover, under conditions of chronic under-funding, multimedia can provide an enhanced or augmented learning experience at a low cost per unit. It is here that the power of multimedia can be unleashed to provide long-term benefit to all. Multimedia enables learning through exploration, discovery, and experience. Technology does not necessarily drive education. That role belongs to the learning needs of students. With multimedia, the process of learning can become more goals oriented, more participatory, and flexible in time and space, unaffected by distances and tailored to individual learning styles, and increase collaboration between teacher sand students. Multimedia enables learning to become fun and friendly, without fear of inadequacies or failure.

As such multimedia can be defined as an integration of multiple media elements (audio, video, graphics, text, animation, etc.) into one synergetic and symbiotic whole that results in more benefits for the end user than any one of the media element can provide individually.

4.1. 3D Modelling and Animation

Due to the proximity of processes that are performed in the RFID lab, this application was accompanied by 3D animation. It is a process related to the transfer of data over a LAN, where a SAP SERVER communicates with other devices and equipment separate from the server.

4.1.1. Modelling

In order to animate the models it was necessary to create a final scene. This consists of a number of 3D models whose work is described in this subchapter through words and pictures [4].

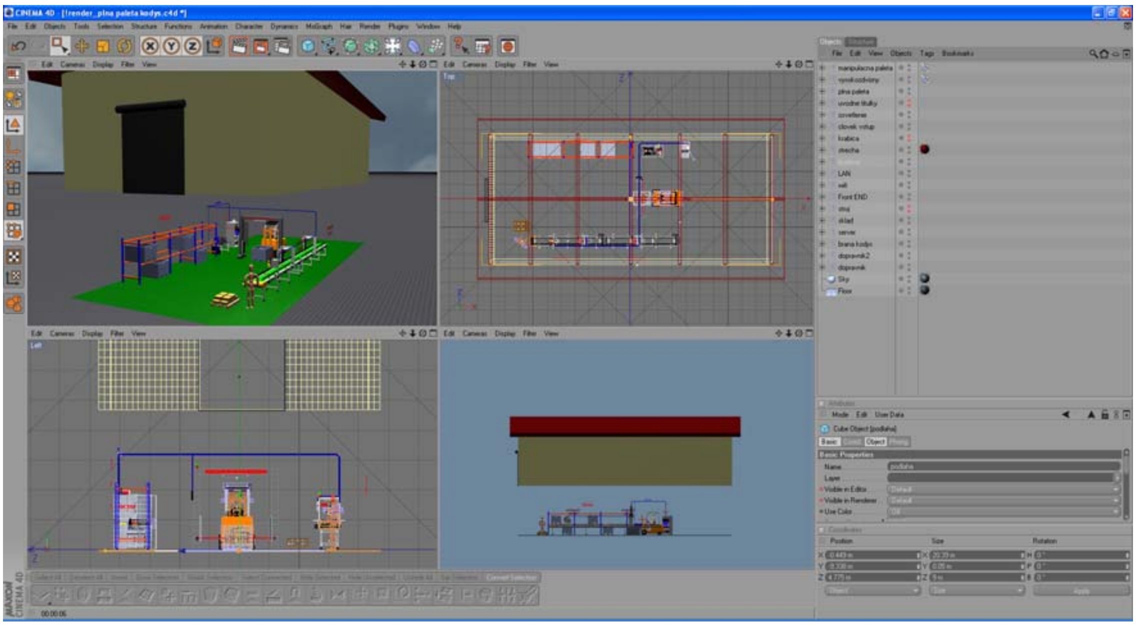

Figure 5. Work Environment of the program Cinema 4D R10 at modelling RFID lab [2]

Figure 5 shows the preview of the work environment. Cinema 4D R10 was used to remodel likenesses of all the objects, and place them in the final scene. The Y axis of the building was moved for clarity in the picture. Preview the template of modelling, which is designed for modelling objects in the program Cinema 4D R10. Units of length used Cinema 4D R10 uses meters as units of length. Generated models were modelled in scale, the reality that the observed ratio of the various parts of models.

Conveyor belt number 1, modelled according to its design drawings contained in the instructions for its maintenance, together with the printer and Zebra RFID gate No 1, is shown on Figure 6.

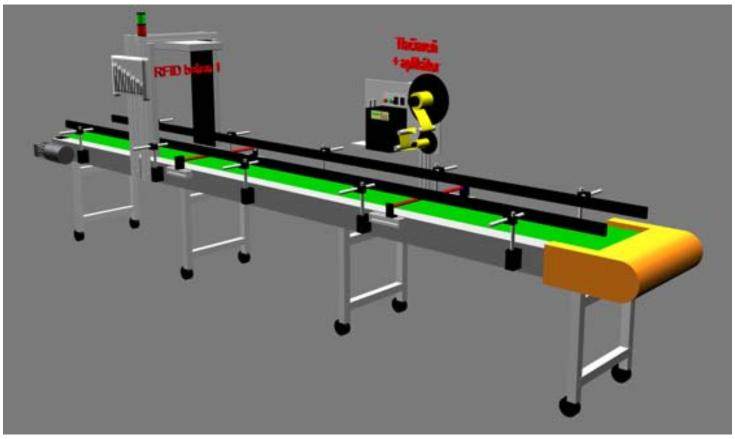

Figure 6. Model of the conveyor belt, printers and ZEBRA RFID Gate No. 1[2]

The following sections of individual processes were modelled in a similar way to the previous conveyor belt number 1. They are:

- Conveyor belt number 2.
- Zebra printer and label applicator.
- RFID Gate KODYS / VECTRA.
- Store.
- Server.
- Building.
- Wood pallets, boxes.
- Forklifts and pallet fence.
- FrontEnd.

4.1.2. Animation

When the scene was modelled the animation was made by technical parts of the scenario. All animated scenes were created with 25 images (frames) per second. Frames will be referred to below by letter. Animation took place in the layout window in the program Cinema 4D R10 by templates Animation. Here a timeline has been added to the standard view (Timeline) shown on Figure 7 [4].

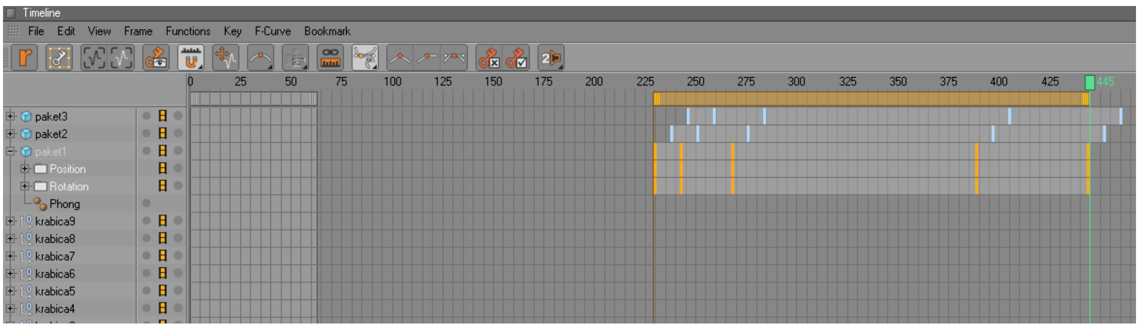

Figure 7. The time line window in the program Cinema 4D R10

The following scenes of individual processes were animated:

- Goods Receipt – this part featured the animation motion model of a forklift truck, which carries a variety of materials for input into production.
- Data from the Frontend pass to the server and then to the printer ZEBRA – this animation was used because of representations from – where transmit data after entering production.
- Data from the RFID gate No.1 forwarded to the server – the animation showed the transition of data from RFID gate No. 1 to the server after reading an RFID tag placed on the box. First it was necessary to animate the movement patterns of boxes on the model conveyor belt.
- Data from the RFID gate No. 2 forwarded to the server.
- Data from the RFID gate KODYS / VECTRA forwarded to the server.
- Applied Ethics.
- Entering Warehouse.
- WiFi router and server [2].

Exporting of animation

Finally, it was necessary to export our animation (rendering of scenes). It is divided into set of rendering parameters and rendering using Net Render Cinema.

Set rendering parameters:

Export of video was the same after completion of each animation. They made two kinds of settings, export animation. The first was a video animation at 267x150 resolutions, due to faster rendering. This video served to check that everything was as requested.

The second set of exports was made up to suit the requirements of the animation, which was verified in a video with lower resolution. The second set of the exports was as follows: video resolution 1280 x 720 pixels with a size relative to the first the final format was 16 at the ninth were all selected frames. The number of frames per second (frame rate) was 25th AVI format was chosen for better picture and the possibility of creating a video with higher resolution.

Render using Net Render Cinema:

It was about two programs that allow the resulting animation rendering on multiple computers involved in the network. Condition was imposed as an animation project. The first program was Net Render Server. The running conditions were created at the beginning of rendering network.

5. Conclusions

RFID is a very useful and exciting technology. It seems that everywhere one looks there is some article about RFID and the huge benefits its technology promises. Moreover, there are many examples that demonstrate how this technology is fulfilling its potential. This article is intended to bring opportunities for implementing RFID technology in the storage and production lines. Through the use of RFID lab a specific model example has been realised. The results of the modelling and animation of each scene are applications that simulate the processes in the RFID lab. Through these applications it may be easier to understand warehousing operations based on RFID technology. This article is a part of the projects described below, which together with the afore-mentioned application will improve the learning process at the Department of Communications.

The given article was written to support the following projects:

1) AV: 4/2045/08 "Aplikácie technológie RFID pre vybrané poštové procesy na podmienky HSS".

2) KEGA 077-059ŽU-4/2010 "Implementácia nových technológií do vzdelávania (vytvorenie RFID laboratória ako podporného prvku pre vzdelávanie)".

3) KEGA 089-068ŽU-4/2010 "Aplikácia RFID pri sledovaní pohybu diplomových a bakalárskych prác v rámci univerzitného campusu".

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SYNTHESIS OF TWO-CHANNEL EVEN-ORDER FILTERING SYSTEMS ON PHASE UNITS

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The fundamental opportunity of synthesis of even-order two-channel filters on phase units is described in article. The suggested approach is based on an artificial leading of structural- and electrical-*asymmetric* circuit to structural- and electrical-*symmetric* circuit using special matrix transformations. The major inconvenience of the method is that the complexity of the final analytical expression of the two-channel filter transfer function almost directly depends on the filter's order.

The synthesis examples of low-frequency and pass-band two-channel filters on phase units for small orders are given. The frequency characteristics are also provided.

Keywords: phase filter, synthesis, digital filters

1. Introduction

Multi-channel filtering systems allow its time-parallel realization, which, in some cases, may lead to significant performance improvements in comparison with usual cascade realizations. Furthermore, sometimes the strict requirements may be applied to the architecture and frequency responses of each channel because of the chosen software or hardware realization. As a result, phase units might be a good solution for its using in each channel. In spite of the fact that the phase units are widely used in the systems of phase corrections, there're not so many investigations in the literature, which are devoted to the filtering structures on phase units, unfortunately. Moreover, some of structures of phase units are pretty irrational – they have respectively many multipliers and adders. Previously [3] the new phase structures have been developed, which, in general, has less amount of real multipliers and adders in comparison with known phase realizations. Therefore we will consider some synthesis methods of filtering systems, which have only phase units in its structures.

The synthesis method of ***odd-order*** two-channel filters on phase units using the theory of quadripoles is described in the paper [1]. The fundamental principle of such a method is based on a transformation of initial odd-order structural- and electrical-symmetric LC-prototype into a two-channel realization, where each channel represents a cascade combination of phase units. The advantage of this method consists in its perfect simplicity since the complexity of the analytical expression of the filter's transfer function doesn't depend on its order. Unfortunately, the basic principle of such a method does not allow its easy usage for similar synthesis of ***even-order*** two-channel filters on phase units, since its initial even-order LC-prototype is structural- and electrical asymmetric.

On the basis of the theory of quadripoles, the fundamental opportunity of synthesis of even-order two-channel filters on phase units is described in the article. The frequency characteristics are also provided.

2. Description of Method

It is known that the physically realizable analogue polynomial prototypes of even-order Butterworth or Chebyshev type I filters with equal input and output loads belong to electrical-asymmetric circuits. The method of synthesis of two-channel even-order circuit on phase units suggested below is based on artificial leading of structural- and electrical-asymmetric circuit (Fig. 1) to structural- and electrical-symmetric circuit. The subsequent known transformations of transfer function of modified circuit allow realizing it as a two-channel system on phase units [1].

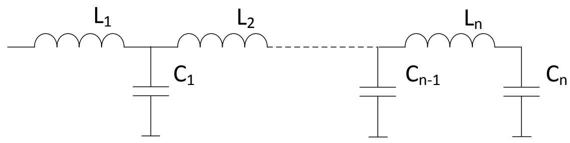


Figure 1. LC-prototype of electrical- and structural-asymmetric circuit

The simplest reversible transformation of electrical-asymmetric circuit into electrical-symmetric circuit is based on a multiplication of A-matrix of the circuit by the complex J-matrix as follows:

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix} = j \begin{bmatrix} a_{12} & a_{11} \\ a_{22} & a_{21} \end{bmatrix}. \tag{1}$$

here the a_{12} is equal to a_{21}.

Following the (1), the one of LC-prototype realization possible variants of electrical-symmetric even-order circuit is the following prototype structure as follows (Fig. 2):

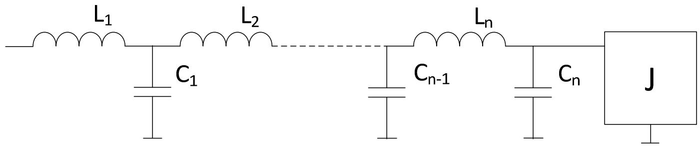


Figure 2. LC-prototype of electrical-symmetric circuit

Since the only structural-symmetric circuit might be realized in the form of two-channel system with phase channels, it is necessary to modify the structure shown on Figure 2 in the way as follows (Fig. 3):

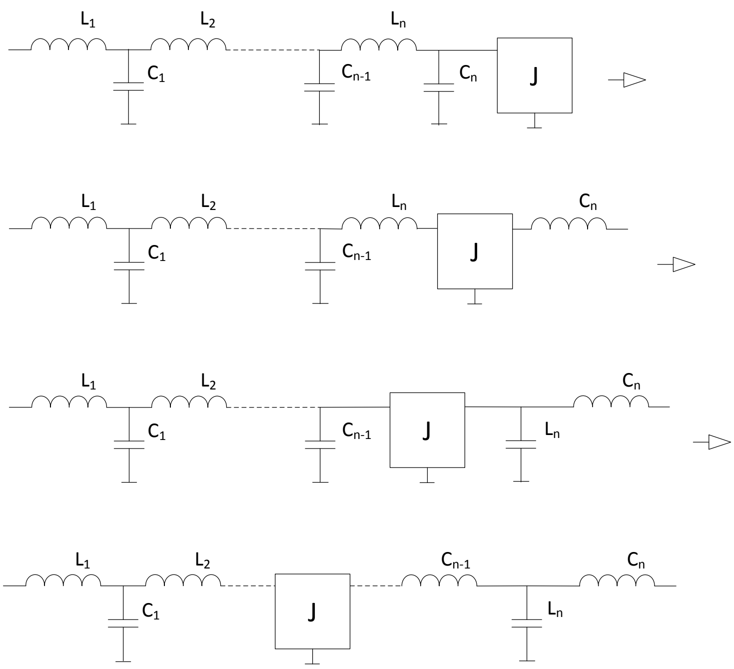


Figure 3. Transformation of the electrical-symmetric structural-asymmetric circuit into structural-symmetric

Apparently, the normalized factors of such circuit (Fig. 3) are pair-equal for Butterworth or Chebyshev Type I filters, i.e. $L_1 = C_n$, $C_1 = L_n$, $L_2 = C_{n\text{-}1}$, etc. [2]. Moreover, it is known, that the complex J-matrix might be realized by one of the two ways (Fig. 4):

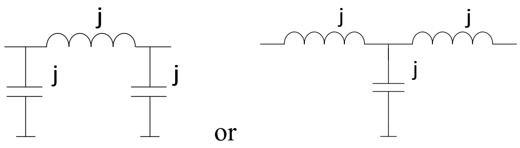


Figure 4. Variants of J-matrix realization

Therefore, we can substitute the J-structure, shown on Fig. 3, with one of variants, shown on Figure 4. For simplicity we will consider the electrical- and structural-asymmetric circuit of 4th-order (Fig. 5):

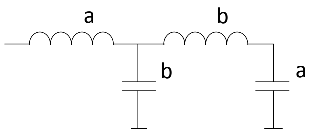


Figure 5. LC-prototype of asymmetric 4th-order circuit

Here *a* and *b* are the parameters of the normalized circuit. According to the Figures 3, 4 and 5, the modified structural-symmetric 4th-order circuit might be represented, for example, in the way as follows (Fig. 6):

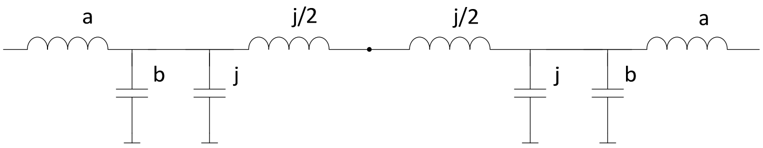


Figure 6. Structural-symmetric circuit with insertion of j-elements

Let us describe the half of the circuit shown on Figure 6, through factors of its A-matrix:

$$
\begin{aligned}
\left[A_{half}\right] &= \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} 1 & pa \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ pb & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}\begin{bmatrix} 1 & j/2 \\ 0 & 1 \end{bmatrix} = \\
&= \begin{bmatrix} 1+p^2ab & pa \\ pb & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}\begin{bmatrix} 1 & j/2 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1+p^2ab+jpa & pa \\ pb+j & 1 \end{bmatrix}\begin{bmatrix} 1 & j/2 \\ 0 & 1 \end{bmatrix} = \\
&= \begin{bmatrix} 1+p^2ab+jpa & \tfrac{1}{2}(j+jp^2ab+pa) \\ pb+j & \tfrac{1}{2}(jpb+1) \end{bmatrix}
\end{aligned} \tag{2}
$$

It might be shown [1], that the transfer function of any structural-symmetric circuit with equal input and output loads can be represented in its turn as a sum of transfer functions of two phase channels. Hence for 4th-order filter:

$$
\begin{aligned}
H &= \frac{1}{2}\left(\frac{a_{11}-a_{21}}{a_{11}+a_{21}} + \frac{a_{22}-a_{12}}{a_{22}+a_{12}}\right) = \\
&= \frac{1}{2}\left(\frac{1+p^2ab+jpa-pb-j}{1+p^2ab+jpa+pb+j} + \frac{jpb+1-j-jp^2ab-pa}{jpb+1+j+jp^2ab+pa}\right) = \\
&= \frac{1}{2}\left(\frac{p^2-p\left(\frac{b-ja}{ab}\right)+\left(\frac{1-j}{ab}\right)}{p^2+p\left(\frac{b+ja}{ab}\right)+\left(\frac{1+j}{ab}\right)} - \frac{p^2-p\left(\frac{b+ja}{ab}\right)+\left(\frac{1+j}{ab}\right)}{p^2+p\left(\frac{b-ja}{ab}\right)+\left(\frac{1-j}{ab}\right)}\right).
\end{aligned} \tag{3}
$$

We will not show the synthesis of high-frequency filter since it uses completely the same approach like was shown above with corresponding modifications in the initial prototype structure.

Following the same pattern used for synthesis of low-frequency even-order filter with two phase channels, let us consider the synthesis of ***pass-band*** even-order two-channel filter on phase units. In order to simplify the subject we will use the base 4th-order prototype of low-frequency filter (Fig. 5). As far as it is known, in order to describe the pass-band filter structure each inductance of low-frequency filter prototype must be replaced with serial combination of the same inductance and capacity, which value is chosen based on the condition to provide the frequency resonance at the f_0 frequency. Similarly, each capacity must be replaced with the parallel combination of the same capacity and inductance, which value is chosen based on the condition to provide the frequency resonance at the f_0 frequency. Therefore, the Figure 5 might be easily transformed into a pass-band form as it is shown below (Fig. 7).

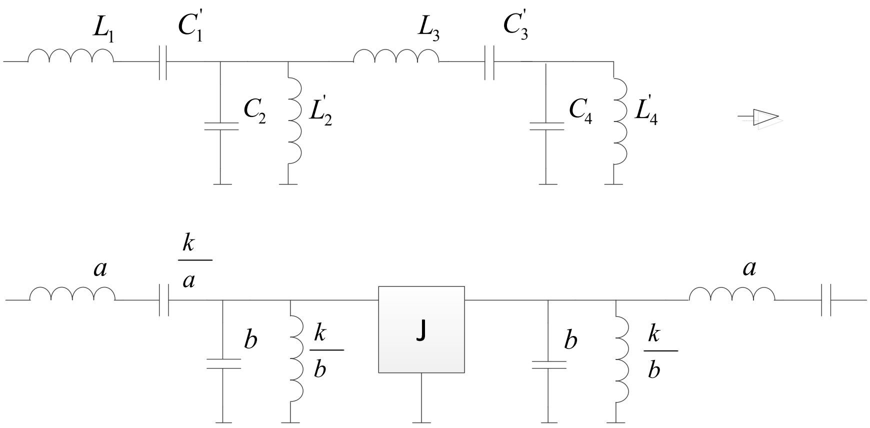


Figure 7. LC-prototype of 4th-order pass-band filter

where $C_1' = \dfrac{1}{\omega_0^{\,2} L_1}$, $L_1' = \dfrac{1}{\omega_0^{\,2} C_1}$, ω_0 – central frequency, $k = \dfrac{1}{\omega_0^{\,2}}$. Since the normalized values of L_1 is equal to normalized value of C_4 in the given case, as well as normalized value of C_2 is equal to normalized value of L_3, we will replace them by a and b correspondingly. Therefore, following (2), the half of the circuit shown on Fig. 7 with connection of half of complex J-matrix might be described the following way:

$$\left[A_{half}\right] = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} 1 & pa \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & \dfrac{a}{pk} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ pb & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \dfrac{b}{pk} & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix} \begin{bmatrix} 1 & j/2 \\ 0 & 1 \end{bmatrix} =$$

$$= \begin{bmatrix} 1 + \left(pa + \dfrac{a}{pk}\right)\left(pb + \dfrac{b}{pk}\right) & pa + \dfrac{a}{pk} \\ pb + \dfrac{b}{pk} & 1 \end{bmatrix} \begin{bmatrix} 1 & j/2 \\ j & 1/2 \end{bmatrix} =$$

$$= \begin{bmatrix} 1 + \left(pa + \dfrac{a}{pk}\right)\left(pb + \dfrac{b}{pk}\right) + j\left(pa + \dfrac{a}{pk}\right) & \dfrac{1}{2}\left(j + j\left(pa + \dfrac{a}{pk}\right)\left(pb + \dfrac{b}{pk}\right) + \left(pa + \dfrac{a}{pk}\right)\right) \\ pb + \dfrac{b}{pk} + j & \dfrac{1}{2}\left(j\left(pb + \dfrac{b}{pk}\right) + 1\right) \end{bmatrix}. \quad (4)$$

Following [1] and (4), the result transfer function of the pass-band 4th-order filter with two phase channels might be described as follows (5):

$$H=\frac{1}{2}\left(\frac{a_{11}-a_{21}}{a_{11}+a_{21}}+\frac{a_{22}-a_{12}}{a_{22}+a_{12}}\right)=$$
$$=\frac{1}{2}\left(\frac{1+\left(pa+\frac{a}{pk}\right)\left(pb+\frac{b}{pk}\right)+j\left(pa+\frac{a}{pk}\right)-pb-\frac{b}{pk}-j}{1+\left(pa+\frac{a}{pk}\right)\left(pb+\frac{b}{pk}\right)+j\left(pa+\frac{a}{pk}\right)+pb+\frac{b}{pk}+j}+\right.$$
$$\left.+\frac{j\left(pb+\frac{b}{pk}\right)+1-j-j\left(pa+\frac{a}{pk}\right)\left(pb+\frac{b}{pk}\right)-\left(pa+\frac{a}{pk}\right)}{j\left(pb+\frac{b}{pk}\right)+1+j+j\left(pa+\frac{a}{pk}\right)\left(pb+\frac{b}{pk}\right)+\left(pa+\frac{a}{pk}\right)}\right). \qquad (5)$$

Based on the previous computations, let us derive the general formula for the transfer function of the even-order two-channel filters on phase units. As it has been shown before, the suggested approach is based on the artificial leading of structural-asymmetric circuit to structural-symmetric. Since it's enough to use the only half of the entire even-order circuit to evaluate its transfer function, let us suppose that this half is described by the A-matrix of the half of initial LC-circuit in conjunction with the half of J-matrix. Therefore the half of the entire circuit is described by the A_{half}–matrix as follows (6):

$$\left[A_{half}\right]=\begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}=\left[A\right]\cdot\left[J/2\right]=\begin{bmatrix}A_{11} & A_{12}\\ A_{21} & A_{22}\end{bmatrix}\cdot\begin{bmatrix}1 & j/2\\ j & 1/2\end{bmatrix}=\begin{bmatrix}A_{11}+jA_{12} & 1/2\left(jA_{11}+A_{12}\right)\\ A_{21}+jA_{22} & 1/2\left(jA_{21}+A_{22}\right)\end{bmatrix}. \qquad (6)$$

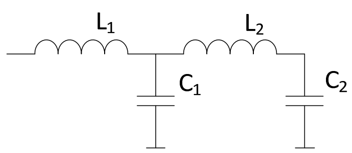
Following [1] and (6), the entire transfer function of the structural-symmetric even-order filtering system with two phase channels might be described in the way as follows:

$$H=\frac{1}{2}\left(\frac{a_{11}-a_{21}}{a_{11}+a_{21}}+\frac{a_{22}-a_{12}}{a_{22}+a_{12}}\right)=$$
$$=\frac{\left(A_{11}-A_{21}\right)+j\left(A_{12}-A_{22}\right)}{\left(A_{11}+A_{21}\right)+j\left(A_{12}+A_{22}\right)}-\frac{\left(A_{11}-A_{21}\right)-j\left(A_{12}-A_{22}\right)}{\left(A_{11}+A_{21}\right)-j\left(A_{12}+A_{22}\right)}=$$
$$=2j\frac{\sqrt{\left(A_{11}-A_{21}\right)^2+\left(A_{12}-A_{22}\right)^2}}{\sqrt{\left(A_{11}+A_{21}\right)^2+\left(A_{12}+A_{22}\right)^2}}\sin\left(arctg\left(\frac{A_{12}-A_{22}}{A_{11}-A_{21}}\right)-arctg\left(\frac{A_{12}+A_{22}}{A_{11}+A_{21}}\right)\right). \qquad (7)$$

3. Examples

Example 1

As an example, let us consider the analogue polynomial prototype of Chebyshev type I 4^{th}-order filter. Below the normalized values of filter elements at equal input and output loads are given (a_{max} = 0.28 dB) [2]:



L_1 (a)	1.146
C_1 (b)	1.513
L_2 (b)	1.513
C_2 (a)	1.146

The module of amplitude-frequency response of LC-prototype of aforementioned structural-asymmetric circuit is show on Figure 8.

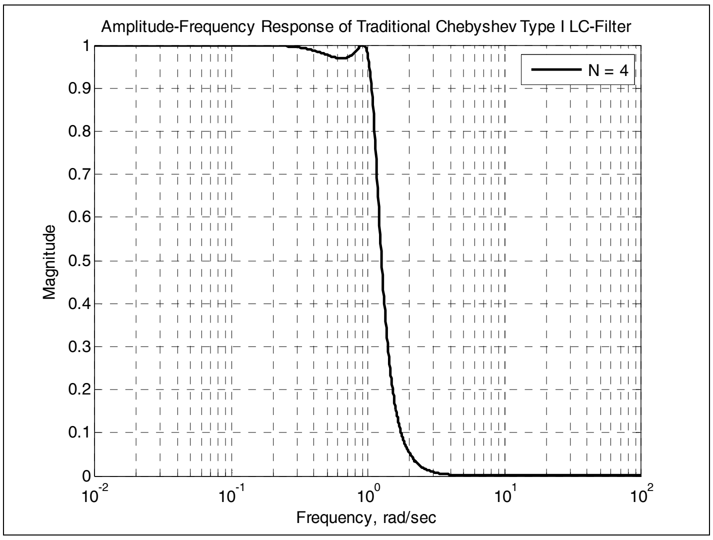


Figure 8. The module of amplitude-frequency response of Chebyshev type I 4th-order filter

Accordingly, the module of amplitude-frequency response of two-channel 4th-order system on phase units is shown on Figure 9.

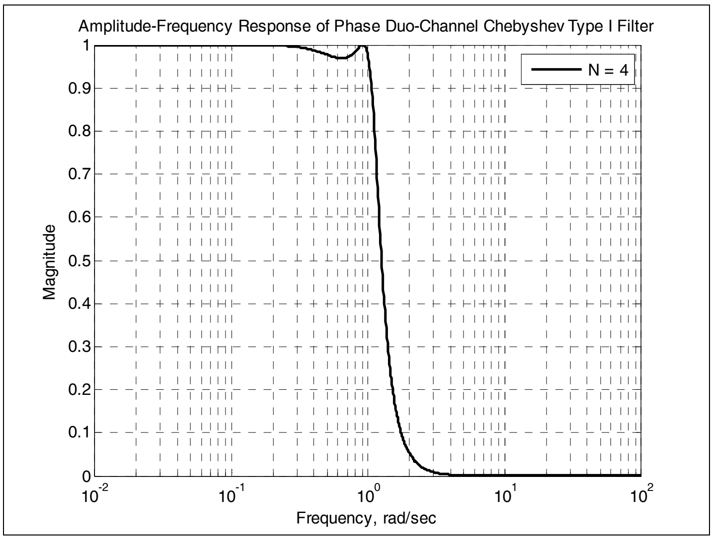
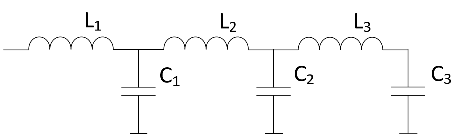


Figure 9. The module of amplitude-frequency response of two-channel Chebyshev type I 4th-order filter on phase units

It might be also shown, that these modules of amplitude-frequency responses (Fig. 8 and 9) are accurate within machine arithmetic error.

Example 2

As the second example, let us show the normalized factors of the 6th-order Chebyshev Type I filter, as well as its traditional amplitude-frequency response (simple LC-model, Fig. 10) and the amplitude-frequency response of the two-channel phase implementation (Fig. 11):



L_1 (a)	1.036
C_1 (b)	1.516
L_2 (c)	1.878
C_2 (c)	1.878
L_3 (b)	1.516
C_3 (a)	1.036

In this case the final transfer function of the two-channel phase system is as follows (8):

$$H=\frac{1}{2}\left(\frac{a_{11}-a_{21}}{a_{11}+a_{21}}+\frac{a_{22}-a_{12}}{a_{22}+a_{12}}\right)=$$
$$=\frac{1}{2}\left(\frac{p^2ab-pb+1+j(p^3abc-p^2bc+p(a+c)-1)}{p^2ab+pb+1+j(p^3abc+p^2bc+p(a+c)+1)}\right)-$$
$$-\frac{1}{2}\left(\frac{p^3abc-p^2bc+p(c+a)-1-j(pb-1-p^2ab)}{p^3abc+p^2bc+p(c+a)+1+j(pb+1+p^2ab)}\right). \qquad (8)$$

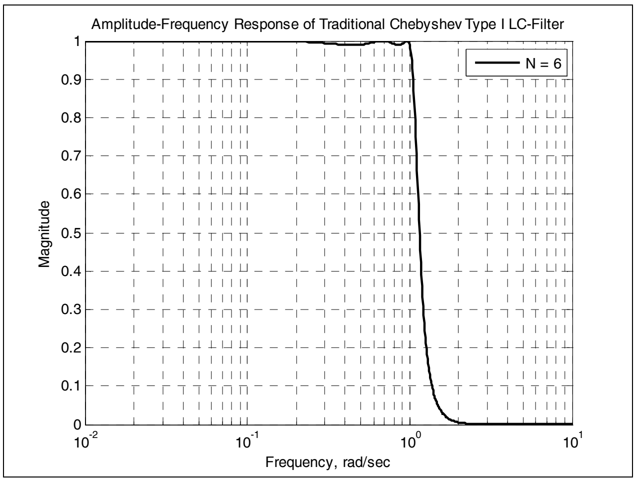


Figure 10. The module of amplitude-frequency response of Chebyshev type I 6th-order filter

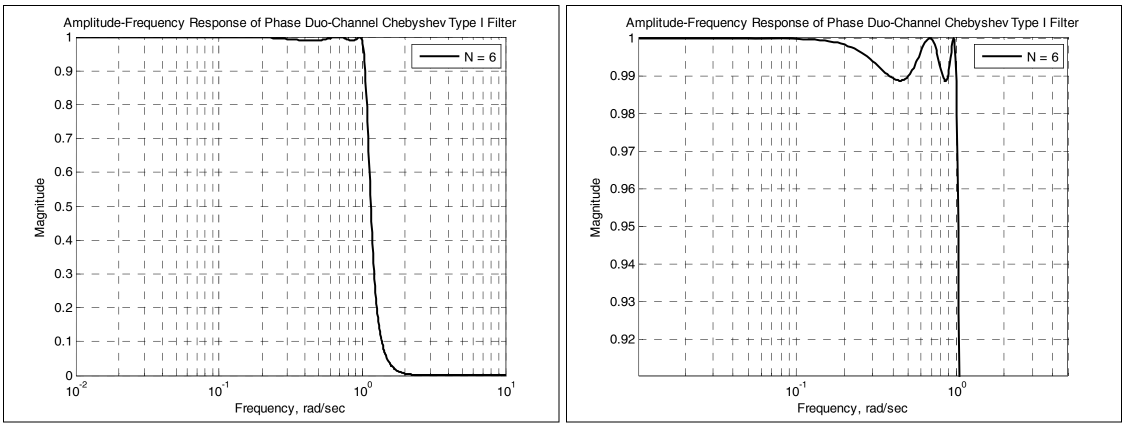
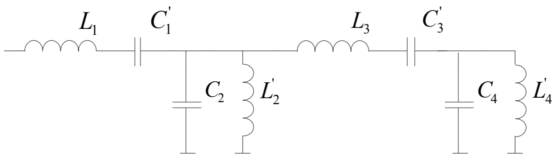


Figure 11. The module of amplitude-frequency response of two-channel Chebyshev type I 6th-order filter on phase units

Example 3

Finally, we will show the amplitude-frequency response of 4th-order pass-band filter with two phase channels, based on the prototype parameters from [2] (Fig. 12). The pass-band LC-prototype structure and its normalized parameters are shown below. The central frequency ω_0 is 3 rad/sec.



L_1 (a)	1.146	L_3 (b)	1.513
$C_1^{'}$	0.097	$C_3^{'}$	0.073
$L_2^{'}$	0.073	$L_4^{'}$	0.097
C_2 (b)	1.513	C_4 (a)	1.146

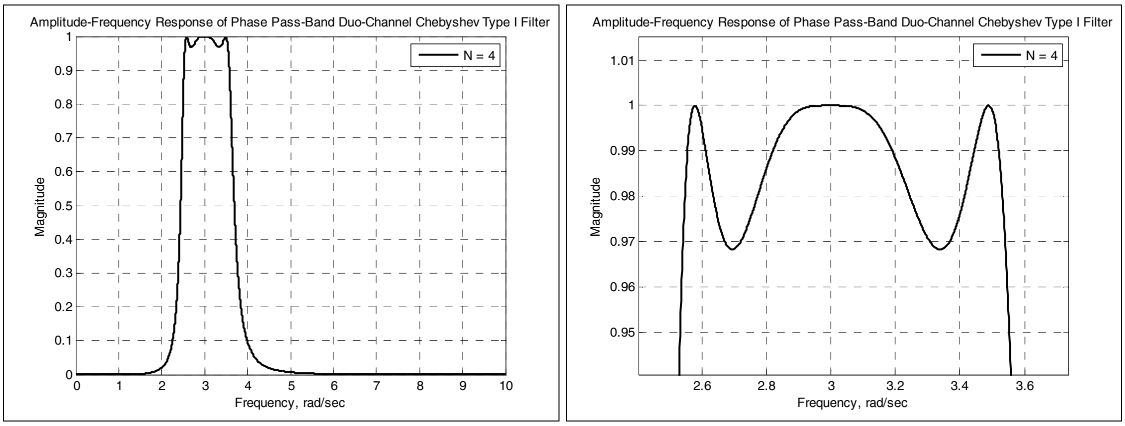


Figure 12. The module of amplitude-frequency response of pass-band Chebyshev type I 4^{th}-order filter

4. Conclusions

The fundamental opportunity of synthesis of two-channel even-order filters on phase units, using the traditional matrix transformations of transfer function, is shown. Some examples for low-frequency and pass-band filters are also provided. The frequency responses of the new structures are equal to the original within the whole frequency range.

Unfortunately, it requires some efforts to derive the A_{half}-matrix since there is no easy analytical method to describe it for any given order. Moreover, some types of narrow-band digital filters [5] require factorisation of nominator and denominator polynomials, which may also be another more or less complicated task for its implementation as two-channel phase filters.

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FLEET MANAGEMENT PROBLEM ANALYSIS IN DISCRETE TRANSPORT SYSTEMS

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The paper describes a novel approach to analysis of management algorithms in discrete transport systems (*DTS*). The proposed method is based on modelling and simulating of the system behaviour. Monte Carlo simulation is a tool for *DTS* performance metric calculation. No restriction on the system structure and on a kind of distribution is the main advantage of the method. The system is described by the formal model, which includes reliability and functional parameters of *DTS*.

The paper proposes to change the classic time-table based on management system of *DTS* by dynamic heuristic algorithms and algorithms based on artificial neural networks. The paper gives numerical results of simulation experiments. The results allow comparing mentioned above fleet management algorithms in different case studies.

Keywords: discrete transport system, reliability, Monte-Carlo simulation, fleet management algorithms, dispatching system

1. Introduction

The serious problem in transport system analysis is to find the suitable methodology for modelling of the management presented in a real system. The performance of the system can be impaired by various types of faults related to the transport vehicles, communication infrastructure or even by traffic congestion [13]. Moreover, it is hard for human (administrator, owner) to understand the system behaviour. To overcome the problems we propose a functional approach. The transport system is analysed from the functional point of view, focusing on business service realised by a system [9]. The analysis is following a classical [4]: modelling and simulation approach. It allows calculating different system measures, which could be a base for decisions related to administration of the transport systems. The metric are calculated using Monte Carlo techniques [7]. No restriction on the system structure and on a kind of distribution is the main advantage of the method. The proposed approach allows forgetting about the classical reliability analysis based on Markov or Semi-Markov processes [2] – idealised and hard for reconciliation with practice. The systems are often driven by a dispatcher – a person who allocates vehicles to the tasks introduced into system. The dispatcher ought to take into account different features which describe the actual situation of all elements of transport systems. The modelling of transport systems with dispatcher is not a trivial challenge. Our previous works [17][18] showed that it is hard to create an "intelligent" algorithm of dispatcher – an algorithm giving significantly better results from pure random algorithms. In this paper we propose a heuristic approach and the neural network based solution to solve this problem. The system is described by the formal model, which includes reliability and functional parameters of transport system. The proposed, novelty approach can serve for practical solving of essential management problems related to an organisation of transport systems. The paper is divided into seventh sections. The second describes Polish Post transport system. The third is focused on dispatcher problem discussion. The possible solutions for dynamic traffic modelling, microscopic model discussion and container manoeuvres problems are presented. Fleet management systems are described in the fourth section. Section number five is focused on definitions of proposed *DTS*. The next section describes the simulation process, used tools and collects the results. A conclusion we find as the last section.

2. Idea of Transport System Based on Polish Post Solution

The analysed transport system is a simplified case of the Polish Post. The business service provided the Polish Post is the delivery of mails. The system consists of a set of nodes placed in different geographical locations. Two kinds of nodes could be distinguished: central nodes (*CR*) and ordinary nodes (*PK*). There are bi-directional routes between nodes. Mails are distributed among ordinary nodes by trucks, whereas between central nodes by trucks, railway or by plain. The mail distribution could be understood by tracing the delivery of some mail from point *A* to point *B*. At first the mail is transported to the nearest to *A* ordinary node. Different mails are collected in ordinary nodes, packed in larger units called containers and then transported by trucks scheduled according to some time-table to the nearest central node. In central node containers are repacked and delivered to appropriate (according to delivery address of each mail) central node. In the Polish Post there are 14 central nodes and more than 300 ordinary nodes. There are more than one million mails going through one central node within 24 hours. It gives a very large system to be modelled and simulated. Therefore, we have decided to model only a part of the Polish Post transport system – one central node with a set of ordinary nodes.

Essential in any system modelling and simulation is to define the level of details of modelled system. Increasing the details causes the simulation becoming useless due to the computational complexity and a large number of required parameter values to be given. On the other hand a high level of modelling could not allow recording required data for system measure calculation. Therefore, the crucial think in the definition of the system level details is to know what kind of measures will be calculated by the simulator. Since the business service given by the post system is the delivery of mails on time. Therefore, we have to calculate the time of transporting mails by the system. Since the number of mails presented in the modelled system is very large and all mails are transported in larger amounts containers, we have decided to use containers as the smallest observable element of the system. Therefore, the main observable value calculated by the simulator will be the time of container transporting from the source to the destination node. The income of mails to the system, or rather containers of mails as it was discussed above, is modelled by a stochastic process. Each container has a source and destination address. The central node is the destination address for all containers generated in the ordinary nodes. Where containers addressed to any ordinary nodes are generated in the central node. The generation of containers is described by some random process. In case of central node, there are separate processes for each ordinary node. Whereas, for ordinary nodes there is one process, since commodities are transported from ordinary nodes to the central node or in the opposite direction. The containers are transported by vehicles. Each vehicle has given capacity – maximum number of containers it can haul. Central node is a base place for all vehicles. They start from the central node and the central node is the destination of their travel. The vehicle hauling a commodity is always fully loaded or taking the last part of the commodity if it is less than its capacity. Vehicles operate according to the time-table. The time-table consists of a set of routes (sequence of nodes starting and ending in the central node, times of leaving each node in the route and the recommended size of a vehicle). The number of used vehicle and the capacity of vehicles do not depend on temporary situation described by number of transportation tasks or by the task amount for example. It means that it is possible to realise the route by completely empty vehicle or the vehicle cannot load the available amount of commodity (the vehicle is too small). Time-table is a fixed element of the system in observable time horizon, but it is possible to use different time-tables for different seasons or months of the year. Summarising the movement of the containers in the system, a container is generated with destination address in some of node (source) at some random time. Next, the container waits in the node for a vehicle to be transported to the destination node. Each day a given time-table is realised, it means that at a time given by the time table a vehicle, selected from vehicles available in the central node, starts from central node and is loaded with containers addressed to each ordinary nodes included in a given route. This is done in a proportional way. When a vehicle approaches the ordinary node it is waiting in an input queue if there is any other vehicle being loaded/unload at the same time. There is only one handling point in each ordinary node. The time of loading/unloading vehicle is described by a random distribution. The containers addressed to given node are unloaded and empty space in the vehicle is filled by containers addressed to a central node. Next, the vehicle waits till the time of leaving the node (set in the time-table) is left and starts its journey to the next node. The operation is repeated in each node on the route and finally the vehicle is approaching the central node when it is fully unloaded and after it is available for the next route. The process of vehicle operation could be stopped at any moment due to a failure (described by a random process). After the failure, the vehicle waits for a maintenance crew (if there are no available due to repairing other vehicles), is being repaired (random time) and after it continues its journey. The vehicle hauling a commodity is always fully loaded or taking the last part of the commodity if it is less than its capacity.

3. Fleet Management Discussion

3.1. Traffic Modelling Problem

Modelling traffic flow for design, planning and management of transportation systems in urban and highway area has been addressed since the 1950s mostly by the civil engineering community. The following definitions and concepts of traffic simulation modelling can be found in works such as Gartner et al. [8]. Depending on the level of detail in modelling the granularity of traffic flow, traffic models are broadly divided into two categories: macroscopic and microscopic models. According to Gartner et al. [8], a macroscopic model describes the traffic flow as a fluid process with aggregate variables, such as flow and density. The state of the system is then simulated using analytical relationships between average variables such as traffic density, traffic volume, and average speed. On the other hand, a microscopic model reproduces interaction of punctual elements (vehicles, road segments, intersections, etc) in the traffic network. Each vehicle in the system is emulated according to its individual characteristics (length, speed, acceleration, etc.). Traffic is then simulated, using processing logic and models describing vehicle driving behaviour, such as car-following and lane-changing models. Those models reproduce driver-driver and driver-road interactions. Despite its great accuracy level, for many years this highly detailed modelling was considered a computationally intensive approach. Since the last twenty years, with the improvements in processing speed, this microscopic approach becomes more attractive. In fact, Ben-Akiva et al. [3], Barcelo et al. [1] and Liu et al. [12] claim that using microscopic approach is essential to track the real-time traffic state and then, to define strategy to decrease congestion in urban transportation networks. For the control of congestion, they explain that the models must accurately capture the full dynamics of time dependant traffic phenomena and must also track vehicles' reactions when exposed to Intelligent Transportation Systems (ITS). From the latter assertions, in order to control traffic congestion in internal transportation networks it appears that the microscopic modelling will be more appropriate. A common definition of congestion is the apparition of a delay above the minimum travel time needed to traverse a transportation network. As stated in Taylor et al. [14], this notion is context-specific; and complex because a delay may always appear in dynamic transport system, but this delay must exceed a threshold value in order to be considered.

3.2. Microscopic Analysis

Few works have considered the traffic behaviour when studying outdoors vehicle-based internal transport operational problems. In the surface mining environment, pickup and delivery operations involve a fleet of trucks transporting materials from excavation stations to dumping stations, through a designed shared road network. At pickup stations, shovels are continuously digging during a shift according to a pre-assigned mining production plan. Trucks are moving in a cyclical manner between shovels (pickup stations), and dumping areas (delivery stations). A truck cycle time is defined as the time spent by a truck to accomplish an affected mission that consists of travelling to a specific shovel, being serviced by the shovel and hauling material to a specific dumping area. Burt and Caccetta [5] state that mine productivity is very sensitive to truck dispatching decisions which are closely related to the truck cycle time. Thus several papers have studied and proposed algorithms and software to resolve this problematic issue. In fact, this critical decision consists of finding, according to the real environment, to which best shovel a truck must be affected. Such decision has to be generated continuously during a shift, whenever a truck finished dumping at a delivery station. Despite the several proposed dispatching software, recent articles by Krzyzanowska [11] formally criticize the simplistic assumption behind those software which tend to provide dispatching decisions with the objective to optimise a truck cycle times previously calculated. Generally speaking, those software systems based the optimisation process on the past period collected data of trucks cycle times and assume that for the next period trucks will spend on average the same time to accomplish missions. But in the reality of mining operation, the duration of truck travel time appears to be very sensitive to the variable traffic state and road conditions. Burt and Caccetta [5] and Krzyzanowska [11], point out the unresolved problematic of truck bunching and platoon formation in mining road network which apparently induce lower productivity.

3.3. Container Movement

Similarly to material transportation in mining operation, several papers (Ioannou [10], Vis [15]) have provided methods for improving container terminal complex operations. In such applications, three types of handling operations are defined: vessel operations, receiving/delivery operations and container handling and storage operations in the stack yards. As we are interested by internal transportation systems, our review concerns the papers dealing with the container handling and storage operations in the stack yards. Generally speaking, vessels bring inbound containers to be picked up by internal trucks and distributed to the respective stocks in the yard. Once discharged, vessels have to leave with on board outbound containers which also are delivered by internal trucks from the storage yard. For this purpose, trucks are moving through a terminal internal road network. In order to decrease the vessel turnaround time, which is the most important performance measure of container terminals, it is important to perform those operations as quickly as possible. In fact according to [3], this movement of containers between quay sides and storage yards appears to greatly affect the productivity of containership's journey. Vis and Koster [15] gives an extended review of numerous research papers, providing algorithms to solve this complex routing and scheduling problem. They criticize the lack of consistency of the simplistic assumptions made to solve the proposed models within the real-world highly stochastic environment. The ignored traffic situation in the complex seaport internal transportation network is strongly criticized in recent papers [4], [10]. For example, in [3], a travel time of a container internal truck is modelled as a static mean time of travel, based on the distance and the truck average speed. Duinkerken et al. [6], put a uniform distribution between zero and 30% of the nominal travel time formulation, aiming to assimilate the complexity of traffic. More accurate work to solve this issue is the one provided recently by Liu, Chu and Recker [12]. They integrate a traffic model to the internal service model and reported the effectiveness of this integration which allows analysing the tractor traffic flow in a port container terminal. Conscious about the critical problem of congestion in the road network inside a terminal, a quantitative measure of congestion to be added as a controllable decision variable had been developed. For this purpose, they considered the road system inside the terminal as a directed network and they measured flows on arcs in units of trucks travelling per unit time. Those two last works appear as providing the leader approach in term of consideration of congestion and traffic in container terminals; however, their approach is ultimately macroscopic. As we have lately discussed, even if this macroscopic approach allows analysing the traffic behaviour, the highly detailed microscopic model is more efficient for an effective real-time traffic monitoring and control.

4. Fleet Management System

4.1. Formal Model of Discrete Transport System

The described in the section two regional part of the Polish Post transport system with one central node and several ordinary nodes was a base for a formal model definition of the discrete transport system with central node (*DTS*). Users generate tasks, which are being realised by the system. The task to be realised requires some services available in the system. A realisation of the service needs a defined set of technical resources. Moreover, the vehicles transporting mails between system nodes are steering by the management system. Therefore, we can model discrete transport system as a quadruple [18, 20]:

$$DTS = \langle Client, BS, TI, MS \rangle, \tag{1}$$

Client – client model,
BS – business service, a finite set of service components,
TI – technical infrastructure,
MS – management system.

During modelling of technical infrastructure we have to take into consideration functional and reliability aspects of the post transport system. Therefore, the technical infrastructure of *DTS* could be described by three elements:

$$TI = \langle No, V, MM \rangle, \tag{2}$$

where: *No* – set of nodes; *V* – set of vehicles; *MM* – maintenance model.

Set of nodes (*No*) consists of single central node (*CR*), a given number of ordinary nodes (PK_i). The distance between each two nodes is defined by the function:

$$distance : No \times No \to R_+ . \tag{3}$$

Each node has one functional parameter the mean (modelled by normal distribution) time of loading a vehicle:

$$loading : No \to R_+ . \tag{4}$$

Moreover, the central node (*CR*) has additional functional parameter: number of service points (in each ordinary node there is only one service point):

$$servicepoints : CR \to N_+ . \tag{5}$$

Each vehicle is described by the following functional and reliability parameters:

- mean speed of a journey
  $$meanspeed : V \to R_+ , \tag{6}$$
- capacity – number of containers which can be loaded
  $$capacity : V \to R_+ , \tag{7}$$
- mean time to failure
  $$MTTF : V \to R_+ , \tag{8}$$
  a time when failure occurs is given by exponential distribution with mean equal to a value of *MTTF* function,
- mean repair time
  $$MRT : V \to R_+ . \tag{9}$$

The traffic is modelled by a random value of vehicle speed and therefore the time of vehicle (v) going from one node (n_1) to the other (n_2) is given by a formula:

$$time(v, n_1, n_2) = \frac{distance(n_1, n_2)}{Normal(meanspeed(v), 0.1 \cdot meanspeed(v))} , \tag{10}$$

where *Normal* denotes a random value with the Gaussian distribution.

Maintains model (*MM)* consists of a set of maintenance crews which are identical and unrecognized. The crews are not combined to any node, are not combined to any route, they operate in the whole system and are described only by the number of them. The time when a vehicle is repaired is equal to the time of waiting for a free maintains crew (if all crews involved into maintenance procedures) and the time of a vehicle repair which is a random value with the Gaussian distribution ($Normal(MRT(v), 0.1 \cdot MRT(v))$.

Business service (*BS*) is a set of services based on business logic that can be loaded and repeatedly used for concrete business handling process. Business service can be seen as a set of service components and tasks that are used to provide service in accordance with business logic for this process. Therefore, *BS* is modelled a set of business service components (*sc*),):

$$BS = \{sc_{1,} ..., sc_n\}, n = length(BS) > 0 , \tag{11}$$

the function *length*(*X*) denotes the size of any set or any sequence *X.*

Each service component in *DTS* consists of a task of delivering a container from a source node to the destination one.

The service realised by the clients of the transport system are sending mails from a source node to a destination one. Client model consist of a set of clients (*C*).

Each client is allocated in one of nodes of the transport system:

$$allocation : C \to No . \tag{12}$$

A client allocated in an ordinary node is generating containers (since, we have decided to monitor containers not separate mails during simulation) according to the Poisson process with destination address set to ordinary nodes. In the central node, there is a set of clients, one for each ordinary node. Each client generates containers by a separate Poisson process and is described by intensity of container generation:

$$intensity : C \to R_+ . \tag{13}$$

The central node is the destination address for all containers generated in ordinary nodes.

4.2. Legacy Approach

The management system (*MS*) of the *DTS* controls the operation of vehicle. It consists of a sequence of routes:

$$MS = \langle r_1, r_2, ..., r_{nr} \rangle . \tag{14}$$

Each route is a sequence of nodes starting and ending in the central node, times of leaving each node in the route (t_i) and the recommended size of a vehicle (size):

$$r = \langle CR, t_0, n_1, t_1, ..., n_m, t_m, CR, size \rangle \quad v_i \in No - \{CR\} \quad 0 \le t_0 < t_1 < ... < t_m < 24h . \tag{15}$$

The routes are defined for one day and are repeated each day. The management system selects vehicles to realise each route in random way, first of all vehicles (among vehicles available in central node) with capacity equal to recommended size are taken into consideration. If there is no such vehicle, vehicles with larger capacity are taken into consideration. If still there is no vehicle fulfilling requirements vehicle of smaller size is randomly selected. If there is no available vehicle a given route is not realised.

4.3. Heuristic Approach

As it was mentioned in the introduction, we proposed a replacement of legacy management system by a heuristic decision algorithm [19]. The decisions (send a truck to a given destination node) are taken in moments when a container arrives to the central node. The truck is sent to a trip if:

- the number of containers waiting in for delivery in the central node of the same destination address as that just arrived is larger than a given number,
- there is at least one available vehicle,
- the simulated time is between 6 am and 22 pm minus the average time of going to and returning from the destination node.

The truck is sent to a node defined by destination address of just arrived container. If there is more than one vehicle available in the central node, the vehicle with size that fits the best to the number of available containers is selected, i.e. the largest vehicle that could be fully loaded. If there are several trucks with the same capacity available the selection is done randomly. The restriction for the time of truck scheduling (the last point in the above algorithm) are set to model the fact that drivers are working on two 8-hours shifts.

4.4. Soft Computing Approach

As it was mentioned in the introduction we also proposed the other replacement of the legacy management system based on a neural network based [21]. The system consists of a multilayer perceptron to decide if and where to send trucks. The input to the neural network consists of:

$$in = \langle pkc_1, pkc_2, ..., pkc_{npk}, crc_1, crc_2, ..., crc_{npk}, nfv \rangle , \tag{16}$$

npk – number of ordinary nodes,
pkc_i – number of containers waiting for delivery in the central node with destination address set to *i*-th ordinary node,
nfv – number of free vehicles in the central node,

Each output of the network corresponds to each ordinary node:

$$nnout = \langle out_1, out_2, ..., out_{npk} \rangle . \tag{17}$$

The output of the network is interpreted as follows (for sigmoid function used in output layer):

$$j = \arg\max_{i=1...npk} \{out_i\} . \tag{18}$$

If out_j is greater than 0.5 sending a vehicle to node j else do nothing. If there are more vehicles available in the central node, the largest vehicle that could be fully loaded is selected. If there are available several trucks with the same capacity selection is done randomly. The neural network decision (send a truck or not and where the truck should be sent) are taken at the given moments of time. These moments are defined by the following states of the system:

- the vehicle comes back to the central node and is ready for the next trip,
- if in central node there is at least one available vehicle and the number of containers of the same destination address is larger than the size of the smallest available vehicle.

The neural network used in the management system requires a learning process that will set up the values of its weights. The most typical learning in the case of multilayer perceptron is the back propagation algorithm. However, it cannot be used here since it is impossible to state what should be the proper output values of the neural network. Since it is hard to reconcile what are the results of a single decision made by the management system. Important are results of the set of decisions. Since the business service realised by transport system is to move commodities without delays, the neural network should take such decisions that allows reducing delays as much as possible. To train neural network to perform such task we propose to use genetic algorithm [18,21]. Similar approach to training neural network is applied in case of computer games. The most important in case of genetic algorithm is a definition of the fitness function. To follow business service requirements of transport system we propose following definition of the fitness function calculated for a given neural network after some time (T) (therefore after a set of decisions taken by neural network):

$$fitness(T) = \frac{N_{ontime}(0,T) + N_{ontimeinsystem}(T)}{N_{delivered}(0,T) + N_{insystem}(T)}. \qquad (19)$$

It is a ratio of on-time containers (delivered with 24h and being in the system but not longer than 24h) to all containers (that already delivered $N_{delivered}(0,T)$ and still being presented in the system $N_{insystem}(T)$).

5. Metrics Set for DTS

5.1. Introduction

The formal model described previously was designed to allow developing a simulator, which allows observing the time of transporting each container. Based on these observations several metrics could be defined. As it was mentioned in the introduction we focus here on the service oriented approach [13]. Therefore we propose that the availability to be a key parameter for the evaluation of the quality of the *DTS*. One can define the availability in different ways, but always the value of availability can be easy transformed into economic or functional parameters perfectly understood by owner of the system. The availability is mostly understood as a probability that a system is up. And it is defined as a ratio of the expected value of the uptime of a system to the observation time. It is a simple definition but requires defining what does it mean that transport system is working. The similar metric is the acceptance ratio defined in information since as a number of accepted requests to the total number of requests.

5.2. Acceptance Ratio

Let introduce the following notation:

- T – a time measured from the moment when the container was introduced to the system to the moment when the container was transferred to the destination (random value),
- T_g – a guaranteed time of delivery, if exceeded the container is delayed.

In [16] we have proposed performance metric – acceptance ratio. It is defined as a ratio of on-time containers (containers for which $T < T_g$) to all containers within a given time period (24h was used). Therefore a sequence of time moments ($\tau_0, \tau_2, \ldots, \tau_i, \ldots, \tau_n$) when the metric is calculated has to be set – a midnight of each day was used (i.e. $\tau_i - \tau_{i-1}$ = 24h). Within each time period (τ_{i-1}, τ_i), a given number of containers are delivered ($N_{delivered}(\tau_{i-1}, \tau_i)$), a part of if or all delivered on time ($N_{ontime}(\tau_{i-1}, \tau_i)$), but at the end of analysed period time there could be some containers not yet delivered (waiting in the source node or being transported) ($N_{insystem}(\tau_i)$) and all or part of them being not late yet ($N_{ontimeinsystem}(\tau_i)$). Taking into consideration introduced symbols the availability could be calculated as the expected value (Monte-Carlo approach) of ratio of on-time containers to all containers:

$$AR\ (t_i) = E\left(\frac{N_{ontime}(\tau_{i-1},\tau_i) + N_{ontimeinsystem}(\tau_i)}{N_{delivered}(\tau_{i-1},\tau_i) + N_{insystem}(\tau_i)}\right). \tag{20}$$

6. DTS Simulation Analysis

6.1. Event-Driven Simulation

Once a model has been developed, it is executed on a computer. It is done by a computer program which steps through time. One way of doing it is so called event-driven simulation. Which is based on an idea of event, which could is described by time of event occurring and type of an event. The simulation is done by analysing a queue of event (sorted by time of event occurring) while updating the states of system elements according to rules related to a proper type of event. Due to a presence of randomness in the *DTS* model the analysis of it has to be done based on Monte-Carlo approach [21]. What requires a large number of repeated simulations?

Summarising, the event-driven simulator repeats *N*-times the following loop:

- beginning state of a *DTS* initialisation,
- event state initialisation, set time $t = 0$,
- repeat until $t < T$:
- take first event from event list,
- set time equals time of event,
- realise the event – change state of the *DTS* according to rules related to proper type of event: change objects attributes describing system state, generate new events and put them into event list, write data into output file.

6.2. Events and Elements of DTS Simulator

In case of *DTS* following events (mainly connected with vehicles) have been defined:

- vehicle failure,
- vehicle starts repair,
- vehicle repaired,
- vehicle reached the node,
- vehicle starts from the node,
- vehicle is ready for the next route,
- time-table (starting the route in the central node).

The processing of events of done in objects representing *DTS* elements. The objects are working in parallel. Following types of system elements were distinguished: vehicle, ordinary node, central node, time table.

The life-cycle of each object consists of waiting for an event directed to this object and then execution of tasks required to perform the event. These tasks includes the changes of internal state of the object (for example when vehicle approaches the node it is unloaded, i.e. the number of hauled containers decreases) and sometimes creating a new even (for example the event vehicle starts from the node generates new event vehicle reached the node – next node in the trip). The random number generator is used to deal with random events, i.e. failures. It is worth to notice that the current analysed event not only generates a new event but also could change time of some future events (i.e. time of approaching the node is changed when failure happens before). The time of a new event is defined by the sum of current time (moment of execution of the current event) and the duration of a given task (for example vehicle repair). Only times of starting a given route (event vehicle starts from the central node) are predefined (according to the time table). Duration of all other tasks is defined by the following states of the system elements:

- time when vehicle waits in the queue for loading/unloading,
- time when vehicle waits in the queue for maintains crew,

or are given by random processes:

- time of vehicle going between two nodes,
- time of loading/unloading,
- time to failure,
- repair time.

Moreover each object representing a node has additional process (working in parallel) which is responsible for generating containers. The life-cycle of this process is very simple: waiting a random time, generating a container with a given destination address (central node for all ordinary nodes, and each ordinary nodes for process in the central node) and storing a container in the store house (implemented as a queue) of a given node.

6.3. DTS Simulator Implementation

The event-simulation program could be written in a general purpose programming language (like C++), in a fast prototyping environment (like Matlab) or a special purpose discrete-event simulation kernel. One of such kernels, is the Scalable Simulation Framework (*SSF*) [17] which is a used for *SSFNet* [17][18] computer network simulator. *SSF* is an object-oriented *API* - a collection of class interfaces with prototype implementations. It is available in C++ and Java. *SSFAPI* defines just five base classes: Entity, inChannel, outChannel, Process, and Event. The communication between entities and delivery of events is done by channels (channel mappings connects entities).

For the purpose of simulating *DTS* we have used Parallel Real-Time Immersive Modelling Environment (*PRIME*) [17] implementation of *SSF* due to a much better documentation then available for the original *SSF*. We have developed a generic class derived from *SSF* Entity which is a base of classes modelling

DTS objects which models the behaviour of presented in section 2 and 4 discrete transport system.

As it was mentioned a presence of randomness in the *DTS* model, the Monte-Carlo approach is used. The original *SSF* was not designed for this purpose so some changes in *SSF* core were done to allow to restart the simulation from time zero several times within one run of simulation programme.

The statistical analysis of the system behaviour requires a very large number of simulation repetition, therefore the time performance of developed simulator is very important.

6.4. Exemplar DTS

To compare a heuristic and soft computing management system with legacy we will use an exemplar *DTS* based on Polish Post regional centre in Wroclaw, Poland, proposed by us in [16]. We have modelled a system consisting of one central node (Wroclaw regional centre) and twenty two other nodes – cities where there are local post distribution points in Dolny Slask Province of Poland. The length of roads was set according to real road distances between cities used in the analysed case study. The intensity of generation of containers for all destinations was set to 4.16 per hour in each direction giving in average 4400 containers to be transported each day. The vehicles speed was modelled by Gaussian distribution with 50km/h of mean value and 5km/h of standard deviation. The average loading time was equal to 5 minutes. There are 30 vehicles with capacity 10 containers and 35 with capacity 15. The *MTF* of each vehicle was set to 3000 hours. The average repair time was set to 5h (Gaussian distribution). The time table for legacy management system consists of 209 routes per day. The system was simulated using a computer tool developed by the author [20].

6.5. Calculation of Availability

The simulation time was set to 100 days and each simulation was repeated 10.000 times. We have calculated functional metrics defined in section 4. The achieved results, functional availability and average one for guaranteed delay 24 and acceptable delay 10 containers, are presented on Figure 1. The functional availability is dropping down each 24 hours due to a definition of time table, vehicles are not working at night, but containers are entering the system all the time.

6.6. Discussion of a Critical Situation

All three presented management algorithms give acceptance ratio almost equal 1 for presented system. To compare these algorithms more deeply we propose to analyse the transport system performance in case of some critical situations [16]. Let's assume that for some days the system is working at 50%. The tie-up of the system could be caused for example by a drivers' strike or some contagious diseases resulting in situation that only 50% of vehicles are in operation. After a given number of days the system is again fully working. The achieved results (acceptance ratio calculated according to (20)) for 4 and 14 days tie-up are presented on Figure 2 and Figure 3. As it could be expected the acceptance ratio in day 10 (when critical situation starts) is starting to drop down and when drivers come back is enlarging. However the system with heuristic management as well as with soft computing one is coming back to normal operation much faster than legacy one. The soft computing one is slightly outperforming the heuristic one.

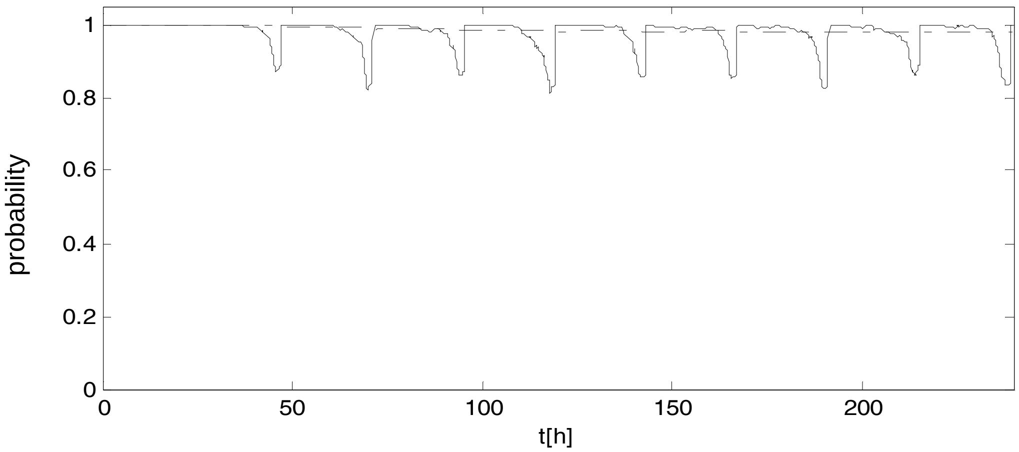

Figure 1. Availability (solid line) and average availability (dashed-dot line) for the exemplar *DTS*

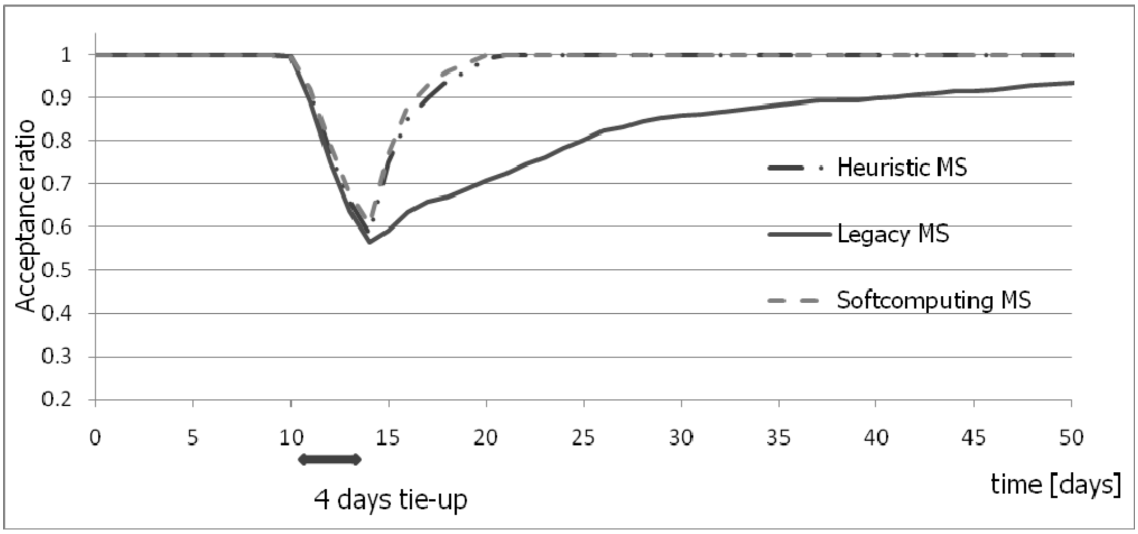

Figure 2. Acceptance ratio for 4 days tie-up vehicles
for legacy, heuristic and soft computing management system

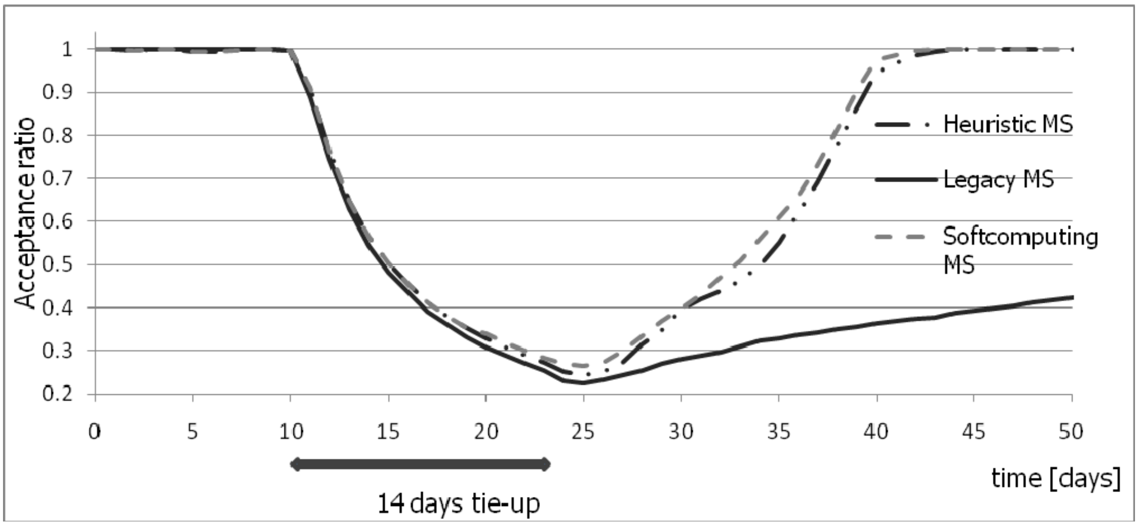

Figure 3. Acceptance ratio for 14 days tie-up vehicles
for legacy, heuristic and soft computing management system

Next, we have analysed the ability of each management system to return the *DTS* to normal performance after critical situation of different duration. Results are presented on Figure 4. As it could be seen soft computing and heuristic algorithm give almost identical results, which significantly out performance the legacy management system.

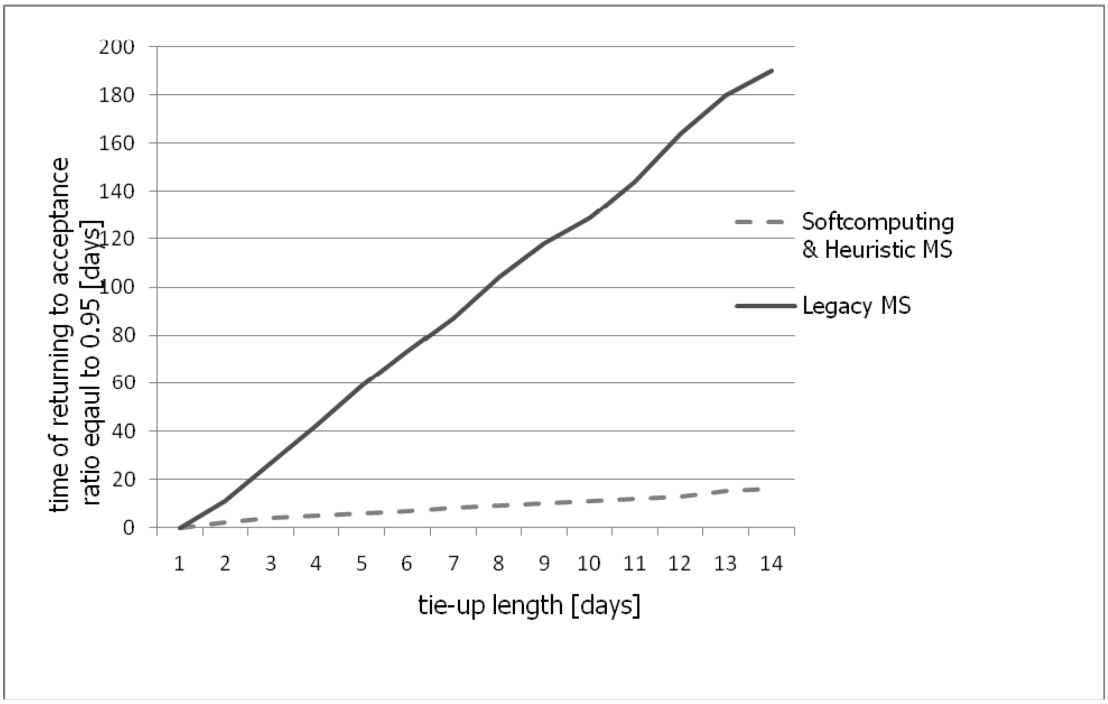

Figure 4. Time of returning *DTS* performance (measured by acceptance ratio) to 0.95 of normal performance after a critical sitauation (tie-up) ocuurance for legacy, heuristic and soft computing management system

7. Conclusions

We have presented an approach to analyse management algorithms of discrete transport system (*DTS*) by modelling and simulation. The *DTS* model was simulated using developed by the authors' simulation software. The simulator was implemented using the Scalable Simulation Framework (*SSF*). It allows performing reliability and functional analysis of the *DTS*, for example:

- determine what will cause a "local" change in the system,
- make experiments in case of increasing number of containers per day incoming to system,
- identify weak point of the system by comparing few its configuration,
- better understand how the system behaves.

We have compared three different management algorithms: legacy one (based on real time-table management in Post system), heuristic and soft computing one. The presented results show that soft computing management system allows the *DTS* to return to normal operation after some critical situation in the shortest time. The results for heuristic management system are very close to soft computing approach, whereas, the legacy system is performing much worse. Since the soft computing algorithm requires a time consuming learning procedure we propose to use in practice much simpler heuristic management system. The performance of heuristic solution (measured as the time of returning *DTS* to normal work) is only slightly worse than available by soft computing approach. The achieved simulation results look promising. We hope that it could be implemented in real transport system.

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MULTI-TIER SPATIAL STOCHASTIC FRONTIER MODEL FOR COMPETITION AND COOPERATION OF EUROPEAN AIRPORTS

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This paper is devoted to a statistical analysis of spatial competition and cooperation between European airports. We propose a new multi-tier modification of spatial models, which will allow an estimation of spatial influence varying with distance. Competition and cooperation effects do not diminish steadily relative to distance from a given airport; their structure is more complex. The suggested model is based on a set of distance tiers, with different possible effects inside each tier.

We apply the proposed modification to the standard spatial stochastic frontier model and use it to estimate competition and cooperation effects for European airports and airport efficiency levels. We identify three tiers of spatial influence with different competition-cooperation ratios in each one. In the first tier (closest to an airport) we note a significant advantage for cooperation effects over competition ones. In the second, more distant, tier we discover the opposite situation; a significant advantage for competition effects. There is no significant advantage for cooperation or competition effects with the most distant tier. In this paper we also consider some other possible applications of the proposed spatial multi-tier model.

Keywords: spatial stochastic frontier, airport efficiency, competition, cooperation

1. Introduction

Late 1970s almost all airports and airlines were owned by government bodies. Therefore all interactions between airports were formalised and a level of competition and cooperation in the industry was insignificant. Monopolies and duopolies (supported by the famous “two airlines” law) didn’t have to care too much about efficiency of airports’ operations and thus weakly competed and cooperated. After a series of deregulation acts and privatisation decisions the industry was liberated; privately held companies positively influenced on a level of competition on the market.

Over the past few years, airports have been considered in the popular ‘competition vs. cooperation’ debates [1]. Before the recent economic crisis, discussion focused mostly and sometimes only on issues of competition. However, when airports met additional difficulties related to the overall decline in passenger traffic, cooperation became increasingly important and attracted the attention of researchers.

The area of competition between airports is wide and varied. It includes competition between adjacent airports in overlapping catchment areas for passengers and for local resources, competition to attract airlines, competition between airport groups (formal or informal), and other aspects. This research is oriented to the analysis of spatial competition for passengers between adjacent airports. The situation in which more than one airport serves a population is usual in Europe. This can be seen in major urban areas (London, Paris, etc) and also in peripheral areas which are not served by an airport in their immediate surroundings. When alternative airports are available to a population, competition effects appear [2].

In many cases when airports have overlapping catchment areas, cooperation effects also occur [3]. These effects can have different forms. Firstly, airports operating in the same areas, can be joined to different types of alliances or even have the same owners (for example, Heathrow and Gatwick, or Charles de Gaulle and Orly). Another common form of cooperation between airports is ’main airport plus satellites’. The main airport handles a significant part of the passenger traffic (usually international), while satellites serve special groups of customers (for example, domestic passengers or low-cost airlines). Finally, cooperation effects can appear without any formal or informal agreements between airports, but due to the nature of their operations. Often, if an airport operates successfully in a particular area, it promotes overall regional development, resulting in more businesses, more tourists, better infrastructure and better transport networks. Consequently, adjacent airports obtain additional utility, and therefore cooperation effects increase.

It is obvious that both competition and cooperation affect each airport areas of activity. However, much research is oriented towards the analysis of one aspect only (usually competition). In this research we try to examine both aspects simultaneously. Note that the task of separating competition and cooperation effects completely appears very problematic (if not impossible), so the aggregative effects on an airport are estimated and observed for different distances from the airport.

The modern approach to analysis of dependences between adjacent economic units is spatial econometrics [4]. Spatial models utilise information about the units' geographical locations and distances between them to estimate interacting effects. The famous Tobler's Law says "everything is related to everything else, but near things are more related than distant things", and this statement is the basis of spatial models.

Usually spatial models are constructed focus on only one spatial effect (for example, competition between adjacent airports). However, we believe that spatial effects are not so straightforward, and it is possible that the effects of neighbours located in the immediate vicinity and the effects of more remote neighbours could be completely different, even differently directed. In this research we introduce a modification of spatial models (called *multi-tier*) and apply it to the data set of European airports.

2. The Spatial Multi-Tier Autoregressive Stochastic Frontier Model

Operating efficiency is a key indicator for a company, acting in a competitive market. There are a set of methodologies developed to estimate company's efficiency in last decades; many of them take a multivariate, relative nature of efficiency indicator into consideration. Frontier-based approach is based on constructing of a set (real or hypothetical) of absolutely efficient companies (an efficiency frontier) and estimating of company's efficiency as a distance from this frontier. Stochastic frontier analysis utilises probabilistic philosophy to construct the efficiency frontier and estimate companies' efficiency levels.

The stochastic frontier model is usually presented as [5]:

$$
\begin{aligned}
& y = f(x,\beta) + \varepsilon, \\
& \varepsilon = v - u, \\
& v \sim N(0,\sigma_v^2), u \geq 0,
\end{aligned}
$$

The model specification considers economic units as producers of an output y which use resources x, but act with some level of inefficiency u.

Usually ([6], [7]) distance is included into spatial models in the form of a contiguity matrix W, whose components w_{ij} are metrics of spatial relation between objects i and j. Specification of the matrix W is usually under researcher's responsibility, and the main question here is to determine a power of interrelation between objects on the base of their geographical locations. There are some different approaches to specification of the matrix W, but first of all we need to distinguish two cases, related with a type of given geographical objects:

- Objects have geographical areas with borders (strictly defined or fuzzy). We always can specify if two objects of this type are adjacent and have a common frontier. For example, countries, regions within a country, districts of a city can be considered as objects with an area.
- A geographical border between two objects cannot be specified. For these object we cannot define exactly if two objects are neighbour, we just can measure a distance between them. Very often researchers consider these objects as mathematical points (without areas).

There are different approaches to define the contiguity matrix for objects of first and second types.

The easiest form of the matrix W for first type objects is a binary matrix of neighbourhood. In this approach a matrix item equals to 1 if two objects are adjacent (have a common border) and equals to 0 otherwise. For calculation purposes the matrix should standardised, so frequently matrixes values are divided by a total number of object's neighbours:

$$
w_{ij} = \begin{cases} \dfrac{1}{count\ of\ objects\ adjacent\ with\ an\ object\ j}, if\ objects\ i\ and\ j\ are\ adjacent \\ 0, otherwise \end{cases}.
$$

Generally speaking, the resulting matrix is not a stochastic one, because a data set can contain objects without neighbours, and the sum of values for this row will be equal to 0, not to 1.

Approaches for the second type objects are usually based on a distance between them. The distance d_{ij} should be considered as a geographical distance, but can be estimated in different ways [8]:

- An exact distance in kilometres between two objects. For relatively close objects the distance can be calculated as Euclidean distance for objects' coordinates, but objects are relatively far one from another (so a spherical form of the Earth becomes significant), a great circle distance should be used.
- Time required for a trip from one object to another. This metric is better than the previous one in case when accessibility should be included into consideration.
- Travel cost is also often used as a metric of a distance.

Travel time and cost should be used when we suppose a spatial structure related with human activities. For example, if we consider tourism in two cities and we assume that tourists travel from one city to another, we should use travel time or cost as a metric of a spatial dependence between cities. But if we study a spatial structure of farm production and we assume that local climate characteristics have an influence then physical distance metrics will be probably better.

Power of spatial interdependence can be non-linearly reduced with a distance between objects. In this case a distance decay function should be considered.

Finally, spatial influence can be limited with a predefined distance value h, so the objects located farther than h kilometres (or minutes, or Euros) one from another have 0 values for their relationship in the contiguity matrix.

We consider airports as objects of the second type (without borders) in this research. We used a great circle geographical distance as a metric of relation between airports, without any distance decay function. Different distance tiers are used in the model to separate different distance-related types of influence of neighbour airports.

Spatial interrelation is possible between all components of the stochastic frontier model, including the output y. We include the spatial dependence of the output in the specification and the resulting model is autoregressive.

In general case, spatial data structure can have an influence on three components of the model:

- the efficiency frontier $f(X,\beta)$;
- the inefficiency term u as a distribution parameter;
- the dispersion of the inefficiency term u (heteroskedasticity).

Finally the general spatial autoregressive stochastic frontier model with Cobb-Douglass functional form of the frontier and truncated normal distribution of the inefficiency component can be specified as

$$\begin{aligned}&\ln(y) = \rho \ln(W_1 y) + \beta \ln(X) + \nu - u,\\ &u \sim N^{+}(\lambda W_2 y, W_3 \sigma_u^2),\\ &\nu \sim N(0, \sigma_\nu^2)\end{aligned}$$

Contiguity matrixes W_1, W_2, and W_3 show spatial dependences in the efficiency frontier, inefficiencies and inefficiency dispersions respectively. The model specification does not force matrixes to be the same, and the spatial structure can be different for all three components. The definition of the matrix W is critically important for the model specification.

The main problem we note in the standard model specification is unidirectional dependence on spatial components. The ρ coefficient shows the dependence between the output of a given unit and outputs of its neighbouring units, and only one conclusion (positive/negative influence or no influence) is possible.

Tobler's Law states that neighbouring objects influence one another, but this does not mean that they have the same influence, or even influence in the same direction. It is possible that objects located immediately around a unit have an influence in one direction, and objects located 1 km away influence in another direction.

Let's image a shopping centre with a set of shops, some of which are operating in the same market (clothes shops, for example). Obviously these are competitors. However, since these shops are located in the same shopping centre, cooperation between them (open or hidden) is also possible. If one of the shops runs an advertising campaign and attracts new customers to the shopping centre, the other competitors capture positive effects from this. So we can speak about the cooperation effects in this situation.

Now let's consider a new shopping centre located near to the first one. Customers who visit the second shopping centre buy their clothes there and rarely visit the first centre. In this case we can observe a high level of competition and a low level of cooperation.

Finally, let's consider a town where there are a lot of shopping centres and shopping tourists from all over the world visit this town for clothes. In this situation we also can note possible cooperation effects.

A similar situation can be observed with airports. Airports which are located near to each other can cooperate efficiently for several reasons:

1. An airport contributes to the overall development of a region in terms of businesses, tourists, and infrastructure. All these factors have positive influences on neighbouring airports.
2. An airport creates a culture of using air travel and forms passengers' habits. If a person gets accustomed to using airlines for his business and recreational trips, there is a higher chance that he will use neighbouring airports.
3. Airports can use the same infrastructure and other resources (R&D, for example)

However, beyond a certain distance cooperation effects become weaker, and competition effects can surpass them. For example, the development of airports in the neighbouring regions can lead to resources being redirected to this region. This is strengthening, and therefore increasing the level of competition pressure. We can speak about competition between regions in this case. Airports will be under the pressure of competition in without any of the positive effects of cooperation.

Therefore, the influence of neighbouring enterprises can differ depending on their distance. Mathematically speaking, we have a non-linear influence, and if we try to approximate this influence with a line we can obtain insignificant or even incorrect results. We suggest a modification of spatial models to prevent these problems. Instead of using one contiguity matrix which covers all the areas around the point, we can construct a set of matrices, each covering a ring around the point. For example, the first ring (first tier) includes all objects within 2 km of the point, the second – from 2 to 4 km, and so on (see Figure 1).

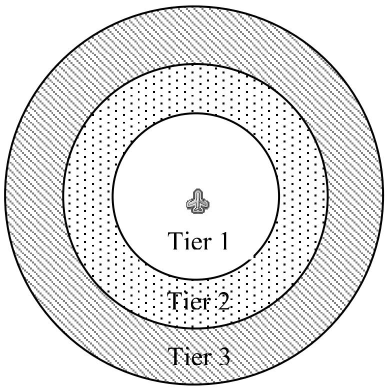

Figure 1. Airport tiers of spatial dependence

The specification of the suggested spatial multi-tier autoregressive model is (discrete case):

$$y = \sum_{tier=1}^{k} \rho_{tier} W_{tier} y + \beta X + \varepsilon ,$$

where

- W_{tier} are contiguity matrices, which contain real distances to objects within the tier and 0 for all objects outside the tier;
- ρ_{tier} are coefficients, which show the influence of the neighbours of this tier.

A respective spatial specification of the stochastic frontier model:

$$\ln(y) = \sum_{tier=1}^{k} \rho_{tier} \ln(W_{tier} y) + \beta \ln(X) + v - u, \\ u \sim N^{+}(\mu, W\sigma_u^2), v \sim N(0, \sigma_v^2)$$

3. Data

In this research author use the same dataset as in the previous study [2]. New spatial components are calculated on the base of existing data. The data set includes the characteristics of European airport activities from 2003 to 2007.

Three main data sources are used:

1. The Eurostat (the Statistical Office of the European Community) database is a source of information about airport activities. The information about each airport includes the number of passengers carried (excluding direct transit passengers), the number of direct flights by destination country, the number of airport employees of (directly employed), and airport infrastructure (check-in facilities, gates, runways, and parking spaces)
2. The Atlas of Airports from the Ruimtelijk Planbureau, Netherlands. This supplements the Eurostat database.
3. The Digital Aeronautical Flight Information File (DAFIF) database and Google Earth as sources of the geographical coordinates of European airports.

Descriptive statistics of main indicators are presented in Table 1.

Table 1. Data descriptive statistics

Variable	**Mean**	**Min**	**Max**
Passengers carried, mln.	11.8	0.9	67.9
Check-ins	89.14	10	481
Gates	38.20	2	147
Parking spaces	7610.50	1	36500
Runways	1.91	1	6
Employment, persons	1856.23	87	15526

Detailed information about the parameters used is presented in [2].

4. Empirical Results

In this research we consider an airport as an economic unit which uses its resources to carry passengers (*PassengersCarried*). Airport resources include runways (*RunwaysNumber*), parking spaces (*ParkingSpaces*) and employees (Employees). In this research this basic set of resources was supplemented with spatial components.

The first empirical problem for spatial model specification is the principle of contiguity matrix selection. We investigated some approaches to matrix construction (distance-based, travel time-based, and cost-based) and chose the distance-based approach as it was the simplest from the point of view of calculation. We assumed that this was appropriate as there are usually no direct trips between airports. Two airports can be considered as neighbours if they service the same area (i.e. their catchment areas are intercepted). In this approach there is considered to be no significant difference in distance between airports regardless of whether there are connecting high-speed/low-cost road/railway links or not. The distance between two points on a sphere (the Earth) is correctly calculated using the great-circle distance formula.

At the first stage of the research we formulated the general model and calculated a set of contiguity matrices for circles with different radii around the airport. 10 standard spatial models were constructed starting from a model with a 220 km radius of spatial dependence (Model SPAT2) to a model with a 1210 km radius (Model SPAT11), with steps in 110 km distances (1 in Euclidean distance ≈ 110 km in great-circle distance). Estimated results for Model SPAT4 (440 km) and Model SPAT 10 (1100 km) are presented in Table 2.

Table 2. Model SPAT4 (440 km) and Model SPAT 10 (1100 km) estimation results

	Model SPAT4			**Model SPAT10**		
	Coefficient	*z*	*p-value*	*Coefficient*	*z*	*p-value*
Dependent variable Ln(PassengersCarried)						
Frontier						
Ln(ParkingSpaces)	0.095	3.850	0.000	0.102	3.490	0.000
Ln(RunwaysNumber)	1.205	12.910	0.000	1.152	12.120	0.000
Ln(Employees)	0.299	7.670	0.000	0.353	8.030	0.000
Ln(W· PassengersCarried), ρ	0.030	2.640	0.008	-0.155	-2.010	0.045
Constant	12.119	39.070	0.000	15.587	10.620	0.000
Inefficiency						
Ln(W· PassengersCarried), λ	0.308	0.560	0.577	-0.205	-1.770	0.077
Constant	-7.996	-0.520	0.606	4.518	2.120	0.034
Statistics						
γ	0.833			0.681		
Log likelihood	–252.135			–253.337		

General conclusions were the same for all 10 models:

1. All basic resources (runways, parking spaces, and employees) have positive significant coefficient estimates, which match our expectations.
2. Stochastic frontier models are significantly better than simple OLS estimate (γ-statistic values are close to 1) and a significant level of inefficiency is present in the data.
3. The influence of the spatial components is not stable over the models; frontier and inefficiency coefficients change significance and even direction.

We do not pay significant attention to overall model analysis in this paper, but concentrate on the analysis of spatial components. Estimates of frontier (ρ) and inefficiency (λ) coefficients for all 10 models are presented in Table 3 and on Figure 2.

Table 3. Estimates of frontier and inefficiency coefficients for 10 standard spatial models

Model		**Frontier component, ρ**			**Inefficiency component, λ**		
	Approx. distance, km	*ρ*	*z*	*p-value*	*λ*	*z*	*p-value*
SPAT2	220	0.008	1.15	0.249	0.195	0.53	0.597
SPAT3	330	0.042	1.68	0.093	0.066	2.3	0.021
SPAT4	440	0.030	2.64	0.008	0.308	0.56	0.577
SPAT5	550	0.044	3.13	0.002	0.719	0.77	0.443
SPAT6	660	0.052	2.12	0.034	1.258	0.38	0.702
SPAT7	770	0.045	1.04	0.298	0.883	0.53	0.596
SPAT8	880	-0.125	-1.55	0.121	-0.203	-1.78	0.075
SPAT9	990	-0.138	-1.78	0.075	-0.194	-1.73	0.084
SPAT10	1100	-0.155	-2.01	0.045	-0.205	-1.77	0.077
SPAT11	1210	-0.164	-2.11	0.035	-0.212	-1.85	0.065

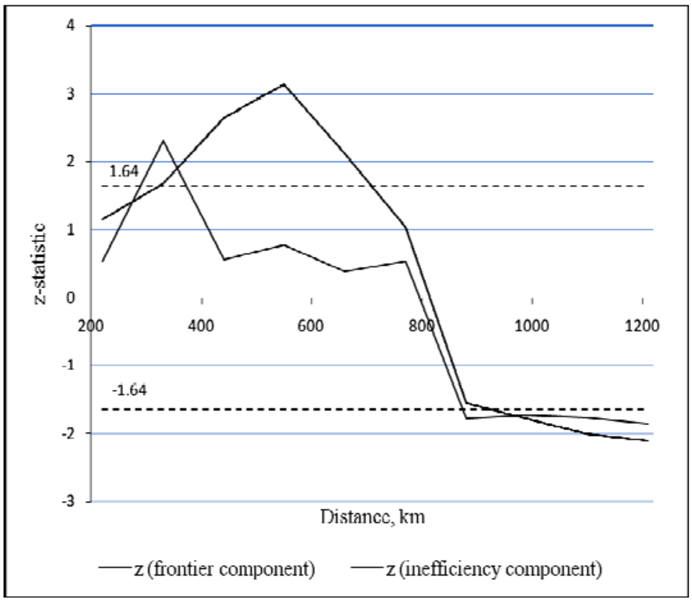

Figure 2. Dependence between frontier and inefficiency coefficients and a radius of spatial dependence

Positive values of the frontier coefficient ρ indicate that passengers carried by neighbouring airports increase the 'production' of a given airport, so this can be considered as a resource. This influence can be interpreted as a cooperation effect, and we can see that these effects are significant for Models SPAT4, SPAT5, and SPAT6 (440-660km radius).

Negative values of the frontier coefficient ρ indicate that the successful operations of neighbouring airports decrease a given airport's production. These can be explained as competition effects and are noted for model SPAT10 and SPAT11 (1100+ km radius).

Estimated values of both coefficients take as significant positive as significant negative values, which support our hypothesis about the non-stable influence of neighbouring airports on a given airport.

Behaviour of the inefficiency coefficient λ looks similar to the frontier coefficient. For models with cooperation effects on the frontier we note positive (significant or near-significant) influences of the spatial component on inefficiency (increasing it), and for models with competition effects – negative influences are noted (decreasing inefficiency). So competition appears to lead to the more efficient operation of airports. This conforms to economic theory.

Note that the spatial components of the estimated models are nested, because greater circles of spatial dependence contain smaller ones. For example, the influence of the spatial component in Model SPAT6 (660 km) includes the influence of the Model SPAT5 (550 km) spatial component and adds the influence of airports located in the 550-660 km ring around an airport. This cumulative effect makes analysis difficult. For example, the positive significant value of ρ for Model SPAT6 indicates cooperation effects, but as we can see on the chart, the influence of airports within 550 km, and the 550-660 km tier only reduces these effects.

To avoid this difficulty, and to separate the influences of each tier, we modified the standard spatial model and instead of one circle spatial component we included a set of spatial tiers (rings) around an airport. We noted on the chart that cooperation effects increase up to 550 km distance (Model SPAT5), but decrease after that until 880 km (Model SPAT8), and stabilise after this distance. Therefore we chose three tiers:

1. 220-550 km
2. 550-880 km
3. 880+ km

Respective tier spatial matrices were calculated and included in the spatial multi-tier autoregressive stochastic frontier model specification. Models estimation results are presented in Table 4.

Table 4. Spatial multi-tier autoregressive stochastic frontier model estimation results

	Coefficient	*z*	*p-value*
Dependent variable Ln(PassengersCarried)			
Frontier			
Ln(ParkingSpaces)	0.103	4.04	0.000
Ln(RunwaysNumber)	1.255	13.93	0.000
Ln(Employees)	0.350	9.45	0.000
Ln($W_{2\text{-}5}\cdot$ PassengersCarried), ρ_1	**0.032**	2.75	**0.006**
Ln($W_{5\text{-}8}\cdot$ PassengersCarried), ρ_2	**-0.057**	-4.83	**0.000**
Ln($W_{8+}\cdot$ PassengersCarried), ρ_3	**0.010**	1.21	**0.227**
Constant	12.386	36.20	0.000
Statistics			
γ	0.936		
Log likelihood	-239.733		

The most interesting values (in terms of the model's specification) are marked in bold in the table.

The estimated influence of the number of passengers carried by neighbouring airports is significantly positive within the 220-550 km distance tier. From this we can form a conclusion about significant cooperation effects between airports located in one region.

The influence of airports located in the 550-880 km tier is significantly negative, so competition effects for these airports are significantly higher than cooperation effects.

Finally, there is no significant dependence of airports located at 880 km and further from an airport, so cooperation and competition effects are absent, or compensate for each other.

A possible pattern of cooperation-competition effect power is presented on Figure 3.

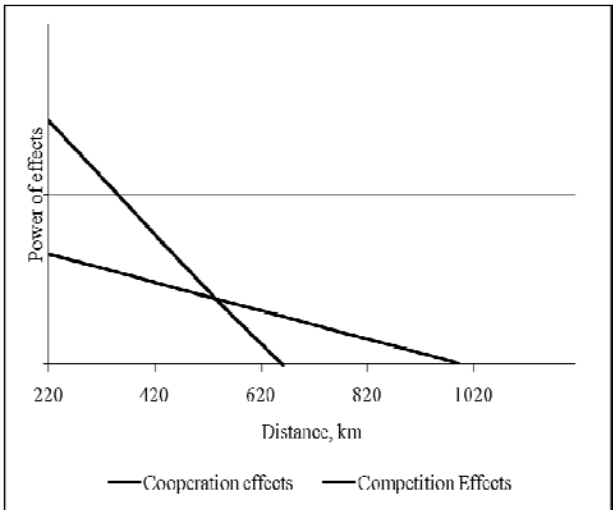

Figure 3. Possible pattern of competition-cooperation effects

According to the graph, cooperation effects are stronger immediately around an airport, but diminish much faster than the effects of competition. This pattern exactly matches observable behaviour; there is significant cooperation influence within the first tier, competition influence within the second tier and no significant effects for greater distances.

This analysis could be very important for airport managements, airport associations and government bodies.

One of stochastic frontier model's advantages is a resulting set of individual levels of efficiency for every airport and every time point. The analysis of efficiencies, its patterns, and dynamics is not presented in this paper; here we just discuss a difference between efficiency estimates, received from the non-spatial and spatial models.

First of all, we can't directly compare efficiency levels in two models. Spatial components change the specification of the frontier, so the resulting values are not comparable. So in this research we compare not efficiency levels directly, but their ranks. Spearman's rank correlation coefficient, frequently used for these purposes, has been calculated:

$\rho = 0.9387$,

$P\{\rho = 0\} = 0.000$.

Spearman's ρ shows a strong positive relationship between efficiency ranks in the non-spatial and spatial models. We calculated differences of ranks in two models to investigate it in details. The extreme difference values are presented in Table 5.

Table 5. Differences of efficiency ranks for the non-spatial and spatial models.

Airport name	**Country**	**Difference of efficiency ranks, $Rank_{non\text{-}spatial} - Rank_{spatial}$**
Malta/Luqa	Malta	-17
Larnaka	Cyprus	-17
Toulouse Blagnac	France	-8
Stockholm/Arlanda	Sweden	-8
Bologna/Borgo Panigale	Italy	-6
…	…	…
Koln/Bonn	Germany	6
Bruxelles/National	Belgium	8
Paris/Orly	France	8
Faro	Portugal	24
Sevilla	Spain	25

As we expected the most significant changes in efficiency estimates turned out for airports with the smallest or the biggest number of powerful neighbour airports. The ranks are affected both by competition and cooperation effects, so there is no general explanation of differences, each airport should be considered separately. Negative rank difference values show that airport's rank in the spatial model is higher than in the non-spatial model; the non-spatial model underestimates efficiency levels. We can note from the Table 5 that these airports are generally located far from the nearest big neighbours, so cooperation effects are low for them. The non-spatial model overestimates efficiency levels for airports with positive ranks in Table 5, which means that the airports are supported by positive cooperation effects from adjacent airports.

5. Conclusions

In this paper the author suggests new modifications of spatial models called spatial multi-tier stochastic frontier models. The feature of these models is an embedded possibility to estimate changes in the influence of spatial components, depending on the distance from a given economic unit. This type of model can be useful in situations where the influence of neighbouring units is not unidirectional, but can vary, and where this variation is related to the distance between units. Incorporating spatial components into the model for different distance borders (tiers) separately in order to analyse the differences in the relationships are suggested.

The proposed spatial model modification has a various areas of application. Competition vs. cooperation between economic units, positive vs. negative effects of new buildings/enterprises in a city, new directions in social sciences and other applications presuppose that its influence has different power and directions. In cases where these differences are spatial and can be explained by the distance between units, the new model specification seems to be useful. One possible direction for further research is the development of a spatial model without discrete tiers, but with non-linear (possibly functional) dependency from spatial components.

In this research the suggested model to analysis of European airports and their efficiency levels is applied. The data from 2003 to 2007 is used and estimates of airport efficiency levels are received. A conclusion about a significant level of inefficiency in airports operations was made.

The assumption about the varying influence of neighbouring airports was confirmed. Cooperation effects outweigh competition effects for airports located inside the 550 km circle. In the next tier, (550-880 km), completion effects become stronger and cooperation is weaker, and so the aggregate influence is one of competition. Finally, for the third tier, 880 km and more, no competition or cooperation effects are noted.

Finally, the author has investigated individual airport efficiency levels and discovered a significant effect of including spatial components into the model for some airports.

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AN ARTIFICIAL INTELLIGENCE AS A TOOL FOR MONITORING THE RELIABILITY, THE SAFENESS AND ECONOMIC EXPEDIENCE OF THE TRANSPORT DEVICES

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There is a basic concept of the inference engine designed using decision according to criteria described in this article, as well as the basic concept of an artificial intelligence and the main parts of an expert system (designed and created by the author) especially – Communication module, Basis of knowledge, Inference engine, Basis of facts, Module for getting information. There are results of described expert system in praxis in the airports and hardware and software requirements for expert system realization.

Keywords: the artificial intelligence, the expert system, inference engine, communication module, basis of knowledge, basis of facts, module for getting information, aircraft, failure rate, flying hours cost

1. Introduction

Using of informatics technologies is indispensable trend in the all areas of our life. In this time we cannot imagine any activity without using up-to-date technologies. One of the most important trends in informatics is artificial intelligence and its expert systems development.

An Artificial Intelligence is the area of computer science focusing on creating machines that can engage on behaviours that humans consider intelligent. The ability to create intelligent machines has intrigued humans since ancient times and today with the advent of the computer and 50 years of research into AI programming techniques, the dream of smart machines is becoming a reality. Researchers are creating systems which can mimic human thought, understand speech, beat the best human chess player, and countless other feats never before possible. Find out how the military is applying AI logic to its hi-tech systems, and how in the near future artificial intelligence may impact our lives. A big success of artificial intelligence was an expert system's creation.

Expert systems are sets of computer programs and appropriately chosen and structured data, which nature and quality of its functions can in some cases equally substitute qualified and skilled work of experts in the field of their specialization.

Expert systems have got legitimate place also in operating the aircrafts, as it is described in the further parts of the article.

The aircraft operator is asking these questions when purchasing a device – how is the device able to fulfil its function, is it better to operate older device or buy new, what is the maintenance quality comparing to other operators? Expert system described in this article helps to find the right answers to these questions.

2. Why to Create the Expert System for Monitoring the Reliability, the Safeness and Economic Expedience of the Transport Devices?

People in its whole history meet a problem with reliability of systems they are working with. The problem is all the time the same – to achieve working of this systems as long as possible without accidents or at least with number of accidents as small as possible. To this basic request are associated the other: to achieve from these systems performing their functions as good as possible, be as cheap as possible, using energy as small as possible, having weight as little as possible, accusing space as small as possible, etc.

It is the nature of people to do their job the best they can. It's necessary to make a lot of decisions every day. Many times a small mistake in a decision might have a strong effect on further success of performed work. And that's why it is important to have a chance to consult decision-making with someone who knows the subject of decision the best – i.e. with an expert. Sometimes you can't find such an expert. One of the outcomes of IT application development is expert systems that can substitute this expert.

Expert systems are one of the most successful applicable solutions in the research of artificial intelligence. Expert systems are sets of computer programs and appropriately chosen and structured data which nature and quality of its functions can in some cases equally substitute qualified and skilled work of experts in the field of their specialization..

Expert systems have got legitimate place also in operating of devices, as is described in the next part of the article.

During using arbitrary systems are there question, if way of operating is appropriate for given devices, what are reliability parameters of their devices in comparison with another operators, what is the maintenance quality comparing to other operators, what is the maintenance influence on reliability these devices considering to economic of devices running.

Main target of manufacturer and operator is to raise safeness and reliability of their devices while reducing operational costs. It is necessary for this purpose „to measure" someway reliability and then evaluate if arrives and when. Operator of transport devices asks himself next questions:

- Can I guard device running better and cheaper?
- Are the other operators better?
- Is it advisable to operate old device or to buy a new one?
- What device on the market is the best for me?
- Will a new device be able sub serve the required tasks all right?
- Will organization or technologic change contribute to raising of affectivity and reliability our work?

Answers to these questions are offered by the expert system described in the next part that is designed by the author.

3. Design of Expert System for Evaluation of Transport Devices

A main target of the science of the safeness and reliability problem is to find out methods and procedures that enable practice analysis safeness and reliability already existing systems. These methods are included in the expert systems modules that are able to perform this analysis using given values and „advise "to the operator to find out answers to listed above questions.

Described expert system can give well-knit view over ability several types of devices from the point of view of many different criteria – it can be safeness, operating economic, fitness for using for specific operator and lot of others. Expert system executes calculating inscribed characteristics and then is able to evaluate types of devices according to computing results.

It enables to choice the importance of single criteria according to what criteria is now most important and it allows to insert another criteria by them would be possible to evaluate devices. It enables perform another evaluations, for example comparing of operating effectiveness of the same device types from various operators. The comparison width will depend on entry values quantity into the expert system.

This expert system has a very important property – it can work very simply with available information and user need not a lot of money for getting this information.

There is a basic configuration of expert system showed on Figure 1.

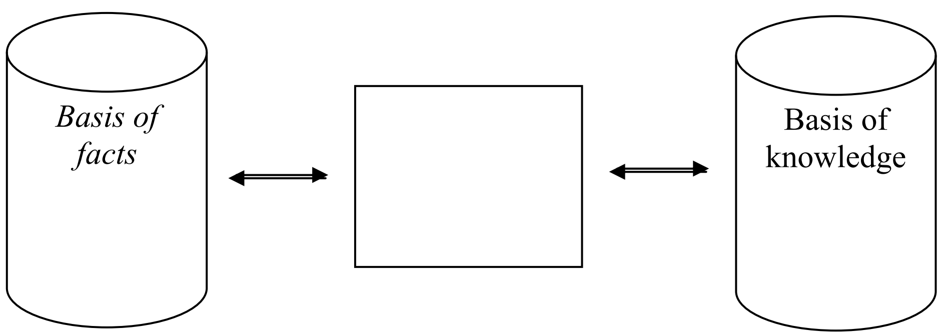


Figure 1. Basic configuration of an expert system

3.1. An architecture of expert system for transport devices evaluation

I have designed the expert system according to scheme showed on Figure 2. Its configuration is created of the following components:

- Communication module
- Basis of knowledge
- Inference engine
- Basis of facts
- Module for getting information

In the next part the most important components of expert system in details are described, that is, the Basis of facts and the Basis of knowledge that present input values of expert system and the Inference engine that make the required output values by data computing the input values. Output values of expert system will be device evaluations from the point of view of the required criteria.

Communication module – created in any object–oriented language program, is used by operator to communicate with an expert system. It allows to start the expert system, to put input values, to perform values processing, choosing criteria and to end running of expert system.

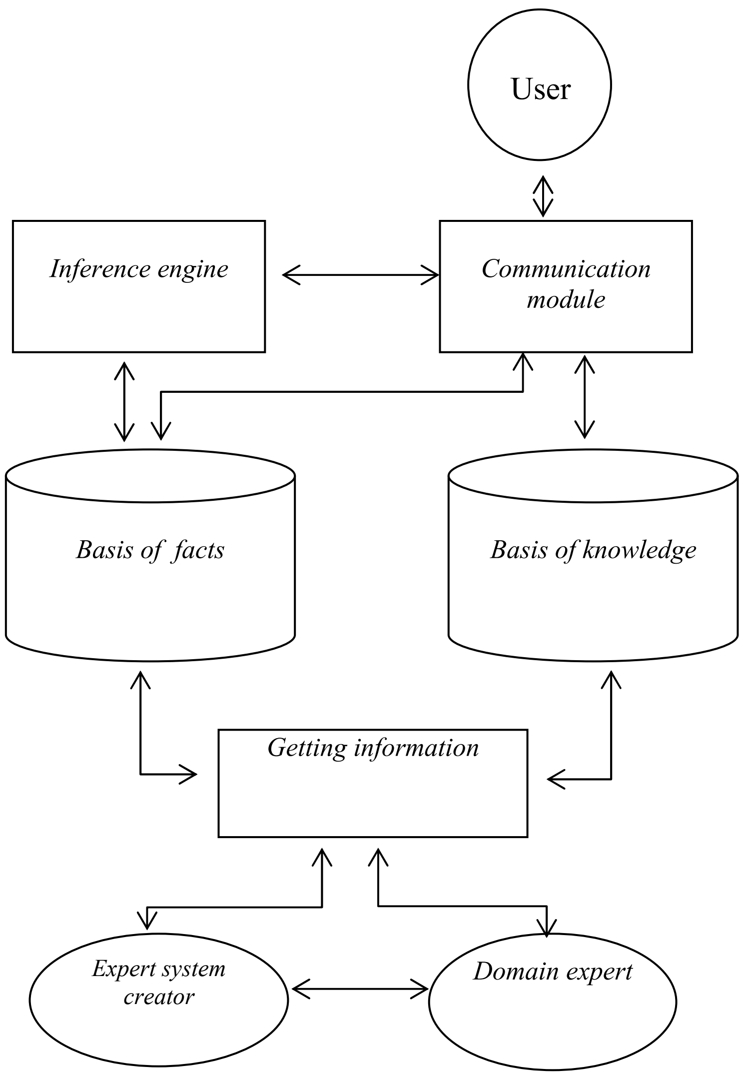


Figure 2. Expert system scheme

Basis of knowledge – contains modules for computing individual criteria, functions and formulas for criteria calculation and data from „expert” for maintenance.

Design of Inference engine – creates one of the most important and most complicated part of the expert system design. Inference engine is selected in the way to exactly answer the purpose that expert system has to solve. It is not too complicated and blind for possibility to operatively modify expert system and to update with new modules. It is composed with Basis of knowledge rules concatenation and creating of various rule sequences for achieving the final result. It is created from program modules in VBA language executing overall evaluations concerning all criteria; it allows making choice of some criteria and putting weights to the criteria, which are the most important in the moment.

Basis of facts is created by inputs about operation and maintenance devices at transport operator. They are inputs of expert system**.**

4. Filling the Expert System for Airlifting

In the next part the expert system that I have established by filling of specific inputs from aircraft operating on university of Žilina and SNA in Bratislava is described.

Basis of knowledge is created by:

Mc. Crackens model of aircraft operating reliability for calculation of smartness and the probability of failure-free operating.

Function for failure rate calculation for failure evaluation.

Standard method for straight operating expense evaluation – SBAC for calculating of flying hour expense

Basis of facts included as follows:

Technical data about aircraft periodical maintenance on University of Žilina

Total air-raid in spotted periods in operator of university of Žilina

Average daily air-raid

Average daily count of starts

Inputs from the maintenance „expert“

Inputs about failures and repairs of individual aircraft in ŽU and SNA

Data for tax calculating of a flying hour

4.1. Description of the Inference Engine

If we are available to a big amount of values that are of different character it is very difficult to compare them without any transformation or data handling into the form, that would suffer realizing this transformation automatically. Problems of this type are solved by application of the more-criteria decision method, for example, by the concordant analysis. But in this case are expected accounts with matrix of values what is very complicated problem and especially we achieve the same regular result with more simple solution.

In described expert system is used school marks principle. Each area is evaluated particularly so that the type of the airplane that fly in the given area (according the criteria of the given area) obtains the best result, obtains mark 1. The other types get mark by degrees lower. It enables to use this criteria processing method because amount of aircraft the expert system is processing with is not very large, i.e. the count of the device types is relatively little.

Final valuation is the mark that is composed by arithmetic average of the all marks.

It may occur at the situation that all results will be the same for all the aircraft types or almost the same. In this case the user can enter to weight for any criteria. To put the weight for any criteria is possible whenever, it depends on the criteria important.

If it isn't important any criterion in decisive moment, expert system will allocate to this criteria value 0 as the mark for every type of an aircraft.

For using this expert system in the future is suitable opening this expert system for the choice of other criteria. It is designed in such way that will be possible put in it certain amount of the criteria while the user will have to execute calculations for the particular aircraft types without expert system, if the calculation algorithms are not known in this time.

5. Realization of the Described Expert System in the Airport Žilina and SNA Bratislava

To filling my expert system I have used actual data from airports Žilina and SNA Bratislava. At first an expert system has made the following account:

5.1. Failure evaluation of the same types of aircrafts at operators Žilina and SNA Bratislava

Input data are – number and type of a failures and the air raid number of aircrafts Z 42, Z 142, L 200 a Z 43 in the Table 1.

Table 1. The aircrafts failure comparison at Žilina and SNA Bratislava

Year 2006	**Failure rate – Žilina**	**Failure rate – SNA**	**Lower failure rate has:**
Aircraft Type	Light	Light	
Z – 43	0,022528442	0,002684564	**SNA**
Z – 42	0,030176533	0,055555556	**Žilina**
Z – 142	0,015168857	0,005008347	**SNA**
L – 200	0,037243948	0,016260163	**SNA**

5.2. Field reliability evaluation of several types of aircraft at operator in Žilina

To get the final evaluation values of the several criteria for all of aircraft types have been calculated and the best aircraft type for each evaluated. Criteria are the following:

failure rate evaluation,

flying hours costs evaluation,

evaluation of the no-failure operation expectation,

the ground alert evaluation.

5.2.1. Final evaluation according all of criteria – the weight of criteria is the same (Tables 2-6)

Table 2. The aircrafts sequence in the comparison of the several criteria

Failure rate	Flying hours costs	No-failure operation	Severability
Z – 142	**Z – 42**	**Z – 142**	**Z – 142**
Z – 43	Z – 142	Z – 42	Z – 42
L – 200	Z – 43	L – 200	Z – 43
Z – 42	L – 200	Z – 43	L – 200

Table 3. Marks assignment according to particular criteria without weight of criteria

Aircraft type	Failure rate	Flying hours costs	No-failure operation	Severability	Final mark
L – 200	3	4	3	4	3,5
Z – 142	1	2	1	1	1,25
Z – 42	4	1	2	2	2,25
Z – 43	2	3	4	3	3

Table 4. Marks assignment according to particular criteria using weight of criteria (weight of criteria =1)

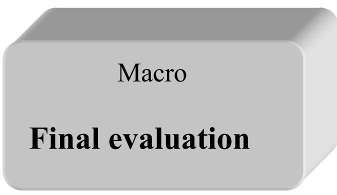
Aircraft type	Failure rate	Flying hours costs	No-failure operation	Severability	Final mark
L – 200	3	4	3	4	3,5
Z – 142	1	2	1	1	1,25
Z – 42	4	1	2	2	2,25
Z – 43	2	3	4	3	3

Table 5. Final evaluation

Failure rate	Final mark
Z – 142	**1,25**
Z – 42	2,25
Z – 43	3
L – 200	3,5

Table 6. Criteria

Criteria	Weight of criteria
Failure rate	1
Flying hours costs	1
No-failure operation	1
Severability	1



5.2.2. Final evaluation according to all of criteria – the weight of criteria Flying hours costs has changed (Tables 7-11)

Table 7. Comparison of aircrafts

Failure rate	Flying hours costs	No-failure operation	Alert
Z – 142	**Z – 42**	**Z – 142**	**Z – 142**
Z – 43	Z – 142	Z – 42	Z – 42
L – 200	Z – 43	L – 200	Z – 43
Z – 42	L – 200	Z – 43	L – 200

Table 8. Setting of marks according to several criteria without weight of criteria

Aircraft type	Failure rate	Flying hours costs	No-failure operation	Alert	Final mark
L – 200	3	4	3	4	3,5
Z – 142	1	**2**	1	1	1,25
Z – 42	4	1	2	2	2,25
Z – 43	2	3	4	3	3

Table 9. Setting of marks according to several criteria with weight of criteria

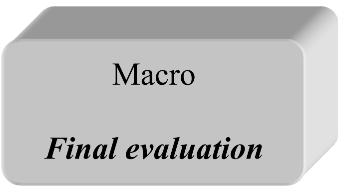
Aircraft type	Failure rate	Flying hours costs	No-failure operation	Alert	Final mark
L – 200	3	40	3	4	12,5
Z – 142	1	20	1	1	5,75
Z – 42	4	10	2	2	4,5
Z – 43	2	30	4	3	9,75

Table 10. Final evaluation

Failure rate	Final mark
Z – 42	4,5
Z – 142	5,75
Z – 43	9,75
L – 200	12,5

Table 11.

Criteria	Weight of criteria
Failure rate	1
Flying hours costs	10
No-failure operation	1
Alert	1



5.2.3. Final evaluation according to all of criteria – the weight of criteria Failure rate has changed (Tables 12-16)

Table 12. Comparison of aircrafts

Failure rate	Flying hours costs	No-failure operation	Alert
Z – 142	**Z – 42**	**Z – 142**	**Z – 142**
Z – 43	Z – 142	Z – 42	Z – 42
L – 200	Z – 43	L – 200	Z – 43
Z – 42	L – 200	Z – 43	L – 200

Table 13. Setting of marks according to several criteria without weight of criteria

Aircraft type	Failure rate	Flying hours costs	No-failure operation	Alert	Final mark
L – 200	3	4	3	4	3,5
Z – 142	1	**2**	1	1	1,25
Z – 42	4	1	2	2	2,25
Z – 43	2	3	4	3	3

Table 14. Setting of marks according to several criteria with weight of criteria Failure rate

Aircraft type	Failure rate	Flying hours costs	No-failure operation	Alert	Final mark
L – 200	3	40	3	4	12,5
Z – 142	1	20	1	1	5,75
Z – 42	4	10	2	2	4,5
Z – 43	2	30	4	3	9,75

Table 15. Final evaluation

Failure rate	Final mark
Z – 142	3,5
Z – 43	7,5
L – 200	10,25
Z – 42	11,25

Table 16.

Criteria	Weight of criteria
Failure rate	10
Flying hours costs	1
No-failure operation	1
Alert	1

Macro

Final evaluation

5.3. Computer results of expert system using at operators Žilina and SNA Bratislava

In the part 5.2.1 – **Final evaluation according to all of criteria – the weight of criteria is the same**, there are evaluated an **aircrafts** according to the next criteria:

failure rate evaluation,

flying hours costs evaluation,

evaluation of the no-failure operation expectation,

the ground alert evaluation.

I have made the sequence of the aircraft according to all of criteria (Table 2) and then I have assigned marks to each aircraft according to all of criteria (Table 3). In the Table 5 is Final evaluation for weight of criteria=1 for all of criteria.

The best was the aircraft Z 142.

In the part 5.2.2. **Final evaluation according to all of criteria – the weight of criteria Flying hour costs has changed,** there are evaluated aircrafts according to all of criteria (presented above). At first I have assigned marks to each aircraft according to all of criteria, I have made the Final evaluation without weight of criteria and then in the Table 10 there is the Final evaluation with the weight of criteria Flying hour costs=10.

The best was the aircraft Z 42.

In the part 5.2.3. **Final evaluation according to all of criteria – the weight of criteria Failure rate has changed,** there are evaluated the aircrafts according to all of criteria (presented above). At first I have assigned marks to each aircrafts according to all of criteria, I have made the Final evaluation without weight of criteria and then in the Table 10 there is the Final evaluation with the weight of criteria Failure rate =10.

In this case the best was the aircraft Z 42.

5.4. Software and Hardware Requirements for Expert System Realization

In the given research I have used programme tools of company Microsoft – objective oriented programming language Visual Basic and operating system Windows. Functions for calculating of individual criteria are executed in Excel using macros VBA and using macros are started all of comparisons and final evaluation of several aircraft types.

6. Conclusions

Expert system scheme is possible to use at operators of arbitrary devices that means in all the cases, when it is needed to compare several objects according to a lot of different and mutually inconsequent criteria. The user can choose arbitrary the evaluated objects count, the count of the criteria is eligible too, and weights are regulated according to neediness. In this case a suitable choosing of other models for examined characteristics calculating is important, as well as to choose such formulas and computing functions to realize them as simple as possible and input data to be available at operator.

It is possible to use it in diagnostics of devices. The user have to know some diagnostics methods that are allowed to use, the Basics of knowledge should be filled in with them.

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Transport and Telecommunication Institute, Lomonosov 1, Riga, LV-1019, Latvia

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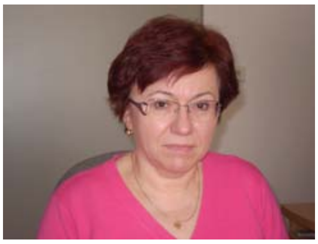

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, Volume 11, No 3, 2010
(Abstracts)

Guseynov, Sh. E., Solovyov, Y. O., Schiptsov, O. V. Construction and Investigation of One Continuous Nonstationary 3D Mathematical Model for Monitoring of Noise Pollution in the Area Surrounding an Airport, *Transport and Telecommunication*, Vol. 11, No 3, 2010, pp. 4–14.

This report is based on a scientific work which is dedicated to the development and research of an unsteady 3D mathematical model for the constant monitoring of the environmental situation of air and water in areas near an airport (airport 'RIX', City of Riga is used as an example). Mainly noise (acoustic) pollution is considered – the anthropogenic noise which interferes with the activities of humans and other living organisms. The report proposes a mathematical model, consisting of a system of two differential equations in partial derivatives with small parameters of the initial and mixed boundary conditions and the relevant consistency conditions. In addition, using monotone difference approximation, the proposed mathematical model is sampled, and the resulting second-order discrete model is solved numerically.

Keywords: noise pollution, dynamics of sound-wave propagation, system of PDE with small parameters, continuous mathematical model, finite-difference approximation

Knutelská, M. Reliability and Replacement of Vehicle Fleet, *Transport and Telecommunication*, Vol. 11, No 3, 2010, pp. 15–25.

Reliability of any product is an integral part of its quality. Depending on the phase of the product lifecycle, certain types of reliability analysis are appropriate. The operational reliability takes into account operational conditions. It can be specified by evaluating the operational data gained during the operation of the object. In the area of operation of road vehicles, it is possible to evaluate records of failures, repairs, maintenance, operation costs, etc. These are stored in an information system or in another digital evidence system and are usable for operation reliability evaluation. The operational data can be also used to prognosticate the development of some reliability parameters. Most of SMEs in the area of transport do not use special software for the monitoring and evaluating of the operational reliability of road vehicles. This article refers to the possibility to acquire some variables of operation reliability from a commonly used Information Systems and to the possibility to create simple programming tool for decision-making and management support in the area of maintenance and replacement of road vehicles by means of common used office software.

Keywords: evaluation, reliability, replacement, road vehicles, software, Excel

Kolarovszki, P., Dúbravka, V. The Presentation of Production Line and Warehouse Management Based on RFID Technology through 3D Modelling and Animation, *Transport and Telecommunication*, Vol. 11, No 3, 2010, pp. 26–36.

The RFID technology is complex, combining a number of different computing and communications technologies to achieve desired objectives. This article primarily deals with the simulation of production line and warehouse management based on RFID technology, through 3D modelling and animation. It describes the various components of a RFID lab (a laboratory for the automatic identification of goods and services), which consist of a production line and a warehouse management system based on RFID technology.

This paper characterizes and describes the processes that take place in the laboratory as well as the technologies which are used. Moreover it describes production line processes and warehouse management. 3D models and animations created to capture the whole process in the laboratory are set up and described.

Keywords: RFID technology, 3D models, warehouse management, simulation

TRANSPORT and TELECOMMUNICATION, 11.sējums, Nr.3, 2010 (Anotācijas)

Guseinovs, Š. E., Solovjovs, J. O., Sčipcovs, O. V. Viena nepārtraukta nestacionāra 3D matemātiskā modeļa konstruēšana un izpēte trokšņa piesārņojuma monitoringam lidostas rajonā. *TRANSPORT and TELECOMMUNICATION,* 11.sēj., Nr.3, 2010, 4.–14. lpp.

Dotais raksts tiek pamatots uz zinātnisku pētījumu, kurš tiek veltīts nestabilam 3D matemātiskam modelim gaisa vides situācijas un ūdens stāvokļa pastāvīgam monitoringam lidostu tuvumā (piem., lidosta 'RIX', Rīgas pilsēta). Rakstā tiek apskatīts galvenokārt trokšņa (akustiskā) piesārņojums – antropogēns troksnis, kurš traucē cilvēku un citu dzīvo organismu aktivitātēs. Pētījumā tiek izstrādāts matemātiskais modelis, kas sastāv no sistēmas ar diviem diferenciālvienādojumiem parciālos atvasinājumos ar sākotnējiem un jauktiem robežnosacījumu un būtiskiem secības nosacījumu maziem parametriem. Turklāt, pielietojot monotonu atšķirību aproksimāciju, piedāvātais matemātiskais modelis ir pārbaudīts, un rezultātā otrās kārtas diskrētais modelis tiek atrisināts skaitliski.

Atslēgvārdi: trokšņa piesārņojums, skaņas viļņu izplatīšanās dinamika, PDF sistēma ar maziem parametriem, nepārtraukts matemātisks modelis, galīgā atšķirību aproksimācija

Knutelska, M. Transporta līdzekļu parka drošums un aizvietošana. *TRANSPORT and TELECOMMUNICATION,* 11.sēj., Nr.3, 2010, 15.–25. lpp.

Jebkura produkta drošums ir tā kvalitātes būtiskā daļa. Noteikti drošuma analīzes veidi ir raksturīgi, atkarībā no produkta dzīvescikla fāzes, Operatīvs drošums ņem vērā operatīvus apstākļus. Tas var būt noteikts, izvērtējot operatīvus datus, kas iegūti objekta darbības laikā. Autotransporta līdzekļu darbības laukā ir iespējams izvērtēt ierakstus par kļūmēm, remontu, ekspluatāciju, darbības izmaksām u.c. Tas tiek saglabāts informācijas sistēmā vai arī kādā citā digitālās liecības sistēmā un ir lietojams darbības drošuma izvērtēšanā. Operatīvie dati var tikt lietoti arī, prognozējot dažu drošuma parametru attīstību.

Dotais pētījums parāda iespēju apgūt darbības drošuma mainīgos no kopēji lietotās Informācijas Sistēmas un līdz iespējai radīt vienkāršu programmēšanas līdzekli lēmumu pieņemšanai un menedžmenta atbalstam ekspluatācijas laukā un autotransporta aizvietošanā ar kopēji lietotas biroja programmatūras līdzekļiem.

Atslēgvārdi: izvērtēšana, drošums, aizvietošana, autotransports, programmatūra, Excel

Kolarovskis, P., Dubravka, V. Ražošanas līnijas un noliktavas menedžmenta prezentācija, kas pamatojas uz RFID tehnoloģijām caur 3D modelēšanu un animāciju. *TRANSPORT and TELECOMMUNICATION,* 11.sēj., Nr.3, 2010, 26.–36. lpp.

RFID tehnoloģija ir sarežģīta, kas ietver sevī veselu skaitu dažādu skaitļošanas un komunikāciju tehnoloģijas, lai sasniegtu vēlamos mērķus.. Dotais raksts galvenokārt izskata ražošanas līnijas un noliktavas menedžmenta imitāciju, kas bāzēta uz RFID tehnoloģiju, caur 3D modelēšanu un animāciju. Tas apraksta dažādus RFID laboratorijas (laboratorija preču un pakalpojumu automātiskai identifikācijai) komponentus, kas sastāv no ražošanas līnijas un noliktavas menedžmenta sistēmas, bāzētas uz RFID tehnoloģiju.

Šis raksts raksturo un apraksta procesus, kas notiek laboratorijā, kā arī tehnoloģijas, kuras tiek pielietotas. Bez tam tiek aprakstīti ražošanas līnijas procesi un noliktavas menedžments. Tas ievieš un apraksta 3D modeļus un animācijas, kas radītas, lai aptvertu visus procesus laboratorijā.

Atslēgvārdi: RFID tehnoloģija, 3D modeļi, noliktavas menedžments, imitācija

Mamirov, T. Divkanālu līdzenas kārtas filtrēšanas sistēmas sintēze uz fāzu vienībām. *TRANSPORT and TELECOMMUNICATION,* 11.sēj., Nr.3, 2010, 37.–44. lpp.

Šajā rakstā tiek parādīta divkanālu līdzenas kārtas filtrēšanas sistēmas sintēzes uz fāzu vienībām fundamentālā iespēja. Piedāvātā iespēja ir balstīta uz strukturāla un elektriska asimetriska riņķa mākslīgu vadību pa strukturālu un elektrisku simetrisku riņķi, lietojot speciālas matrices transformācijas. Galvenā metodes neērtība ir tā, ka divkanālu filtra pārveides funkcijas beigu analītiskās izteiksmes sarežģītība gandrīz vienmēr ir atkarīga no filtra kārtas.

Tiek parādīti sintēzes piemēri zemfrekvences un caurlaides joslas divkanālu filtru uz fāzu vienībām mazām pakāpēm. Tiek dots arī frekvences raksturojums.

Atslēgvārdi: fāzes filtrs, sintēze, digitālie filtri

Mazurkevičs, J., Valkovjaks, T. Parka menedžmenta problēmas analīze diskrētā transporta sistēmā. *TRANSPORT and TELECOMMUNICATION,* 11.sēj., Nr.3, 2010, 45.–56. lpp.

Rakstā autori parāda jaunu pieeju menedžmenta algoritmu analīzei diskrētajās transporta sistēmās (DTS). Piedāvātā metode tiek bāzēta uz modelēšanu un sistēmas uzvedības imitēšanu. Monte Karlo imitēšana ir līdzeklis DTS darbības metriskam aprēķinam. Nekādu sistēmas struktūras ierobežojumu, un metodes galvenā priekšrocība ir sadales veids. Sistēma tiek aprakstīta ar formālu modeli, kurš iekļauj DTS drošumu un funkcionālos parametrus.

Autori iesaka mainīt klasisko grafiku, kas pamatojas uz DTS ar dinamiskiem heiristiskiem algoritmiem menedžmenta sistēmu un algoritmiem, bāzētiem uz mākslīgiem neironu tīkliem. Rakstā tiek doti imitācijas eksperimentu skaitliski rezultāti. Rezultāti ļauj salīdzināt iepriekšminētos parka menedžmenta algoritmus dažādu gadījumu pētījumos.

Atslēgvārdi: diskrēta transporta sistēma, drošums, Monte Karlo imitācija, Parka menedžmenta algoritmi, dispečerizācijas sistēma

Pavļuks, D. Daudzlīmeņu telpas stohastiskās robežas modelis Eiropas lidostu konkurencei un kooperācijai. *TRANSPORT and TELECOMMUNICATION,* 11.sēj., Nr.3, 2010, 57.–66. lpp.

Šis pētījums ir saistīts ar Eiropas lidostu telpas konkurences un kooperācijas statistisko analīzi. Tiek piedāvāta jauna daudzlīmeņu telpas modeļu modifikācija. Šī modifikācija palīdz novērtēt telpas ietekmi, kura mainās ar distances palielinājumu. Konkurences un kooperācijas efekti ar attālināšanu no lidostas samazinās nevienmērīgi, bet tā struktūra ir komplicētāka. Piedāvātā modifikācija balstās uz distanču līmeņu kopumu ar dažādiem ietekmes spēkiem un ievirzēm.

Izstrādātā modifikācija tika lietota telpas stohastiskās robežas modelī Eiropas lidostu konkurences un kooperācijas efektu un efektivitātes līmeņu novērtēšanai. Tiek atklāti trīs telpas ietekmes līmeņi ar dažādām „konkurence-kooperācija" attiecībām. Pirmajā vistuvākajā lidostai līmenī ir zīmīgs kooperācijas efektu pārākums. Otrajā tālākajā līmenī tiek atklāta pretēja situācija – zīmīgs konkurences pārākums. Pēdējā līmenī nav zīmīgas konkurences un kooperācijas ietekmes.

Tāpat šajā rakstā tiek izskatīti citi izstrādātā telpas daudzlīmeņu modeļa iespējamie pielietojumi.

Atslēgvārdi: telpas stohastiskā robeža, lidostu efektivitāte, konkurence, kooperācija

Šustekova, D. Mākslīgais intelekts kā līdzeklis transporta ierīču uzticamības, drošuma un ekonomiskā izdevīguma monitoringam. *TRANSPORT and TELECOMMUNICATION*, 11.sēj., Nr.3, 2010, 67.–75. lpp.

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Atslēgvārdi: mākslīgais intelekts, ekspertu sistēma, izvedummašīna, komunikācijas modulis, sagrāves ātrums, lidojuma stundu izmaksas

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Table 1. This is an example of a Table

Heading	**Heading**	**Heading**
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