ISSN 1407-5806

COMPUTER MODELLING AND NEW TECHNOLOGIES

Volume 14
No 2

2010

Transporta un sakaru institūts
(Transport and Telecommunication Institute)

Computer Modelling and New Technologies

Volume 14, No.2 – 2010

ISSN 1407-5806
ISSN 1407-5814
(On-line: www.tsi.lv)

Riga – 2010

Host Organization:
Transport and Telecommunication Institute

Supporting Organizations:
Latvian Transport Development and Education Association
Latvian Academy of Sciences
Latvian Operations Research Society

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COMPUTER MODELLING AND NEW TECHNOLOGIES, 2010, Vol. 14, No.2
ISSN 1407-5806, **ISSN** 1407-5814 (on-line: www.tsi.lv)
Scientific and research journal of Transport and Telecommunication Institute (Riga, Latvia)
The journal is being published since 1996.

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Editors' Remarks

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I asked my dear friend Orator Prig:
'What's the first part of oratory?' He said: 'A great wig.'
'And what is the second?' Then, dancing a jig
And bowing profoundly, he said: 'A great wig.'
'And what is the third?' Then he snored like a pig,
And, puffing his cheeks out, replied: 'A great wig.'

So if a great panter with questions you push,
'What's the first part of panting?' he'll say 'A pant-brush.'
'And what is the second?' with most modest blush,
He'll smile like a cherub, and say: 'A pant-brush.'
'And what is the third?' he'll bow like a rush,
With a leer in his eye, he'll reply: 'A pant-brush.'
Perhaps this is all a panter can want:
But, look yonder—that house is the house of Rembrandt!

****

FROM 'THE ROSSETTI MANUSCRIPT', **William Blake**, (1757-1827)

This 14th volume No.2 presents results of researches in fields of **Nanodevices and Nanotechnologies** and **Computer Modelling.** A special attention is devoted to selected scientific questions discussed on the recent 9th International Conference **Reliability and Statistics in Transportation and Communication 2009, Riga, Latvia, 2009 October 21-24**, where authors from **Latvia, Russia, Germany, Italy** are presented. The innovative research in the field of applied computer modelling from **India** closes this issue.

Our journal policy is directed on the fundamental and applied sciences researches, which are the basement of a full-scale modelling in practice.

The present edition is the continuation of our publishing activities. We hope our journal will be interesting for research community, and we are open for collaboration both in research and publishing. This number continues the current 2010 year of our publishing work. We hope that journal's contributors will consider the collaboration with the Editorial Board as useful and constructive.

EDITORS

Yu.N. Shunin

I.V. Kabashkin

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 7–19
Transport and Telecommunication Institute, Lomonosova 1, LV-1019, Riga, Latvia

THEORETICAL RESISTANCE SIMULATIONS FOR JUNCTIONS OF SW AND MW CARBON NANOTUBES WITH METAL SUBSTRATES IN NANOELECTRONIC DEVICES

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In the current study, basic attention is paid to the junctions of carbon nanotubes (CNTs) with contacting metallic elements of a nanocircuit. Numerical simulations on the conductance and resistance of these contacts have been performed using the multiple scattering theory and the effective media cluster approach. Two models for CNT-metal contacts have been considered in this paper: a) first principles “liquid metal” model and b) empirical model of “effective bonds” based on Landauer notions on ballistic conductivity. Within the latter we have simulated both single-wall (SW) and multi-wall (MW) CNTs with different morphology. Results of calculations on resistance for different CNT-Me contacts look quantitatively realistic (from several to hundreds kOhm, depending on chirality, diameter and thickness of MW CNT). The inter-wall transparency coefficient for MW CNT has been also simulated, as an indicator of possible ‘radial current’ losses.

Keywords: *carbon nanotubes, single-wall and multi-wall morphology, nanotube-metal (CNT-Me) junction, scattering theory, electronic structure calculations, conductance and resistance in CNT-Me contact, inter-wall transparency in CNTs*

1. Introduction

The miniaturization of electronic devices, the high integration level and increase of the operation frequencies and power density require the use of adequate materials and innovative chip interconnects and vias, to avoid a bottleneck in the existing technologies. Fundamental efforts are directed on the special kinds of nanosystems such as quantum dots, quantum nanowires and nanotubes. Quantum dots, also known as nanocrystals, are a non-traditional type of semiconductor with limitless applications as an enabling material across many industries. They are unique class of semiconductor, because they are so small, ranging from 2–10 nm. (10–50 atoms) in diameter (Fig. 1). Basic attention is paid to carbon nanotubes (CNTs), including their contacts with other conducting elements of a nanocircuit. Due to the unique physical properties, CNTs attract permanently growing technological interest, for example as promising candidates for nanointerconnects in a future high-speed electronics (Figs. 2, 3).

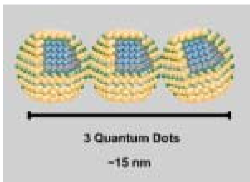

Figure 1. Quantum dots

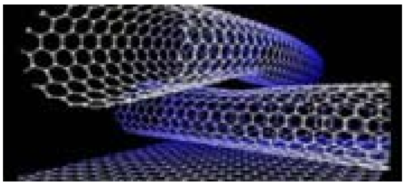

Figure 2. Carbon nanotubes

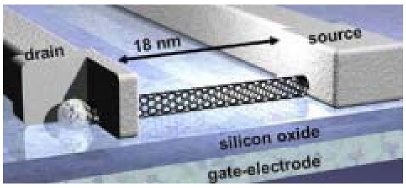

Figure 3. Model of nanoelectronic device

Discovered in 1991 by Iijima and coworkers, carbon nanotubes have quickly become one of the most popular materials in nanoscience and nanotechnology, drawing the interest of researchers worldwide. Many potential applications have been investigated, largely based on theoretical and experimental results, including: conductive and high-strength composites; energy storage and energy conversion devices; sensors; field emission displays and radiation sources; nanometer-sized semiconductor devices, probes, and interconnects.

Due to their unique physical properties, carbon nanotubes (CNTs) attract permanently growing technological interest, for example, as promising candidates for nano-interconnects in a high-speed electronics [1]. The main aim of the current study is the implementation of advanced simulation models, for a proper description of the electrical resistance for contacts between carbon nanotubes of different morphologies and metallic substrates of different nature.

The resistance of contacts between CNTs and metallic catalytic substrates can considerably exceed that observed in the separate parts of these junctions [2, 3]. The conductance between real metals and CNTs still occurs, however, mainly due to the scattering processes, which are estimated to be rather weak [4]. Figure 4 represents the contacts between a CNT and both substrates, as a prototype nanodevice. This is a main subject of our current research and modelling.

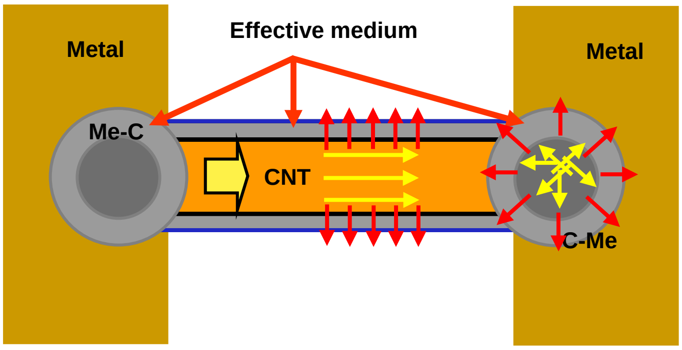

Figure 4. Model of CNT-Me interconnect as a prototype of nanodevice

The toroidal region (CNT-Me) is the object of a microscopic approach responsible for the main contribution to the resistance. As to the nanotube itself and the metallic substrate, their resistances may be considered as macroscopic parameters.

The electronic structure for the CNT-Me interconnect can be evaluated through the electronic density of states (DOS) for carbon-metal contact considered as a 'disordered alloy', where clusters containing both C and Me atoms behave as scattering centers. The computational procedure developed by us for these calculations [5] is based on the construction of cluster potentials and the evaluation of both scattering (S) and transfer (T) matrices.

The general model of multiple scattering with effective media approximation (EMA) for condensed matter based on the approach of atomic cluster is presented on Figure 5. The cluster formalism was successfully applied for metallic Cu [5], as well as for both elemental (Ge and Si) and binary (As_xSe_{1-x} and Sb_xSe_{1-x}) semiconductors [6]. A special attention was paid for the latter, since in solid solutions the concept of statistical weighing was applied for the binary components [5, 6]. When using the coherent potential approach (CPA) as EMA approximation, the resistance of interconnect can be evaluated through the Kubo-Greenwood formalism [7] and Ziman model [8]. Both Figures 6 and 7 depict the idealized images of contacts between CNTs and the Ni substrate.

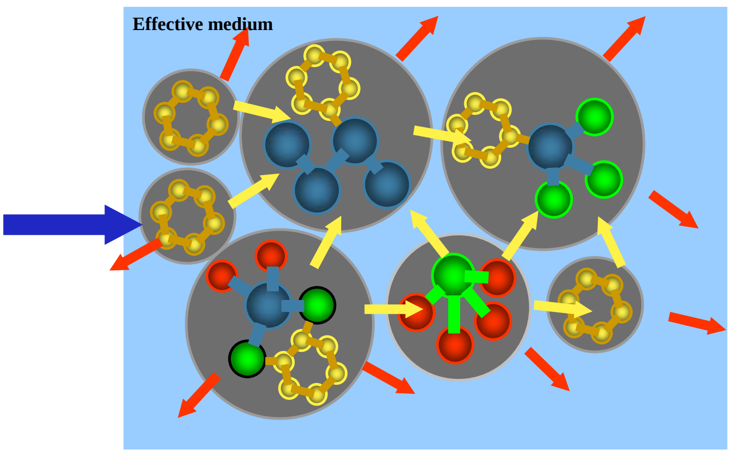

Figure 5. Multiple scattering model of condensed matter described within the effective media approximation

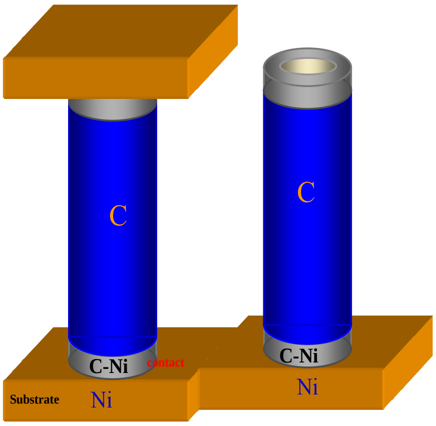

Figure 6. Fragment of interconnects between the Ni substrate and C nanotubes

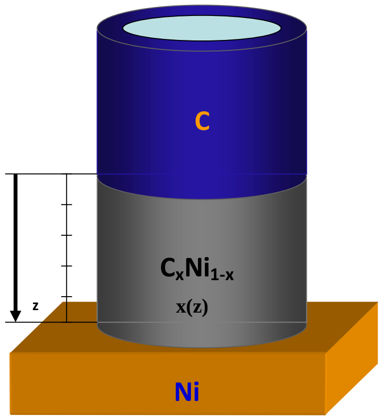

Figure 7. Model of CNT-Ni interconnect as a disordered alloy

The electronic structure for the CNT-Ni interconnects, in the simplest case, can be evaluated through the DOS for C-Ni contact, considered as a 'disordered alloy', where clusters containing carbon and nickel atoms are the scattering centers. However, in many cases, we have to develop more complicated structural models for CNT-metal junctions, based on their precise atomistic structures, which take into account the CNT chirality effect. This is also the subject of the current study. When estimating the resistance of a junction between the nanotube and the substrate, the main problem is caused by the influence of the nanotube chirality on the resistance of SW and MW CNT-Me interconnects (Me = Ni, Cu, Ag, Pd, Pt, Au), for a pre-defined CNT geometry.

2. Multiple Scattering Theory and Effective Medium Approach for CNT Simulations

2.1. Electronic Structure Calculations

We consider the resistivity as a scattering problem, where the current carriers participate in the transport, according to various mechanisms based on the presence of scattering centers (phonons, charge defects, structural defects, *etc.*), including a pure elastic way, called ballistic (Matissien rule). The scattering paradigm is presented on Figure 8. This allows us to realize full-scale electronic structure calculations for condensed matter.

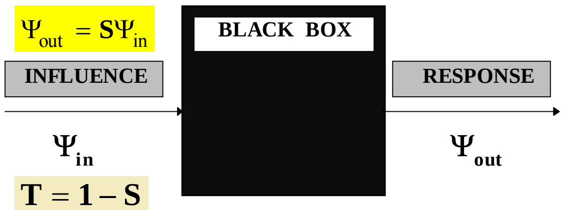

Figure 8. The scattering paradigm: Influence (**in**) and Response (**out**)

We consider a domain where the stationary solutions of the Schrödinger equation are known, and we label them by

$$\psi_{in}(\mathbf{r}) = \phi_{\mathbf{k}}(\mathbf{r}) = exp(i\mathbf{kr}). \qquad (1)$$

The scattering of 'trial' waves, in the presence of a potential, yields new stationary solutions labelled by

$$\psi_{out}(\mathbf{r}) = \psi_{\mathbf{k}}^{(\pm)}(\mathbf{r}) \qquad (2)$$

for the modified Schrödinger equation $\hat{H}\psi_{\mathbf{k}}^{(\pm)}(\mathbf{r}) = E\psi_{\mathbf{k}}^{(\pm)}(\mathbf{r})$.

An electronic structure calculation is considered here as a scattering problem, where the centers of scattering are identified with the atoms of clusters [5]. The first step in this modeling is the construction of potentials, both atomic and crystalline, which uses the special well-tested analytical procedures based on the Gaspar-like potentials and X_α- and $X_{\alpha\beta}$- presentations for the electronic exchange and correlation, in the form of electronic density expansions [4] (see, *e.g.,* the carbon potential calculations, Fig. 9).

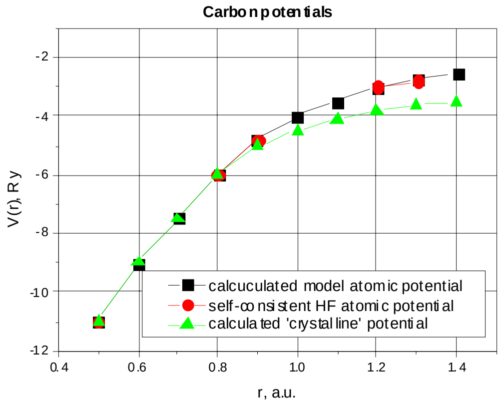

Figure 9. Analytical carbon potentials compared with the results of Hartree-Fock calculations

In order to obtain the electronic structure, the calculations of scattering properties are necessary, generally, in the form of *S*- and *T*-matrices. These calculations start with the definition of the initial atomic structure, to produce a medium for the solution of the scattering problem, for a trial electronic wave [5].

The formalism we use for electronic structure calculations is based on the coherent potential approximation (CPA), the multiple scattering theory and cluster approach. As a *first step* in the modeling procedure, one postulates the atomic structure on the level of short- and medium-range orders. As a *second step* we construct a "crystalline" potential and introduce the muffin-tin (*MT*) approach. This is accomplished by using realistic analytical potential functions.

The scattering paradigm for the simplest cases of spherically symmetrical potential-scatterers (elastic scattering) looks like as follows:

$$\psi(r) \to e^{ikz} + f(\theta)\frac{e^{ikr}}{r} \quad \text{("liquid metal" model case)} \tag{3}$$

and

$$\psi(\mathbf{r}) \to e^{ikz} + f(\theta,\varphi)\frac{e^{ikr}}{r} \quad \text{(spherical cluster model case)} \tag{4}$$

Then, the electronic wave scattering problem is solved, and the energy dependence of the scattering properties for isolated *MT* scatterers is obtained, in the form of the phase shifts $\delta_{lm}(E)$, and the *T*-matrix of the cluster is found as a whole. The indices *l* and *m* arise, as a result of expansions of the functions as Bessel's functions j_l, Hankel's functions h_l and spherical harmonics Y_{lm}.

In general, the modelling of disordered materials represents them as a set of atoms or clusters immersed in an effective medium, with the dispersion $E(\mathbf{K})$ and a complex energy-dependent coherent potential $\Sigma(E)$ found self-consistently in the framework of the CPA. The basic equations of this approach are as follows:

$$\Sigma(E) = V_{eff} + \langle T\rangle(1 + \mathrm{G}_{eff}\langle T\rangle)^{-1}, \tag{5}$$

$$\mathrm{G}(E) = \mathrm{G}_{eff} + \mathrm{G}_{eff}\langle T\rangle\mathrm{G}_{eff} = \langle \mathrm{G}\rangle, \tag{6}$$

$$\langle T(E,\mathbf{K})\rangle = 0, \tag{7}$$

$$\Sigma(E) = V_{eff}, \tag{8}$$

$$\langle G\rangle = G(E) = G_{eff}, \tag{9}$$

$$N(E) = -(2/\pi)\,ln\{det\|G(E)\|\}. \tag{10}$$

Here <...> denotes averaging, V_{eff} and G_{eff} are the potential and the Green's function of the effective medium, respectively, $T(E,\mathbf{K})$ the T matrix of the cluster, and $N(E)$ the integral density of the electronic states. Eq. (5) can be re-written in form:

$$\langle T(E,\mathbf{K})\rangle = \mathbf{Sp}T(E,\mathbf{K}) = \int_{\Omega_{\mathbf{K}}} \langle \mathbf{K}|T(E,\mathbf{K})|\mathbf{K}\rangle d\Omega_{\mathbf{K}} = 0, \tag{11}$$

where $|\mathbf{K}\rangle = 4\pi \sum_{l,m} (\mathrm{i})^l j_l(kr) Y^*_{lm}(\mathbf{K}) Y_{lm}(\mathbf{r})$ is the one-electron wave function and integration is performed over all angles of $\mathbf{K}$ inside the volume $\Omega_{\mathbf{K}}$. Eq. (7) enables one to obtain the dispersion relation $E(\mathbf{K})$ of the effective medium. The DOS calculation in the form of Eq. (10) can be done using the variation principle:

$$\rho(E) = \frac{\delta N(E)}{\delta E}. \tag{12}$$

The paradigm of scattering theory and the developed strategy of simulation of CNTs electronic properties uses the generalized scattering condition for the low-dimensional atomic structures of condensed matter (Quantum Scattering in d-Dimensions):

$$\psi_{\mathbf{k}}^{(\pm)}(\mathbf{r}) \underset{r\to\infty}{\propto} \phi_{\mathbf{k}}(\mathbf{r}) + f_{\mathbf{k}}^{(\pm)}(\Omega)\frac{exp(\pm \mathrm{i}kr)}{r^{\frac{d-1}{2}}}, \tag{13}$$

where superscripts '+' and '–' label the asymptotic behavior in terms of d-dimensional waves:

$$\frac{\partial\sigma_{a\to b}}{\partial\Omega} = \frac{2\pi}{\hbar v}\left|\langle \phi_b | \hat{V} | \psi_a^+ \rangle\right|^2 \rho_d(E), \tag{14}$$

where d is the atomic structure dimension.

In particular, the scattering model for a cylindrical atomic cluster allows us to calculate below the CNTs electronic structure for various diameters and chiralities.

2.2. Calculations of Conductivity and Resistance

The calculations of conductivity are usually performed using Kubo-Greenwood formula [9]:

$$\sigma_E(\omega) = \frac{\pi\Omega}{4\omega}\int\left[f(E) - f(E+\hbar\omega)\right]\left|D_E\right|^2 \rho(E)\rho(E+\hbar\omega)dE, \tag{15}$$

where ω is a real frequency parameter of Fourier transform for the time-dependent functions, $f(E)$ the Fermi-Dirac distribution function, $D_{E,E'} = \int_{\Omega} \Psi^*_{E'} \nabla \Psi_E d\mathbf{r}$, $\Psi_{E(\mathbf{K})} = A\,exp(\mathrm{i}\mathbf{Kr})$ and $\mathbf{K}$ is the complex wave vector of the effective medium. The dispersion function $E(\mathbf{K})$ determines the properties of the wave function $\Psi_{E(K)}$ upon the isoenergy surface in $\mathbf{K}$-space. The imaginary part of $\mathbf{K}$ ($\mathbf{K}_I$) causes a damping of the electron wave, due to the absence of the long-range structural order.

Using the dispersion law, the effective electron mass can be defined as:

$$m^* = (\partial^2 E / \partial K_R^2)^{-1}, \tag{16}$$

where K_R is a real part of $K = \|\mathbf{K}\|$. Thus, the static conductivity can be re-written using Drude formula [10]:

$$\sigma_{E(K)} = \frac{e^2 n^*}{m^*}\tau, \tag{17}$$

where n^* is the effective electron density, with a relaxation time $\tau \approx \frac{l}{v_h}$, $v_h = \left(\frac{3kT}{m^*}\right)^{\frac{1}{2}}$, v_h is a heat velocity and l(T) the free path.

Thus, there exist some ideas to estimate the conductivity in static and frequency regimes and take into account temperature effects. However, in the case of CNT, we must consider not only the diffusive mechanism of conductivity, but also the 'so-called' ballistic one. This is an evident complication in the interpretation of electrical properties of CNTs and related systems.

3. 'Liquid Metal' Model for CNT-Metal Junction: *Ni-CNT Case*

The term "liquid" means the structural disorder of the substance involved, more precisely, only the nearest order is taken into account, as it usually occurs in a liquid. It also means that the inter-atomic distance from the nearest neighbour (first coordination sphere) is fixed, whereas the angular coordinates are random. Another condition is that the average density of matter is maintained also locally. A 'liquid metal' model for CNT-Ni junction is based on calculation of the 'mixed' dispersion law [5, 11]:

$$E_{\text{C-Ni}}(\mathbf{K}_R) = xE_C(\mathbf{K}_R) + (1-x)\,E_{\text{Ni}}(\mathbf{K}_R). \tag{18}$$

The metal alloy model is used for evaluation of mixed effective mass $m^*_{\text{C-Ni}}(E)$. Taking into account the spectral dependence of the effective mass $m^*(E)$ and estimating the spectral resistivity $\rho_x(E)$, we should estimate the average layer resistivity $\rho_{x,av}$ as:

$$\rho_{x,av} = \frac{\int_0^{E_{fin}} \rho_x(E)\,dE}{E_{fin}}, \tag{19}$$

where E_{fin} is the estimated width of conduction band and $x(z)$ the stoichiometry coefficient depending on the coordinate z of ring layer (Fig. 4). An evaluation of resistance for the CNT-Ni contact gives ~ 105 kOhm for the nanotube with the internal and external radii R_1 = 1.0 nm and R_2 = 2.0 nm. Evidently, the results of resistance evaluation for interconnect depend essentially on both the layer height l_0 (C_xNi_{1-x} space, Fig. 7) the spectral integration parameter E_{fin}, which is responsible for the electron transport of really activated electrons. The "liquid metal" model does not take into account CNT chirality in the interconnect space. For this aim, we must construct a model with the realistic atomic structure.

4. Simulation of CNT-Me Interconnect: *'Effective Bonds' Model*

A model of the CNT-Me nanointerconnect [4] (Fig. 4) is developed in the current study. Within the electronic transport formalism, it consists of two regions supporting the two different electron transport mechanisms: ballistic (elastic) and collisional (non-elastic). These electron transport processes are simulated by the corresponding boundary conditions in the form of the effective medium. The CNT chirality (m, n) is simulated by the corresponding orientation of carbon rings within the scattering medium (Fig. 10).

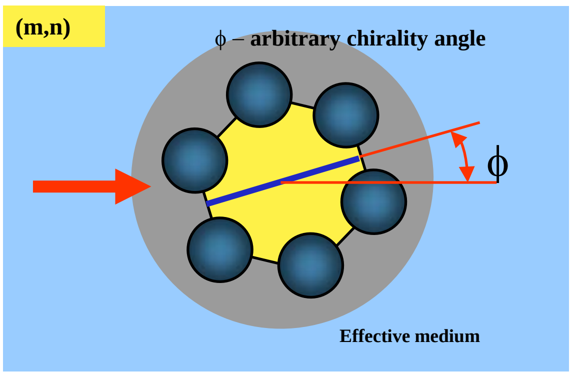

Figure 10. Modeling of chirality effects: carbon ring rotation within CNT

The most problematic regions for simulation are CNT-Me junctions, where atomic structural disorder is observed and the conductivity mechanism is changed. The chirality influence on the resistance in the region of interconnect depends on the number of statistically realized bonds between the CNT and the catalytic substrate (*e.g.*, Ni, Cu, Au, Ag, Pd, Pt) formed during the CNT growth above the metallic catalyst surface.

4.1. Mechanism of the Ballistic Conductivity as a Result of the Multiple Scattering

We assume that the conducting nanotubes are not very long and electrons are not scattered too much by any defect (imperfection) of this nanomaterial. The effect of the charge accumulation is neglected as well. We are dealing with the so called 'ballistic' mechanism of the electronic transport. This situation is a similar to an ideal billiard with moving elastic balls-electrons. According to the Landauer model [12], $g_{mn} = (e^2/h)\mathbf{Sp}(T_{mn}T_{mn}^{+}),\ m \neq n$, where g_{mn} are the conductance coefficients while $(e^2/h)T_{12}\Delta\mu$ is the current flow between the two reservoirs with a difference between the chemical potentials $\Delta\mu = \mu_1 - \mu_2$ (T_{12} is the transmission coefficient found to be between 1 to 2 in the one-channel case) based on the conception of the quantum conductance $2e^2/h$ = 0.077 kOhm^{-1} (or, the resistance is about 12.92 kOhm).

Using the simulation models, presented earlier [5], we have developed resistance models for both SW and MW CNT-Me interconnects, based on the interface potential barriers evaluation and Landauer formula, which defines the integrated conductance:

$$G = \frac{2e^2}{h}\sum_{i=1}^{N} T_i = \left(\frac{1}{12.92(k\Omega)}\right)\sum_{i=1}^{N} T_i = 0.0774\sum_{i=1}^{N} T_i, \qquad (20)$$

where N is the number of conducting channels and T_i the corresponding transmission coefficient.

4.2. Chirality and Thickness Simulations

On Figure 11 is presented a simulation of catalytic growth of CNT on the metal substrate. This is accompanied by creation of C-Me 'effective bonds'. We should also point out that this is a probabilistic process when only more-or-less equilibrium bonds ("effective bonds") are formed at inter-atomic distances corresponding to the minimum total energies. The evaluation of a number of "effective bonds" using Eq. (20) is principal for the number of "conducting channels", since the conductance is proportional to the number of appeared "effective bonds" within the CNT-Me interconnect.

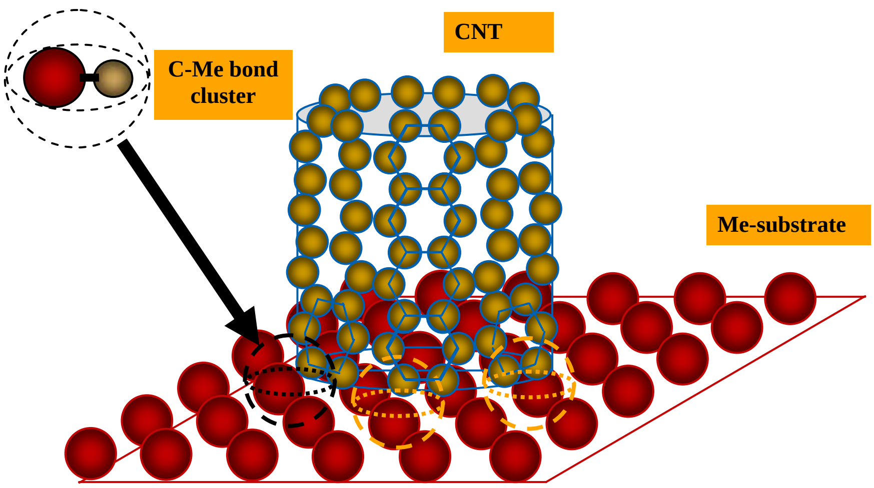

Figure 11. The SW CNT-Me interconnect: model of "*effective bonds*"

The calculation of conducting abilities of "effective bond" leads us to estimate the energy-dependent transparency coefficient of a potential barrier C-Me (Fig. 12), which belongs to scattering problems. The scattering process for a C-Me potential barrier is also regulated by the effect of "thin film" for conductivity electrons, which leads to quantization in voltaic parameters (in the case of full transparency).

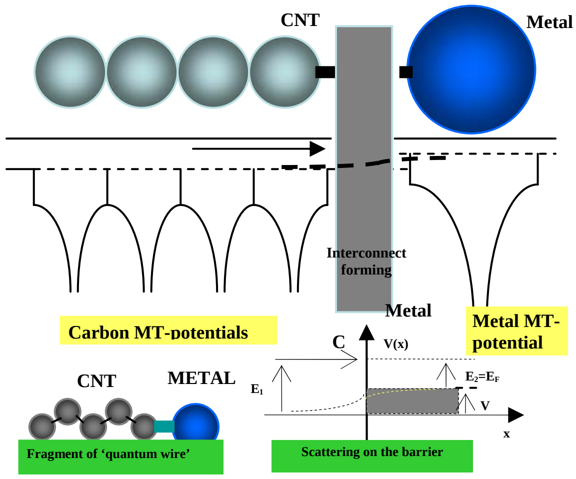

Figure 12. The formation of potential barrier for SW CNT-Me interconnect

The transmission (transparency) coefficient T for the barrier scattering problem (Eq. (20) and Fig. 9) is defined as:

$$T = \sqrt{\frac{E_2}{E_1}}\left(\frac{2\sqrt{E_1}}{\sqrt{E_1}+\sqrt{E_2}}\right)^2, \tag{21}$$

where E_1 and E_2 are the corresponding electron energies.

Evaluation of resistances for CNT-Ni junctions for various nanotube diameters and chiralities are present in Table 1 (see also Figs. 13 and 14). These resistances have been estimated taking into account that only thermally activated electrons (*i.e.*, a small part of all electrons) take a part in the conduction process with Fermi velocity v_F. This ratio can be estimated as:

$$\frac{\Delta n}{n} \approx \frac{3}{4}\frac{kT}{E_F}, \tag{22}$$

where n is the quasi-free electron concentration, for T = 300^0 K, $kT = 0.0258$ eV.

Table 1. Simulation of resistances for the SW CNT-Ni interconnects

Diameter, nm	Chirality indices (Fig. 6)	Number of bonds in contact	Modulus of chirality vector, nm	Interconnect resistance, kOhm
zig-zag, $\varphi = 0^\circ$				
1.010	C(13,0)	12	2.952	665,19
2.036	C(26,0)	24	6.394	333,33
5.092	C(65,0)	64	15.990	124,72
10.100	C(130,0)	129	32.002	61,87
20.360	C(260,0)	259	63.940	30,82
armchair, $\varphi = 30^\circ$				
0.949	C(7,7)	12	2.982	665,19
2.035	C(15,15)	28	6.391	205,71
5.021	C(37,37)	72	15.765	111,11
10.041	C(74,74)	146	31.531	54,79
20.084	C(128,128)	294	63.062	27,21
C(3*m*,*m*), $\varphi = 14^\circ$				
0.847	C(9,3)	3	2.66	2666,66
1.694	C(18,6)	5	5.32	1600,00
5.082	C(54,18)	16	15,96	500,00
10.16	C(108,36)	36	32.05	222,22
20.32	C(216,72)	80	64.10	100,00
C(2*m*,*m*), $\varphi = 19^\circ$				
1.036	C(10,5)	5	3.254	1600,00
2.072	C(20,10)	9	6.508	888,88
4.973	C(48,24)	17	15.614	470,50
10.1528	C(98,49)	47	31.880	170,21
20.5128	C(198,99)	97	64.410	82,47

The role of thermally activated electron is described by the scattering mechanism changing in the space of CNT-Me interconnect.The mean free path L in the CNT is of order 10^2–10^4 a_C, where a_C is a carbon covalent radius, which can be explained by the ballistic mechanism of electron transport within the energy channel of the CNT. At the vicinity of interconnect, we observe a drastic decrease of the electron mean free path down to $1 - 2\ a_C$. From the uncertainty condition $\kappa L \approx 1$ (where $L \sim a_C \sim 2\ a.u.$ is a free path), we can evaluate the Fermi electron wave number $\kappa \propto \kappa_F \approx 1/a_C \approx 0.5$ a.u.$^{-1}$. It means that $E_F \sim 0.25$ Ry, *i.e.*, a large increase of resistance occurs in the interconnect space. In particular, the variation of the chirality angle ϕ within the interconnect space leads to a fluctuation of the number of C-Me atomic bonds. In the case of $0^{\circ} < \phi < 30^{\circ}$**,** a certain number of non-stable and non-equilibrium bonds can be created. Evidently, this leads to a decrease of interconnect conductance, which is well-observed when performing variation of nanotube diameter (Fig. 13):

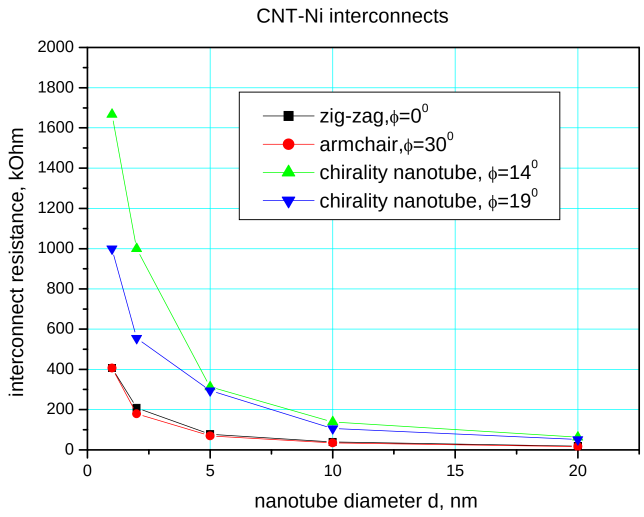

*Figure 13***.** CNT-Ni interconnect resistance *via* NT diameter

Specific results for chirality effect simulations are shown on Figure 14, with an evident maximum of the resistance for $\phi \approx 15^{\circ}$, where the large number of non-equilibrium bonds is formed, with higher potential barriers and lower transparency interconnects for the CNT diameter ~1 nm.

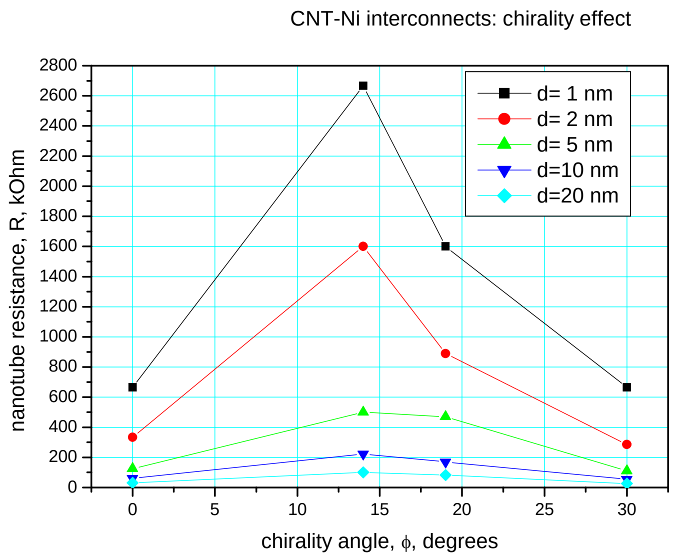

Figure 14. CNT-Ni interconnect simulation: *chirality effects*

On Figure 15 are showed the generalized results of simulations on resistance of junctions obtained for various metallic substrates. It is clear that Ag and Au substrates are more effective electrically while Ni is rather a ‘worse’ substrate for interconnect, although it yields the most effective catalyst for CNT growth. On the other hand, the catalysts which are usually used for the SW CNT growth (*e.g.*, Fe, Co and Ni), have a stronger bound to the ends of SW CNTs than noble metals [13], *i.e.*, some compromise exists between electrical parameters and strengths of the interconnect bonding.

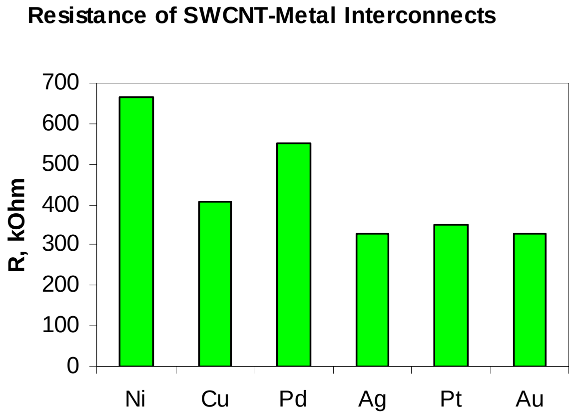

Figure 15. Resistance of the zigzag-type SW CNT-Me

5. Simulations on MW CNT-Me Interconnects: Conductance and Resistance

Our study was focused on the development of models describing the growth mechanism of carbon nanotubes upon nanostructured Ni catalyst inside the pores of Al_2O_3 membranes. The scope of these simulations allows us to predict that a specific morphology of CNTs could be formed inside the specific membranes having defined periodicity and hole dimensions. These simulations are necessary, in order to understand the basic mechanism of CNT growth and to achieve the tight control on the fabrication process. We have constructed atomistic models of both SW CNT bundles and MW CNTs which could fit into a porous alumina with holes diameters ~ 20 – 21 nm. In particular, a multi-shell model of MW CNT is presented on Figure 16, with a pre-defined combination of *armchair* (*ac*) and *zig-zag* (*zz*) shells (Table 2).

Using the simulation models presented earlier [14] we have developed an “effective bonds” model for MWCNT-Me junction resistance, based on the interface potential barriers evaluation and Landauer formula, Eq. (20). Results of these simulations are presented on Figure 17 and in Table 3.

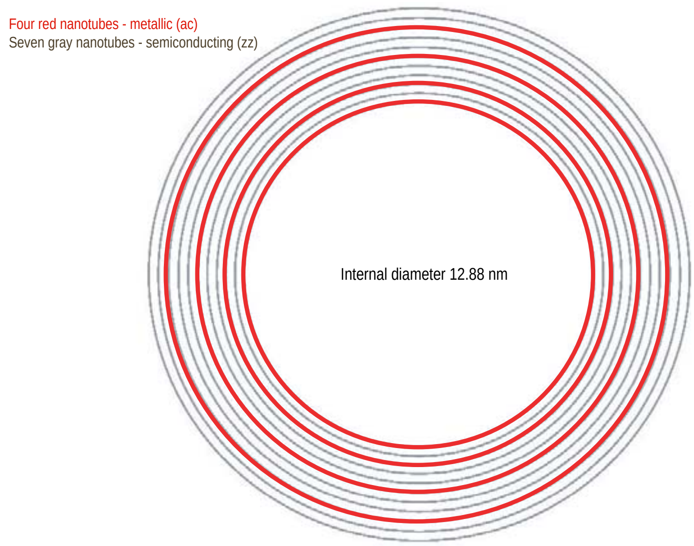

Figure 16. A cross-section of the supercell model for MW CNT with height 6.39 nm and external diameter 19.89 nm

Table 2. Details of the model for MW CNT-Me interconnect

diameter of CNT shell, nm	Chirality
12.88	(95,95) *ac*
13.54	(173,0) *zz*
14.24	(105,105) *ac*
14.87	(190,0) *zz*
15.58	(199,0) *zz*
16.27	(120,120) *ac*
16.99	(217,0) *zz*
17.69	(226,0) *zz*
18.44	(136,136) *ac*
19.18	(245,0) *zz*
19.88	(254,0) *zz*

Again, Figure 17 shows similar ratios of electric resistances as for SW CNTs (Fig. 15), in favour of Au, Ag and Pd. However, in the case of MWCNT-Me junction, the integral mechanical bonding with a corresponding substrate may be not so significant as in the case of SW CNTs, where the weak bonding can be principal.

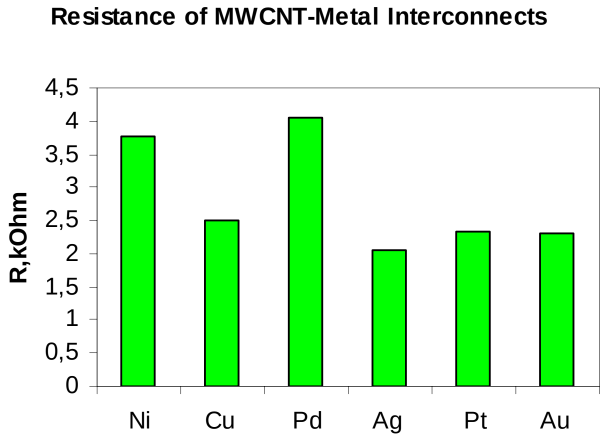

Figure 17. Resistances of various MWCNT- Me interconnects

Table 3. Simulation of resistances for the MW CNT-Me interconnects

Metal	Z	Interconnect resistivity, kOhm
Au	79	2.313
Pt	78	2.345
Pd	47	4.050
Ag	46	2.062
Cu	29	2.509
Ni	28	3.772

6. Evaluation of Current Loss between the Adjacent Shells inside the MW CNT

Using the model of inter-shell potential within the MW CNT we also have evaluated the transparency coefficient, which determines the possible 'radial current' losses. Figure 18 shows the inter-shell potential which is calculated using the developed realistic analytical potentials (see comments of Part 2 and the procedure of the potential construction, *e.g.*, in [2]).

On Figure 18, A is the electron emission energy, E the electron energy, V the height of the potential barrier between the nearest atoms in neighboring nanotube shells. Thus, a radial transparency coefficient T for the two different energy ratios can be defined as:

$$E > V, T = \frac{4Ek_2^2}{(E - k_2^2)\sin^2 k_2 a + 4Ek_2^2}, k_2^2 = E - V, \quad (23)$$

$$E < V, T = \frac{4E\kappa_2^2}{(E - \kappa_2^2)\mathrm{sh}^2\kappa_2 a + 4E\kappa_2^2}, \kappa_2^2 = V - E. \quad (24)$$

where k_2 the electron wave number in the case of above-barrier motion and κ_2 the same for under-barrier motion. For example, between the 2nd and 1st shells (*zz-ac* case, Fig. 13) a = 13.54 – 12.88 = 0.66 nm = 12.47 a.u. and $T = 3.469 \cdot 10^{-6}$ *per* 1 bond.

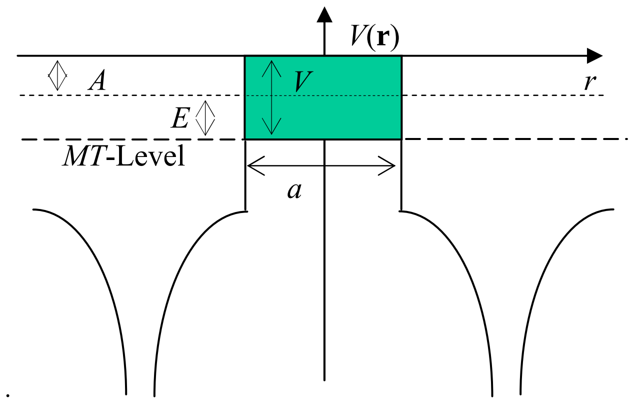

Figure 18. Inter shell transparency and inter-shell *MT*-potential model (*MT*-muffin tin)

Clearly the total radial conductance is proportional to T and the number of effective potential barriers. It is also clear that the 'radial current' losses (or, simply radial current) are similar to the Hall current due to the induced magnetic field of the basic axial current. A pure scattering mechanism is also possible. However, the radial conductance *per* CNT length depends on the morphology (chirality) of the nearest nanotubes, when the number of shortest effective barriers is varied in a probabilistic way. This also means that current-voltage parameters of MW CNTs can be less stable, than in the case of SW CNTs. It was found that inter-shell interactions, such as inter-shell tunneling of electrons and Coulomb interactions [15–17]) cause a reduction of the total MW CNT conductance.

Conclusions

We have predicted the resistance properties of interconnects between the metal substrate (*e.g.*, Ni) and the SW or MW CNTs, using the *'effective bonds'* model. We also expect qualitatively compatible results for the CNT-Me interconnects in both considered approaches, namely, first principles *'liquid metal'* model and empirical *'effective bonds'* model based on the Landauer relationship. The latter is more compatible with experimental measurements, due to the exact description of the local atomic morphology for CNT-Me interconnects.

We have also developed the model of inter-shell interaction in MW CNTs, which allows us to estimate the transparency coefficient as an indicator of possible 'radial current' losses. We point out that a conductance and current-voltage characteristic depends on the morphology of the nearest shell in MWCNT, which means complications for technology and production of nanodevices with stable electric characteristics.

Acknowledgments

This study has been supported by grant EC FP7 ICT-2007-1, Proposal for 21625 CATHERINE Project (2008–2010): *C*arbon n*A*notube *T*echnology for *H*igh-speed n*E*xt-gene*R*ation nano-*I*ntercon*NE*cts. We thank Prof. E. A. Kotomin for stimulating discussions.

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Received on the 1st of December, 2009

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 20–28
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FORECASTING TRAFFIC LOADS: NEURAL NETWORKS vs. LINEAR MODELS

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The main aim of the research was to produce the short-term forecasts of traffic loads by means of neural networks (a multilayer perceptron) and traditional linear models such as autoregressive-integrated moving average models (ARIMA) and exponential smoothing. The traffic of a conventional telephone network as well as a packet-switched IP-network has been analysed. The experimental results prove that in most cases the differences in the quality of short-term forecasts produced by neural networks and linear models are not statistically significant. Therefore, under certain circumstances, the application of such complicated and time-consuming methods as neural networks to forecasting real traffic loads can be unreasonable.

Keywords: telecommunications, packet-switched networks, traffic forecasting, neural networks, ARIMA, exponential smoothing

1. Introduction

The reliable forecasts of traffic generated by users (subscribers) allow planning the capacity of transmission channels, avoiding the overload and sustaining the optimal level of quality of service. A rapid development of packet-switched networks and the transformation of traditional telephone networks into multi-service systems offer new opportunities to a user (subscriber) and expand his/her scope of activities. Though, not only the architecture of telecommunications networks but also the statistical nature of traffic has been changed. It has been proven that empirically observed packet-switched traffic is characterized by self-similarity which comes along with such statistical effects as long-range dependence and a slowly decaying variance. That led to a belief (quite ungrounded) that traditional linear methods are not suitable for solving a forecasting task because of their focusing on short-range dependant processes.

In the analysis of dynamic behaviour of IP-networks the mechanism of neural networks is gaining more and more acceptance. Neural networks provide additional opportunities in modelling non-linear phenomena and recognizing chaotic behaviour of processes. On the other hand, neural networks are often criticized for a very large number of parameters to define in empirical way, difficulties in producing and replicating a stable solution and the risk of losing generalization ability due to over-training. Besides, neural networks are very time-consuming methods which also require powerful technical facilities. Therefore, it is important to define if there is a necessity to apply neural networks and, if so, under which conditions.

Numerous papers dedicated to the application of neural networks to forecasting packet-switched traffic have been published. However, most of them solve a trivial task of forecasting with more or less success and did not pay much attention to evaluating the statistical properties of analysed traffic traces. None of them also carry out a complex comparative analysis of forecasts produced by neural networks and traditional linear methods.

Taking that into account the main goals of the research were specified as:

- to test the ability of traditional linear models such as autoregressive-integrated moving average models (ARIMA) and exponential smoothing to produce the short-term forecasts of real network traffic;
- to compare the quality of the forecasts produced by traditional linear methods with those which are produced by means of neural networks (a multilayer perceptron);
- to specify the conditions under which the mechanism of neural networks has to be applied to forecasting the traffic of telecommunications networks.

From practical point of view the traffic of packet-switched network is of most interest. However, there are only few research papers dedicated to the prediction of conventional telephone traffic by means of neural networks. Therefore, the task of verifying the ability of neural networks to predict telephone traffic was set as well.

2. Background of Forecasting Network Traffic

Solving the task of traffic modelling and forecasting, we usually assume that its values are expressed by discrete time series. A discrete time series is defined as a vector $\{x(t)\}$of observations made at regularly spaced time points $t = 1, 2, \ldots, N$. Unlike the observations of a random variable, the observations of a time series are not statistically independent. This relation sets up the specific base for forecasting an analysed variable (i.e. for producing the estimate $\hat{x}(N+L)$ of an unknown value $x(N+L)$ taking into account the historical values $x(t_1), x(t_2), \ldots, x(t_N)$).

The methods of traffic forecasting are defined by the ITU-T recommendations E.506 and E.507 [0][0]. Even the recommendations are partly obsolete and are supposed to be used for forecasting the traffic of ISDN-networks, some of the methods still can be applied to modern telecommunications networks. In particular, these methods are autoregressive-integrated moving average (ARIMA) models and exponential smoothing.

As it has been already mentioned, the empirically observed traffic of packet-switched networks is self-similar in a statistical sense, over a wide range of time scales. Consider a discrete time stochastic process or time series $\{x(t)\}$, $t \in Z$, where $x(t)$ is the traffic volume – measured in packets, bits or bytes – at time instance t. Under the assumption of stationarity, $\{x(t)\}$ is called *exactly* second-order self-similar with Hurst parameter H ($0.5 < H < 1$) if for all $k \geq 1$ [1][0]

$$\gamma(k) = \frac{\sigma^2}{2}\left((k+1)^{2H} - 2k^{2H} + (k-1)^{2H}\right), \tag{2.1}$$

where $\gamma(k)$ – the autocovariance function of $\{x_t\}$; k – time shift (lag); H – Hurst exponent.

Objects possessing self-similar quality are called fractals. For aggregated processes[2], $\gamma(k) = \gamma^{(m)}(k)$ for all $m \geq 1$, where m – the aggregation period. Thus, second-order self-similarity assumes that correlation structure exactly or asymptotically preserves under time aggregation.

Two important statistical features of self-similar processes are long-range dependence and a slowly decaying variance.

Let $r(k) = \gamma / \sigma^2$ denote the autocorrelation function. Then, $\{x(t)\}$ is called the stationary process with long-range dependence, if under the assumption $0.5 < H < 1$, $r(k)$ asymptotically behaves as $ck^{-\beta}$ for $0 < \beta < 1$ (and $\beta = 2 - 2H$), where $c > 0$ is a constant. It this case $r(k)$ is assumed to be non-summable [0]:

$$\sum_{k=-\infty}^{\infty} r(k) = \infty\,. \tag{2.2}$$

That is, the autocorrelation function of long-range dependent processes decays slowly – i.e., hyperbolically, in contrast to short-rage dependant processes with autocorrelation function decaying quickly.

In its turn, the variance of aggregated self-similar processes decays more slowly as compared to the magnitude inverse to the sample size. For $0.5 < H < 1$, $H \neq 0.5$, it holds [0]

$$\sigma^2(X^{(m)}) \sim m^{-\beta} \tag{2.3}$$

with $0 < \beta < 1$ (and $H = 1 - \beta / 2$).

It implies that for rather large m, a self-similar process is visually more uneven and irregular (i.e. possesses the property of high variance) than a short-range dependant process.

The degree of long-range dependence is usually evaluated by means of a Hurst exponent [0]. In network traffic theory the notions of *self-similarity* and *long-range dependence* are often interchangeable but it is worth noting that not all self-similar processes are long-range dependant and vice versa. However, *asymptotic* second-order self-similarity assumes long-range dependence by the restriction $0.5 < H < 1$, and vice versa [0].

Due to the influence of long-range dependence, a forecasting process of self-similar traffic is more complicated as compared to the prediction of traditional telephone traffic which is characterized by short-range

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[1] The notion of *asymptotic* self-similarity also exists nad can be found in [0].

[2] To formulate scale-invariance, in traffic theory the aggregated process $x^{(m)}$ at aggregation level m is defined as $x^{(m)}(i) = \frac{1}{m}\sum_{t=m(i-1)+1}^{mi} x(t)$ [0]. That is, $\{x(t)\}$is portioned into non-overlapping blocks of size m, their values are averaged, and i is used to index these blocks.

dependence. Non-linear neural networks have won popularity in the prediction of packet-switched traffic. However, numerous research papers dedicated to the application of neural networks usually miss the fact that a fractal nature of packet-switched traffic has a prominent influence only in the case of measurements on a large scale – over the aggregation periods varying from milliseconds to approximately 5–15 minutes (see Fig. 2.1).

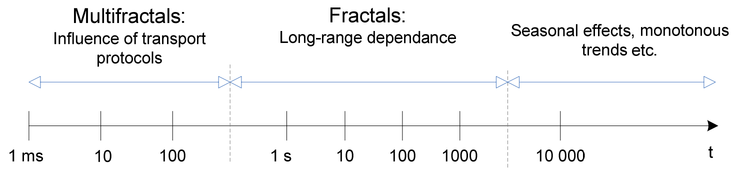

Figure 2.1. Statistical effects of packet-switched traffic depending on a time scale [0, with author's changes]

Such a fine sampling scale is often unreasonable from the point of view of time series forecasting. In this case the selection of the relevant statistical model can be complicated due to a strong influence of autocorrelation between distant observations of a times series as well as due to the influence of extraneous noises and anomalous outliers, which unavoidably entail the measurements on a large scale. Besides, an aggregation/sampling period also determines a forecasting horizon for which reliable forecasts can be produced. In other words, the possible forecasting horizons for time series aggregated over the period of one second or 24 hours are different. At present neural networks are not suitable for real-time forecasting; therefore aggregation on a fine scale does not make sense. Taking that into account and following the ITU-T Recommendation E.492 [0], it is advised to average measurements of network traffic over 15-minutes and/or one-hour intervals. Over these sampling periods, human behaviour and technical progress are those factors that influence the statistical properties of traffic more than self-similarity (Fig. 2.2).

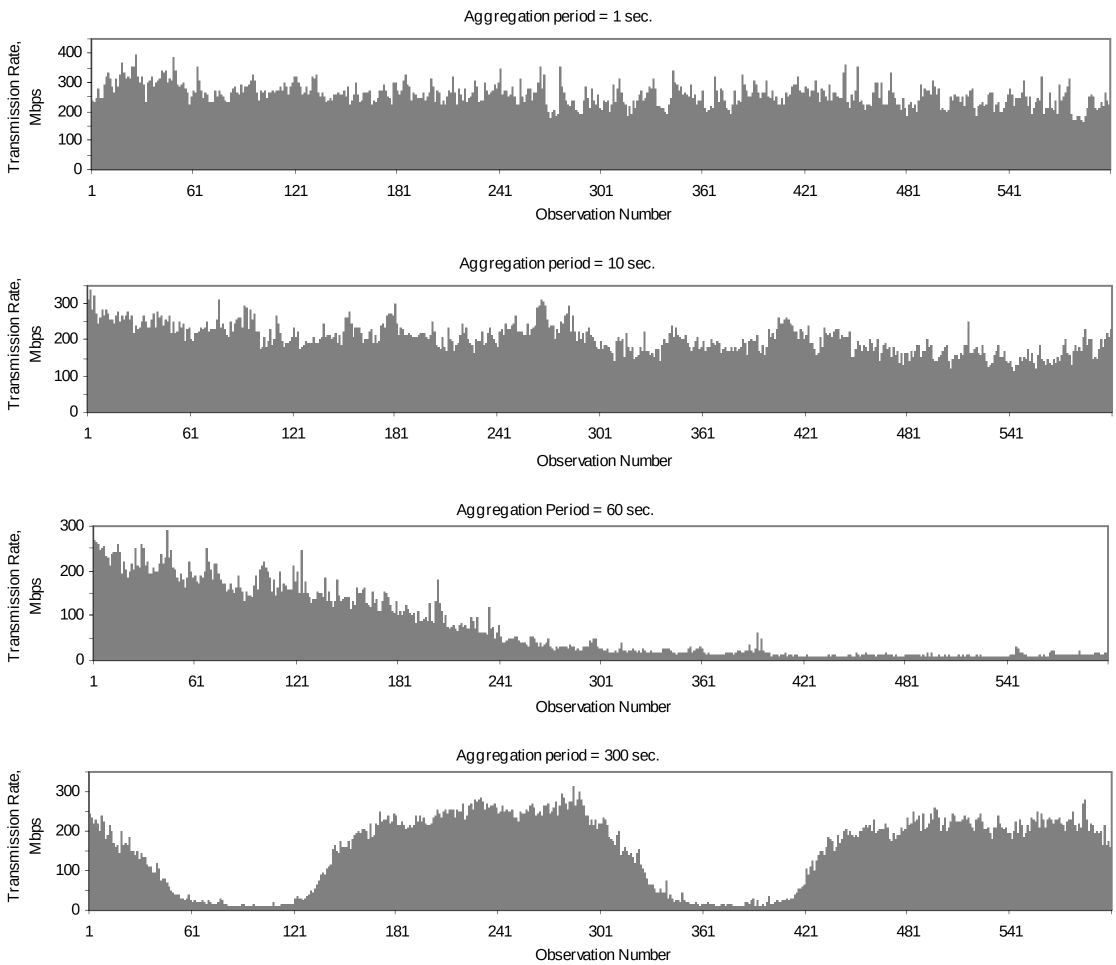

Figure 2.2. Measurements of real packet-switched traffic over different aggregation periods

Therefore, we can often speak about the possibility of applying traditional linear methods of time series forecasting.

The main accent of this research was put on the application of neural networks (i.e. a multilayer perceptron) for forecasting the changes of the traffic of both traditional telephone networks and packet-switched IP-networks. The forecasts produced by non-linear models were compared to those which were produced by traditional linear models. For the purpose of this comparison the models of ARIMA and exponential smoothing were chosen (as the methods recommended by the ITU-T). If the comparative analysis of forecasts produced by neural networks and linear models do not reveal any statistically significant differences, then the application of such a complicated and time-consuming method as neural networks does not make sense.

3. The Methods of Traffic Forecasting

3.1. Neural Networks

Neural networks are massively parallel, distributed processing systems representing a new computational technology built on the analogy to the human information processing system. A neural network consists of a large number of simple processing elements called neurons or nodes. Each neuron is connected to other neurons by means of directed communication links, each with an associated weight. The weights represent information being used by the network to solve a problem.

Neural networks are suitable for solving various tasks including time series forecasting. The temporal structure of an analysed sample is usually built into the operation of a neural network in implicit way when a static neural network is provided with dynamic properties [0]. In this case the input signal is usually uniformly sampled, and the sequence of synaptic weights of each neuron connected to the input layer of the network is convolved with a different sequence of input samples.

For a neural network to be dynamic, the memory must be given, which may be divided into short-term and long-term memory. Long-term memory is built into a neural network through supervised learning, whereby the information content of the training data set is stored in the synaptic weights of the network. Short-term memory is usually build into the structure of a neural network through the use of time delays which can be implemented at the synaptic level inside the network or at the input layer of the network.

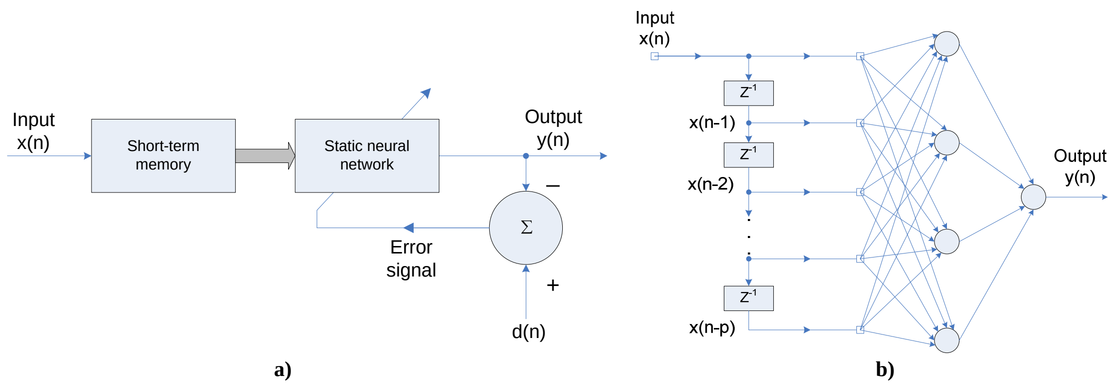

Figure 3.1. Temporal processing using neural networks:
a) nonlinear filter built on a static neural network [0]; b) time lagged feedforward network (TLFN) [0] [0]

Temporal pattern recognition requires processing of patterns that evolve over time, with the response at a particular instant of time depending not only on the present value of the input but also on its past values. Figure 3.1(a) shows the block diagram of a nonlinear filter built on a static neural network. Given a specific input signal consisting of the current value $x(n)$ and the p past values $x(n-1)$, …, $x(n-p)$ stored in a delay line memory of order p, the free parameters of the network are adjusted to minimize the training error (the mean square error) between the output of the network, $y(n)$, and the desired response $d(n)$ [0].

The structure shown on Figure 3.1(a) can be implemented at the level of a single neuron or a network of neurons. A time lagged feedforward network is shown on Figure 3.1(b). It consists of a tapped delay memory of order p and a multilayer perceptron (MLP). A standard back-propagation algorithm can be used to train this type of neural networks.

3.2. ARIMA Models

The processes of autoregression, moving average and their combinations refer to the class of linear models, as all the relations between the observations and random errors of a time series are expressed by means of linear mathematical operations.

In contrast to simulated traffic, the real traffic usually incorporates seasonal and / or cyclic components. In this case one should pay his / her attention to the seasonal modifications of ARIMA.

The ARIMA is the Box-Jenkins variant of conventional ARMA models which is predestinated for applications to non-stationary time series that become stationary after their differencing. In the case of seasonal ARIMA models, seasonal differencing is also applied in order to eliminate a seasonal component of period *s*.

If d and D are non-negative integers, then $\{x(t)\}$ is a seasonal ARIMA(p,d,q)(P,D,Q) process given by [0]:

$$\phi_p(B)\Phi_P(B^s)\nabla^d\nabla_s^D x(t) = \theta_q(B)\Theta_Q(B^s)\varepsilon(t)\,, \tag{3.1}$$

where
s – period of a cyclic component;
B – delay operator;
$\phi(B)$ – autoregressive operator of order p;
$\theta(B)$ – moving-average operator of order q;
$\Phi(B^s)$ – seasonal autoregressive operator of order P;
$\Theta(B^s)$ – seasonal moving-average operator of order Q;
∇ – differencing operator given by $\nabla = \nabla_1 = 1 - B$;
∇_s – seasonal differencing operator given by $\nabla_s = 1 - B^s$
$\varepsilon(t)$ – white noise.

The operators $\phi(B)$, $\theta(B)$, $\Phi(B^s)$ and $\Theta(B^s)$ have to satisfy the conditions of stationarity and reversibility. The indexes p, P, q and Q are introduced here in order to remind about different orders of the operators. The description of the ARIMA process incorporating two and more periodic components is analogous to this.

3.3. Exponential Smoothing

The method of exponential smoothing is the generalization of moving average technique. It allows building the description of a process whereby the latest observations are given largest weights in comparison with earlier observations, and the weights are exponentially decreasing.

There exist different modifications of exponential smoothing, which are suitable for modelling and forecasting the time series incorporating linear/non-linear trends and/or seasonal fluctuations. Such models are based on the decomposition of time series.

Just as in the case of ARIMA models, the task of forecasting real network traffic requires applying the seasonal modifications of exponential smoothing. In this research the model of exponential smoothing with additive seasonality was implemented to constant-level processes. Its mathematical expression is given by [0]:

$$\begin{aligned} S(t) &= \alpha\cdot[x(t) - I(t-p)] + (1-\alpha)\cdot S(t-1) \\ I(t) &= \delta\cdot[x(t) - S(t)] + (1-\delta)\cdot I(t-p) \end{aligned}\,, \tag{3.2}$$

where
α – smoothing parameter for the level of the series;
$S(t)$ – smoothed level of the series, computed after x_t is observed;
δ – smoothing parameter for seasonal factors;
$I(t)$– smoothed seasonal index at the end of the period t;
p – number of periods in the seasonal cycle.

In this case the forecast is calculated as follows [0]:

$$\hat{x}_t(l) = S(t) + I(t-s+l)\,, \tag{3.3}$$

where $\hat{x}_t(l)$ – forecast for *l* periods ahead from origin *t*.

Network traffic measured over long time periods (several years) usually incorporates not only seasonal fluctuations but also a linear trend. Then it is necessary to use seasonal trend modifications of exponential smoothing, the description of which can be found in [0].

4. Practical Research

The object of the research is the time series of different length and aggregation period which characterize the real traffic of both traditional telephone networks (POTS) and packet-switched IP-networks. The main aim was to analyse the statistical properties of time series and to develop such a neural network which is suitable for modelling an underlying process and producing a reliable forecast for a pre-defined forecasting horizon. The selection of the relevant neural network closely followed an advanced algorithm introduced in [0].

The measurements were taken on the transportation level and represent three variables:

- the transmission rate of outgoing international traffic of the IP-network;
- the transmission rate of total outgoing traffic of the IP-network;
- the intensity of the total serviced load of the conventional telephone network.

Following the ITU-T Recommendation E.492 [0] the initial traffic measurements of each variable were averaged over 15-minutes and one-hour periods. The size of the basic sample was equal to 9 and 12 weeks for the first variable, and to 9, 12 and 18 weeks for two other variables. Thus, sixteen time series were produced in total. The forecasting horizon (i.e. the size of a testing sample) for each time series varied from one to 14 days with the step of one day.

All the analysed time series are characterized by the presence of seasonal components with periods of 24 hours and one week. It was revelled by applying a Fourier analysis. The estimates of the Hurst exponent vary from 0.65 for telephone traffic to 0.85 for packet-switched traffic. Such values indicate the persistence of analysed time series and exploit the potentialities of their further forecasting. The specification of the developed neural network is displayed in Table 4.1.

Table 4.1. The main parameters of the developed neural network[3]

Stage	Parameter / Procedure	Parameter Value / Procedure Description
Selection of network topology	Type of topology	Time-lagged feedforward network (multilayer perceptron)
	Number of hidden layers	1
	Number of hidden neurons	Varying from 1 to 10
	Number of output neurons	1
	Activation function	Hidden layer – hyperbolic tangent; output layer – linear function
Training	Number of training epochs	600
	Training algorithm	Back propagation (100 epochs) & conjugate gradient descent (1000 epochs)
	Error function	Mean square error
	Learning rate	0.1
	Momentum term	0.3
	Method of initialisation of weights and biases	Randomised values from a uniform distribution with a range of [-0.5;0.5]
	Number of times to randomise weights and biases	100
	Methods to prevent over-learning	Cross-validation, weight regularization [0]
	Stopping criterion	Training error is invariable during 50 epochs
In-sample and out-of-sample evaluation	The parameters of in-sample evaluation	R, RMSE, MAE, MAPE, AIC, BIC
	Diagnostic testing of residuals	Lagrange multiplier type test [0] , χ^2 - test
	The parameters of out-of-sample evaluation	RMSE, MAE, MAPE, the Diebold-Mariano criterion

Neural networks belong to so called heuristic methods. It means that appropriate values of most parameters of the developed neural network had to be evaluated in experimental way. The architecture of

[3] Notes: R – correlation coefficient, MAE – mean square error, RMSE – root mean square error, MAPE – mean absolute percentage error, AIC – Akaike's information criterion, BIC – Bayesian information criterion.

a neural network was defined as follows. According to the universal approximation theorem [0] the number of hidden layers was equal to one. The size of the input window was equal to the largest period of the cyclic component identified by means of a Fourier analysis. The number of output neurons was equal to one and implied a one-step ahead forecasting. In order to identify the appropriate number of hidden neurons all the architectures with the number of hidden neurons varying form one to ten have been tested and verified.

A two-stage training process was implemented. During the first stage a multilayer perceptron was trained by applying the backpropagation during one hundred epochs, with learning rate 0.1 and momentum 0.3. It usually gives the opportunity to locate the approximate position of a reasonable minimum. During the second stage, a long period of conjugate gradient descent (1000 epochs) is used, with a stopping window of 50, to terminate training once convergence stops or over-learning occurs. Once the algorithm stops, the best network from the training run is restored.

The final neural network was chosen in compliance with the method suggested in [0]. According to that, among competing neural networks the model with uncorrelated residuals and the smallest value of the information criterion (IC) has to be chosen for further forecasting.

The quality of the forecasts was estimated by means of such standard parameters as root mean square error (RMSE), mean absolute error (MAE) and mean absolute percentage error (MAPE). Besides, the Diebold-Mariano test [0] was applied in order to evaluate relative accuracy of forecasts and to reveal any statistically significant differences between the forecasts produced by neural networks and traditional linear methods such as a seasonal ARIMA and seasonal exponential smoothing. The main advantage of this test is that it is non-parametric and can be used even if forecasting errors do not comply with the classic requirements, i.e. they are non-normally distributed, autocorrelated or serially correlated.

For the sake of space saving, only one empirical example illustrating the production of the forecasts for the time series (B) is shown here. However, the main conclusions have been drawn taking into account the whole set of produced forecasts and the complete results of verification.

As a result of verification procedures, three models have been chosen for further forecasting of the time series (B). They are a time lagged multilayer perceptron with one hidden neuron MLP 672-1-1, a seasonal model SARIMA(1,0,6)$(0,1,1)_{672}$, and the model of exponential smoothing with additive seasonality and parameters $\alpha = 0.19$ и $\gamma = 0.00$. The final forecasts produced by these models over a forecasting horizon up to two weeks (1344 observations) are shown on Figure 4.1.

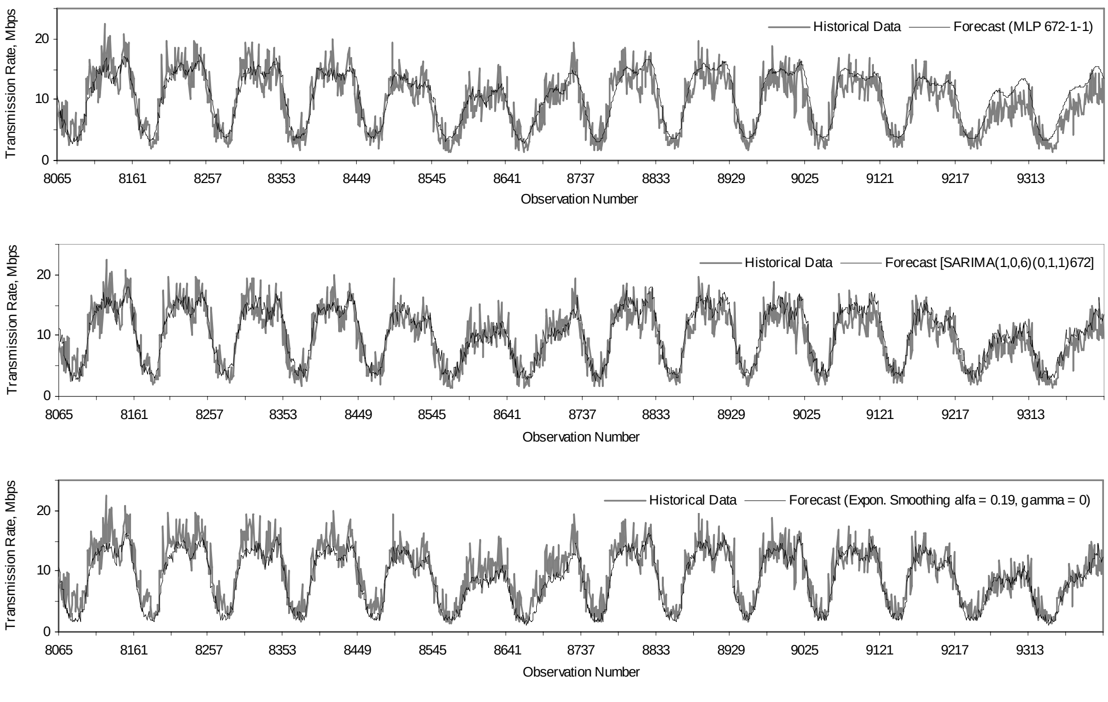

Figure 4.1. Final pseudo-forecasts of the transmission rate of IP-traffic produced by different models

We can see in Table 4.2 that the values of the standard estimates of the quality of produced forecasts do not differ significantly. Therefore it is hard to say which model performs better than others. The Diebold-Mariano test [0] was implemented in order to identify statistically significant differences between produced forecasts for three forecasting horizons such as 24 hours (96 observations), a week (672 observations) and two weeks (1344 observations). It is shown in Table 4.3 that there are no statistically significant differences between forecasts produced by the neural network and SARIMA over the forecasting horizons of 24 hours and one week. However, as a forecasting horizon increases, the quality of forecasts produced by the neural network deteriorates. Thus, the SARIMA model outperforms the neural network over a forecasting horizon of two weeks. On the other hand, forecasts produced by the neural network perform better than those produced by exponential smoothing over the forecasting horizons of 24 hours and one week. Nevertheless, over the horizon of two weeks, the Diebold-Mariano test does not reveal any statistically significant differences between forecasts produced by a neural network and the model of exponential smoothing. We can also see that SARIMA outperforms seasonal exponential smoothing independently of a forecasting horizon. Therefore, in this particular case, it is reasonable to select the SARIMA model for further forecasting. It is a simpler and much less time-consuming method as compared to non-linear neural networks but provides relatively the same preciseness of forecasts.

Regarding other analysed time series, in most cases the comparison of forecasts produced by neural networks and linear models did not reveal any statistically significant differences.

Table 4.2. Standard estimates of the quality of pseudo-forecasts (forecasting horizon =1344 observations or 14 days)

Models \ Parameters	RMSE	MAE	MAPE, %
Neural Network	2.34	1.87	25.91
SARIMA	2.18	1.76	24.45
Seasonal Exponential Smoothing	2.30	1.75	20.48

Table 4.3. The evaluation of statistically significant differences between final pseudo-forecasts by means of the Diebold- Mariano test

Models \ Forecasting Horizon	96 obs. (24 h)		672 obs. (7 days)		1344 obs. (14 days)	
	DM	p_{DM}	DM	p_{DM}	DM	p_{DM}
Neural Network vs. SARIMA	-0.44	0.67	0.80	0.42	-4.83	0.00
Neural Network vs. Seasonal Exponential Smoothing	3.95	0.00	6.05	0.00	-0.75	0.45
SARIMA vs. Seasonal Exponential Smoothing	3.58	0.00	6.95	0.00	3.02	0.00

Notes: DM – the Diebold-Mariano statistics, p_{DM} – the significance level of a DM statistics

Conclusions

Both traditional linear methods and neural methods are accurate in producing short-term forecasts of traditional telephone traffic and packet-switched traffic. The results of the research show that in most cases the differences in quality between forecasts of network traffic produced by neural networks and linear models are not statistically significant. Therefore, contrary to popular belief, the use of such complicated and time-consuming methods as neural networks is not always reasonable.

It is important to keep in mind that the strong influence of fractal nature of packet-switched traffic is apparent only for the measurements taken on a very large-scale, usually over the periods up to 5–15 minutes. If according to the ITU-T recommendations the measurements of real network traffic are averaged over largest periods, the seasonal variations (due to the human behaviour) and monotonous trends (due to the influence of technical progress) are usually becoming those factors which affect the statistical properties of packet-switched traffic to a greater extent than self-similarity. Despite the fact that traffic traces can still poses the property of some "burstiness", the influence of long-range dependence is usually weakened. In this case, linear models can be applied with much success as well.

In the course of the research it was also revealed that a neural network can model and forecast seasonal time series without prior deseasonalization. In this case the most important parameter to define is the size of the input window which has to be equal to the largest period of a seasonal component. The task of forecasting network traffic incorporating periodic fluctuations requires focusing on the seasonal modifications of linear models as well. Just as in the case of neural networks, the correct identification of the periods of seasonal components is important for successful modelling and forecasting.

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Received on the 1st of December, 2009

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 29-34
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STOCHASTIC MODELS OF DATA FLOWS IN THE TELECOMMUNICATION NETWORKS

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One of the successful applications of the stochastic models in engineering lies in the field of telecommunications. There are several branches of telecommunications that use different types of stochastic models. The study of multivariate character of the telecommunication processes is an important aspect for many applications. The aim of the given paper is to overview the use of BMAP-flows in stochastic queueing systems.

The BMAP-flow was described in detail and explained the importance of the generating function for this flow. The family of frequently used by researchers BMAP-flows is considered: Markovian Arrival Process (MAP), Markov-Modulated Poisson Process (MMPP) and PH – Phase Type process (PH).

Keywords: *Poisson flow, Markov's chains, stochastic queueing systems*

1. Introduction

The Poisson flow is very significant for the stochastic queueing systems theory [1, 2]. If the interarrival distribution of the packets can be modelled using an independent and identically distributed exponential distribution, then the packet arrival process can be characterized as a Poisson process with parameter λ, where λ is the mean arrival rate (in the terms of number of packets per unit time). I.e. if λ – is a parameter of flow, then $P\{\xi < t\} = 1 - e^{-\lambda t}$. This fact essentially simplifies the analysis of queueing system, since exponential distribution has the property of the absence of after-effects forgetfulness: $P\{\xi < t + \tau \mid \xi \geq \tau\} = P\{\xi < t\}$, this fact releases us from necessity to look after the time.

If we investigate stochastic model with the arbitrary distribution of service time, the popular mathematical apparatus is embedded into Markov's chains. The important stage of using this method is finding the distribution of a number of the queries arriving at the system during the service time of one query. The probability of the arrival of *k* queries of the stationary Poisson process during the time *t* is calculated so, that: $\frac{(\lambda t)^k}{k!} e^{-\lambda t}, k \geq 0$. Then the probability of the arrival of k queries during the service time that distributed as *B(t)*, equals to:

$$\int_0^\infty \frac{(\lambda k)^k}{k!} e^{-\lambda t} db(t). \tag{1}$$

The generating function of these probabilities looks like as follows:

$$\int_0^\infty e^{-\lambda(1-z)} dB(t) = \beta(\lambda(1-z)), \tag{2}$$

where $\beta(s) = \int_0^\infty e^{-st} dB(t)$ – Laplace-Stieltjes transformation of service time distribution.

During the investigation of the stochastic queueing model with the stationary Poisson flows the function $\beta(\lambda(1-z))$ plays an important role, because many characteristics of these models manage to be obtained in the terms of this function. As an illustration the Pollachek-Hinchin formula for generating function $\Pi(z)$ of number of queries in M/G/1 system at the moments of the termination of queries service and at any moments of time will be used:

$$\Pi(z) = \frac{(1-\rho)(\beta(\lambda(1-z)))}{\beta(\lambda(1-z)) - z}, \rho = \lambda b_1, b_1 = \int_0^\infty t dB(t). \tag{3}$$

2. Characteristics of BMAP -flows

However, the real data flows in modern telecommunication networks are rather far from the stationary. They are neither stationary, nor ordinary, and nor the flows without absence of after-effects forgetfulness. The problem of the exact calculation of the characteristics of the queueing systems of such real flows has demanded the creation of the suitable mathematical model of these flows. On the one hand, this model should describe the real flows very well. On the other hand, it would be desirable, that such a model allowed receiving the analytical results at the calculation of the characteristics of the system in the simplest and elegant form.

The result of more than ten years' work of the researchers of many countries was expressed in such mathematical model in the form of the BMAP (Batch Markovian Arrival Process) flow, whose description had appeared in the works of Lucantoni (the company AT&T Bell Laboratories, USA) in 1991.

The following possible interpretation of the stationary Poisson flow is used as a starting point for BMAP introduction. There is a Markovian chain with continuous time. The chain has one state. It's holding time in this state has the exponential distribution with λ parameter. At the moment when this holding comes to an end, the chain jumps in the same condition, and the demand of flow is generated.

As we wish to have a model of a flow with the changing intensity, we will assume now that we have the Markovian chain ν_t with continuous time and with space of states *{0,1,...,W}*. This process is called the operating process of BMAP flow. The holding time of process in state ν has the exponential distribution with the parameter λ_ν, where $\nu = \overline{0,W}.$ After holding in the state ν comes to an end, the process ν_t jumps to the other state. With the set probability $p_k(\nu,\nu')$ the new state of process ν_t becomes a state ν', and the batch of *k* queries of BMAP-flow will be generated. It is supposed, that jump from a state ν in the same state without generation of queries is impossible, i.e. $p_0(\nu,\nu')=0.$ Of course, it is supposed that probabilities satisfy the normalization requirement:

$$\sum_{k=0}^{\infty}\sum_{\nu'=0}^{W} p_k(\nu,\nu') = 1 \text{ for } \nu = \overline{0,W}\,. \tag{4}$$

Thus, the BMAP-flow is completely characterised by the dimension $W+1$ of operating process, by the intensities λ_ν of the holding times of this process in its states and by a set of probabilities $p_k(\nu,\nu'),\ \nu,\nu' = \overline{0,W},\ k \geq 0$.

Lucantoni has propounded to storing this information in the form of a series of matrices D_k, $k \geq 0$, with the dimension *(W + 1) x (W + 1)*, defined as follows $(D_k)_{\nu,\nu'}$ – (ν,ν') element of matrice D_k such that:

$$(D_k)_{\nu,\nu'} = \lambda_\nu p_k(\nu,\nu'),\ \nu,\nu' = \overline{0,W},\ k \geq 1, \tag{5}$$

$$(D_0)_{\nu,\nu'} = \begin{cases} \lambda_\nu p_0(\nu,\nu'), \nu \neq \nu', \nu,\nu' = \overline{0,W}, \\ -\lambda_\nu, \nu = \nu', \nu = \overline{0,W}. \end{cases} \tag{6}$$

It is easy to see that elements of matrices are the intensities of transition of the process accompanied by the generation of queries. Off-diagonal elements of a matrix D_0 have a similar meaning, and diagonal elements of matrix D_0 are, taken with inverse sign, intensities of process ν_t leaving its states. As the sequence of matrices can be infinite, the information about BMAP-flow appears convenient to be stored in a form of their generating function of matrix:

$$D(z) = \sum_{k=0}^{\infty} D_k z^k, |z| < 1\,. \tag{7}$$

Let's note that the value of this generating function is the infinitesimal generator of the operating process ν_t. I.e. the row vector θ of stationary probabilities of this process is defined as the solution of system of the linear algebraic equations such that:

$$\theta D(1) = \vec{0}\,,\ \theta\mathbf{1} = 1. \tag{8}$$

Here, $\vec{0}$ – the row vector with the dimension W + 1 consisting of zero, but **1** – the column vector of the same dimension consisting of ones. The true relation is $D(1)\ \mathbf{1} = \vec{0}^T$.

Let's note that diagonal elements of matrix D_0 dominate on strings. According to the Adamar's theorem, it entails nonsingularity of this matrix. Let's note also that the matrix is stable and all its eigenvalues have a negative real part. The matrix D_0 is nonnegative.

The elements of matrices D_k define the instantaneous intensities of queries generation. The average intensity of BMAP-flow is defined by:

$$\lambda = \theta D^{'}(z)\,|_{z=1}\,\mathbf{1}. \tag{9}$$

As it is clear from BMAP-flow definition it is not stationary, ordinary and it does not have an absence of after-effects forgetfulness. However, it appears that somewhat this flow is a matrix analogue of stationary Poisson flow. Let's explain this fact.

Let's try to find the probabilities of arrival of *k* queries in BMAP-flow on a time interval *(0,t)*. This probability significantly depends on a state of operating process of BMAP-flow in a moment 0.

Let's consider process *N(t)*, that is a number of queries which have arrived for time *t* and conditional probabilities

$$P_{\nu,\nu^{'}}(n,t) = P\{N(t) = n, \nu_t = \nu^{'} \mid \nu_0 = \nu\}\,. \tag{10}$$

Using the Kolmogorov's method of composition and solution of the equations for Markovian chains with continuous time (*Δt*-method), it is simple to receive the system of the difference equations, and then the differential equations for probabilities $P_{\nu,\nu^{'}}(n,t)$, that is,

$$P_{\nu,\nu^{'}}(n,t) = -\lambda_{\nu^{'}} P_{\nu,\nu^{'}}(n,t) + \sum_{k=0}^{n}\sum_{r=0}^{W} P_{\nu,r}(k,t)\lambda_r\, p_{n-k}(r,\nu^{'})\,,\ \nu,\nu^{'} = \overline{0,W}\,. \tag{11}$$

Denoting a matrix $P(n,t) = \| P_{\nu,\nu^{'}}(n,t) \|_{\nu,\nu^{'} = \overline{0,W}}$, we will rewrite the system in a matrix form:

$$P(n,t) = \sum_{k=0}^{n} P(k,t) D_{n-k}\,, n \ge 0\,. \tag{12}$$

Let's define the matrix generating function

$$P(z,t) = \sum_{n=0}^{\infty} P(n,t) z^n\,, |\,z\,| < 1\,. \tag{13}$$

Multiplying the equations of system by appropriate powers and summarising them, we will receive the homogeneous linear differential equation

$$\frac{\partial P(z,t)}{\partial t} = P(z,t) D(z)\,. \tag{14}$$

As it is natural to assume that $P(0,0) = I$, where I is the identical matrix of dimension *(W + 1) x (W + 1)*, then the solution of the differential equation with this initial condition will look like

$$P(z,t) = e^{D(z)t}\,. \tag{15}$$

Here $e^{D(z)t}$ is the matrix exponent, which can be calculated with a power series or by means of spectral representation of functions from matrixes.

From (6) follows in particular, that the probability of 0 queries arrival at time t with appropriate transitions of process ν_t at time t looks like:

$$P(0,t) = e^{D_0 t}, \tag{16}$$

but the probability of that the first query after the moment 0 will arrive during the moment *t* as a part of group of *k* queries, is equal to

$$e^{D_0 t} D_k dt. \tag{17}$$

Comparing the formula (6) to the formula $p(z,t) = e^{\lambda(z-1)t}$ for the generating function of the stationary Poisson flow, we see that the BMAP-flow is a matrix analogue of the stationary Poisson flow, where the expression $\lambda(z-1)$ role is played by a matrix *D(z)*.

Let's note that the class of BMAP-flows has similarity with the stationary Poisson flow and with respect to superposition and sifting operations.

3. Family of the BMAP-flows

The family of the BMAP-flows is closed with regard to the superposition and the randomised sifting operations that are similar to property of stationary Poisson flows.

The model of the BMAP-flow generalises many known models of flows. We will note some of them:

- MAP – Markovian Arrival Process. This flow differs from the BMAP-flow by that arrival of queries is admitted only by ones.
- MMMP – Markov Modulated Poisson Process. It is a special case of MAP-flow, whose matrices D_0 and D_1 are defined as: $D_1 = \Lambda, D_0 = \Phi(P-I) - \Lambda$, where $\Lambda = diag\{\lambda_0,...,\lambda_W\}$, i.e. the diagonal matrix with the diagonal elements λ_ν, $\nu = \overline{0,W}$, $\Phi = diag\{\varphi_0,...,\varphi_W\}$, P – the stochastic matrix.

The MMPP is the MAP-flow, which has the transparent physical interpretation that is as follows. There are *(W+1)* possible levels of the intensity of arrival flow. On the level ν the flow behaves as an ordinary stationary Poisson flow with the intensity $\lambda_\nu, \nu = \overline{0,W}$. The level ν of the flow is saved during the time having exponential distribution with parameter φ_ν. After that with probability $p_{\nu,\nu'}$ the flow jumps to the ν' level. Here $p_{\nu,\nu'} = (P)_{\nu,\nu'} - (\nu,\nu')th$ *element of matrix P,* $\nu,\nu' = \overline{0,W}$.

The MMPP-flow describes well many real flows, for example, the flows in telephone networks. The special case of the MMPP-flow is the Switched Poisson Process (SPP), which has two possible levels of intensity, and on one of these levels the intensity of the flow is equal to zero.

The PH - Phase Type flow. It is the other popular variety of the MAP-flow. The flow is set by the pair (α, R), where α – a column vector and R – a square matrix. This flow is recurrent, unlike the common MAP-flow and the MMPP-flow, in particular. The distribution function of durations of intervals between the moments of queries arrival looks like

$$F(x) = 1 - \alpha^T e^{Rx}\mathbf{1}, x > 0. \tag{18}$$

The random variable having such distribution function allows probable interpretation as time of some particle in the graph with $W+1$ nodes.

The special case of the PH-flow is the class of Erlang flows E_k, for which

$$F(x) = \int_0^x \frac{\lambda(\lambda\tau)^{k-1}}{(k-1)!} e^{-\lambda\tau} d\tau, x > 0, \lambda > 0, k \geq 1; \tag{19}$$

the class H_k of hyper-exponential flows, for which

$$F(x) = \sum_{i=1}^{k} q_i (1 - e^{-\lambda_i x}), \ q_i \geq 0, \ i = \overline{1,k}, \ \sum_{i=1}^{k} q_i = 1; \tag{20}$$

and the classes of Hyper-Erlang, generalised Hyper-Erlang flows and other flows.

1) BMMPP – Batch Markovian Modulated Poisson Process is the special case of BMAP-flow and generalisation of MMPP-flow in the case of batch arrivals of queries. Thus matrices $D_k, k \geq 0$ are defined as follows:

$$D_0 = \Phi(P - I) - \Lambda, \ D_k = \gamma_k \Lambda, \ \gamma_k \geq 0, \ k \geq 1, \ \sum_{k=1}^{\infty} \gamma_k = 1. \tag{21}$$

Here the variables γ_k are the probabilities that the arrived batch of queries has the size k. This flow generalises the so-called batch stationary Poisson flow of arrival of queries batch with the intensity λ with the distribution γ_k of $k \geq 1$ queries number in the arrived batch. The generating function of this flow is $e^{\lambda(\gamma(z)-1)t}$, where

$$\gamma(z) = \sum_{k=1}^{\infty} \gamma_k z^k . \tag{22}$$

The other examples of special cases of flows, including batch Poisson flows with the correlated sizes of batches, renewal PH-flow, Newts point process etc., can be found in the papers by Lukantoni.

The stationary Poisson flow is the special case of all above-cited flows. It turned out from the BMAP-flow, if we assume $W = 0, D_0 = -\lambda, D_1 = \lambda, D_k = 0, k \geq 1$.

During the investigation of queueing systems with BMAP-flows by a method of embedded Markov chains it is important to know how to calculate the matrix generating function $\int_0^\infty e^{D(z)t} dB(t)$ of queries number that have arrived at the system during a service time having the arbitrary distribution function *B(t)*. This generating function is analogue to the generating function $\beta(\lambda(z-1)) = \int_0^\infty e^{-\lambda(1-z)t} dB(t)$ of queries number, arrived at the system in stationary Poisson flow during a service time with the distribution *B(t)*. We can use this notation:

$$\beta(-D(z)) = \int_0^\infty e^{D(z)t} dB(t). \tag{23}$$

During the investigation of the systems with BMAP-flows the matrix function $\beta(-D(z))$ plays the same important role, as the scalar function $\beta(\lambda(1-z))$ during the investigation of queueing systems with Poisson flows.

At the fixed form of distribution function *B(t)* the matrix $\beta(-D(z))$ is easily calculated by means of an expansion method on a matrix spectrum. In the following example we will also use the matrix $\beta(-D(z))$ expansion coefficients into Macloren's series.

$$\beta(-D(z)) = \sum_{l=0}^{\infty} \Omega_l z^l . \tag{24}$$

The matrix elements $\Omega_l, l \geq 0$ have a concrete physical meaning: $(r,\nu)th$ element of matrix Ω_l is a probability that during service time of query will arrive *l* queries at the system and operating process ν_t of BMAP-flow will transit in a state ν on condition that at the beginning of service process was in state *r*.

In some special cases the matrices defining expansion

$$\sum_{l=0}^{\infty} \Omega_l z^l = \int_0^{\infty} e^{D(z)t} dB(t)\,, \tag{25}$$

can be calculated in an explicit form.

4. Example

It is possible to apply the following approach. [2] If the arrival flow is the MMPP-flow [2] set by matrices $D_1 = \Lambda, D_0 = -\Lambda + H$, where $H = \Phi(P - I), D_k = 0, k \geq 2$, but the service time has the Hyper-Erlang distribution, i.e.

$$B(t) = \sum_{i=1}^{k} q_i \int_0^t \frac{\gamma_i (\gamma_i \tau)^{h_i - 1}}{(h_i - 1)!} e^{-\gamma_i \tau} d\tau\,, \tag{26}$$

$$q_i \geq 0\,,\ \sum_{i=1}^{k} q_i = 1\,,\ \gamma_i > 0\,,\ h_i \geq 1\,,\ i = \overline{1,k}\,,\ k \geq 1,$$

so

$$\int_0^{\infty} e^{D(z)t} dB(t) = \sum_{i=1}^{k} q_i (\gamma_i)^{h_i} (\gamma I - H + \Lambda - \Lambda z)^{-h_i} \tag{27}$$

and

$$\Omega_l = \sum_{i=1}^{k} q_i \gamma_i^{h_i} D_l^{(i)}\,,\ l \geq 0\,, \tag{28}$$

where

$$D_l^{(i)} = \sum_{(n_1,\ldots,n_{h_i}) \in N_{h_i}^{(l)}} \Gamma_{n_{h_i}}^{(i)} \prod_{r=1}^{h_i - 1} \Gamma_{n_{h_i} - n_{h_i - r + 1}}^{(i)}\,, \tag{29}$$

$$\Gamma_l^{(i)} = (S_i \Lambda)^l S_i\,,\ S_i = (\gamma_i I - H + \Lambda)^{-1}\,, N_{h_i}^{(l)} = \{(n_1,\ldots,n_{h_i}) : l = n_1 \geq n_2 \geq \ldots \geq n_{h_i} \geq 0\}\,.$$

Conclusions

The paper described the BMAP-flow and explained the importance of generating function for this flow. Some properties of matrix $D(z)$ in the points $z = 0$ and $z = 1$ were considered and the closure of the class of BMAP-flows concerning operations of superposition and the elementary randomised sifting were established. The known special cases of the BMAP-flow were shortly enumerated. The problem of calculation of matrices Ω_l – expansion coefficients of Laplace-Stieltjes matrix transformation $\int_0^{\infty} e^{D(z)t} dB(t)$ to Macloren's series was revealed.

The experiments of some foreign authors have shown that the BMAP-flow can describe well the behaviour of real flows in the telecommunication networks.

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Received on the 1st of December, 2009

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 35–39
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ALGORITHM TO CALCULATE STATIONARY DISTRIBUTION FOR DUPLEX POLLING SYSTEM

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We consider the duplex system presented by two independent servers and multiple M/M/1-type queues to model the operation of cyclic polling systems in very high throughput wireless mesh-networks. Each server polls its own group of queues. Some queues are common, i.e. accessible for service by both servers. To obtain the joint queue length distribution, we analyse the Markov chain describing the system states by means of the power-series algorithm which is a tool for numerical evaluation of the performance of a broad class of multi-queue models.

Keywords: *wireless mesh-network, duplex system, polling system, power-series algorithm.*

1. Introduction

Duplex polling system is a queueing system presented by two independent servers and N queues of M/M/1-type. Each server polls its own group of customers but some queues are common, i.e. can be visited by each server. We suppose that a common queue is not allowed to be served by both servers simultaneously. If a server having finished a switchover to a common queue finds the other server working there it immediately leaves the queue and switches to the next one (correspondingly to its polling cycle).

The model of duplex polling system finds an application in Russian very high throughput broadband wireless network [1]. Because of the high popularity and wide spread of the innovative type of wireless networks – mesh networks [2, 3], numerous existing techniques are to be modified to be effective in mesh. The polling mechanism introduced in this paper is developed for the novel type of very high throughput broadband wireless mesh network, with throughput not less than 1 gigabit per second. There are some mesh-specific network traits: data could spread in the network by various directions, i.e. a queue could be served by more than one server. High density of mesh points in the network makes it possible for each queue to be served by several servers as well. Nodes with several frequency output are to be used in the very high throughput mesh network, which eliminates collisions in case when more than one server try to serve a queue and polling is accomplished in a duplex mode.

The same approach could be used in cellular and other networks with point coordination function. It should be mentioned that implementation of the mechanism won't be too complicated or expensive since, for one, in cdma2000 already realized an opportunity of simultaneous connection between subscriber station with one frequency output and several servers. The technique is used for soft handoff [4]. Even greater profit could be gained in duplex mode using two or more frequency outputs.

Note that the models of polling systems are very difficult to be analysed. Most of them are intractable of exact analysis by means of existing mathematical techniques. And even if a polling system allows an exact analysis, the analysis still does not always lead to manageable expressions for performance measures such as mean waiting times. Because of this, several numerical techniques have been developed. Numerical techniques, unlike analytical methods, do not give an exact expression for the performance measures as a function of the system parameters, but they can be used to numerically compute performance measures for a given system [5].

In this paper we present the power-series algorithm to obtain the distribution of the joint queue length and positions of the servers in duplex polling system. The power-series technique is a tool for the numerical evaluation and optimisation of the performance of a broad class of stochastic models of multiple queues and a single (multiple) server in light traffic conditions [6, 7].

The paper is organized as follows. In Section 2 we give the model description. In Section 3 we introduce a continuous time Markov chain to describe the system's behaviour and present the balance equations for the stationary state probabilities. In Section 4, these probabilities are expressed in the form of power-series and in Section 5 we elaborate the algorithm to calculate the power-series coefficients. The conclusions are made in Section 6.

2. Mathematical Model

We consider the model presented by N queues of M/M/1-type and two independent servers. The model scheme is shown on Figure 1.

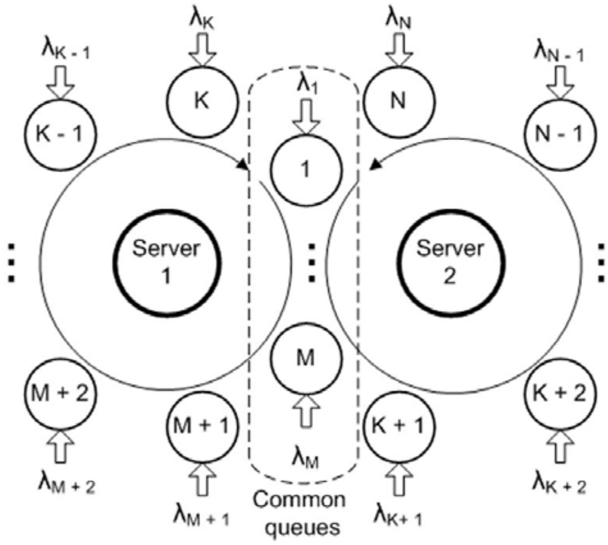

Figure 1. Duplex system of cyclic polling

The first M queues ($1 \le M \le N$) are common, i.e. they are accessible for both servers. The queues M+1 through K ($M \le K \le N$) can be served just by the first server, the rest of queues K+1 through N are visited by the second one.

Denote by $I = \{1,...,M\}$, $I_1 = \{M+1,...,K\}$, $I_2 = \{K+1,...,N\}$. Also let $N_1 = K$ and $N_2 = M + N - K$ denote the number of queues in the first and second systems, respectively.

We suppose that queues with numbers from the set $I \bigcup I_1$ ($I \bigcup I_2$) and the first (second) server form the first (second) polling system. Within the system j (j = 1, 2), a server polls (visits) queues cyclically. After it departs from queue (i–1), it switches to queue i (prepares to serve it) during the time exponentially distributed with parameter s_i, $i \in I \bigcup I_j$. Here we assume that queue numbers 0 and K are K and 1 for j = 1 and numbers 0, K, M + 1 and N + 1 are N, M, K + 1 and 1, respectively, for j = 2.

The moment when server finishes switching to the queue is referred to as *polling moment*. It is assumed that the server has no information on the other server position (which queue of the other system is visited). The server is able just to check if the queue it is polling is being served by the other server or not. In case when the other server is working at the queue, the server immediately departs from the queue and starts switching to the next one. Otherwise, the server starts serving customers (if available) until the queue becomes empty (the service discipline is exhaustive). For both servers, the customer service time is exponentially distributed with parameter μ.

For a server, the polling of a queue is supposed to be *successful* if it finds no other server working at this queue and *unsuccessful* otherwise.

The input of customer to queue i is Poisson with parameter λ_i. The waiting space is unlimited. Denote by $\rho_i = \dfrac{\lambda_i}{\mu_i}$ the traffic intensity to queue i, $i \in I \bigcup I_1 \bigcup I_2$.

The necessary and sufficient conditions for the system to be stable are (see [8])

$$\sum_{i \in I} \rho_i^{(1)} + g^{(1)} < 1, \quad \sum_{i \in I} \rho_i^{(2)} + g^{(2)} < 1, \tag{1}$$

where $\rho_i^{(j)}$ is the mean fraction of time during which server j works at common queue i, $g^{(j)} = \sum_{i \in I_j} \rho_i$ is the total traffic intensity to queues, which are not common in system j, j = 1,2. Let the condition (1) hold.

The values $\rho_i^{(j)}$, j = 1,2, $i \in I$, are obtained in [9] as long as the mean time between successful server's visits to a common queue and probability of successful polling of a common queue.

In [9] we also presented the mean value analysis to obtain the mean waiting time in duplex polling system. And in this paper, we apply the so-called power-series expansions to obtain the probabilities of a given state allowing calculation the performance characteristics.

3. Markov Process Describing the System's Behaviour

Consider the (N+2)-dimensional process
$\xi_t = (r_1(t), r_2(t), ..., r_N(t), n_1(t), n_2(t), s_1(t), s_2(t)), t \geq 0,$
where $r_m(t)$ is the number of customers at queue m at time t, $m = \overline{1, N}$; $n_l(t)$ is the number of queue the server l is attended at, $n_l(t) \in I \bigcup I_l$; $s_l(t)$ is the state of the server l at time t: $s_l(t) = 0$ if the server is switching to queue $n_l(t)$, $s_l(t) = 1$ if the server is working at the queue, l=1,2.
The process $\xi_t, t \geq 0$ is a continuous-time Markov chain describing the system's behaviour at time t.
Denote by $\bar{r} = (r_1, r_2, ..., r_N)$, $|\bar{r}| = r_1 + r_2 + ... + r_N$ and consider the stationary state probabilities

$$A_{ij}(\bar{r}) = \lim_{t\to\infty} P\{\bar{r}(t) = \bar{r}, n_1(t) = i, n_2(t) = j, s_1(t) = 0, s_2(t) = 0\},$$
$$B_{ij}(\bar{r}) = \lim_{t\to\infty} P\{\bar{r}(t) = \bar{r}, n_1(t) = i, n_2(t) = j, s_1(t) = 1, s_2(t) = 0\},$$
$$C_{ij}(\bar{r}) = \lim_{t\to\infty} P\{\bar{r}(t) = \bar{r}, n_1(t) = i, n_2(t) = j, s_1(t) = 0, s_2(t) = 1\},$$
$$X_{ij}(\bar{r}) = \lim_{t\to\infty} P\{\bar{r}(t) = \bar{r}, n_1(t) = i, n_2(t) = j, s_1(t) = 1, s_2(t) = 1\}, i \neq j.$$

Let also $\bar{0} = (0,...,0)$, $\bar{e}_j$ be a null vector the j-th entry equal to 1 and $\lambda = \sum_{i=1}^{N} \lambda_i$.

The stationary state probabilities satisfy the following balance equations:

$$(\lambda + s_i + s_j) A_{ij}(\bar{0}) = A_{i-1j}(\bar{0}) s_{i-1} + A_{ij-1}(\bar{0}) s_{j-1} + B_{i-1j}(\bar{e}_{i-1})\mu + C_{ij-1}(\bar{e}_{j-1})\mu, \tag{2}$$

$$\begin{aligned}(\lambda + s_i + s_j) A_{ij}(\bar{r}) &= \sum_{m=1}^{N} \lambda_m A_{ij}(\bar{r} - \bar{e}_m) + \left[\mu B_{i-1j}(\bar{r} + \bar{e}_{i-1}) + s_{i-1} A_{i-1j}(\bar{r})\right] I_{\{r_{i-1}=0\}} + \\ &+ \left[\mu C_{ij-1}(\bar{r} + \bar{e}_{j-1}) + s_{j-1} A_{ij-1}(\bar{r})\right] I_{\{r_{j-1}=0\}},\end{aligned} \tag{3}$$

$$\begin{aligned}(\lambda + \mu + s_j) B_{ij}(\bar{r}) &= \sum_{m=1}^{N} \lambda_m B_{ij}(\bar{r} - \bar{e}_m) I_{\{r_m>0 if\, m\neq i\, and\, r_m>1\, if\, m=i\}} + s_i A_{ij}(\bar{r}) + \\ &+ s_i B_{ii}(\bar{r}) I_{\{j=i+1, i\in I\}} + \left[\mu X_{ij-1}(\bar{r} + \bar{e}_{j-1}) + s_{j-1} B_{ij-1}(\bar{r})\right] I_{\{r_{j-1}=0\}}, \quad r_i > 0, r_m \geq 0 \ for\ m \neq i,\end{aligned} \tag{4}$$

$$\begin{aligned}(\lambda + \mu + s_i) C_{ij}(\bar{r}) &= \sum_{m=1}^{N} \lambda_m C_{ij}(\bar{r} - \bar{e}_m) I_{\{r_m>0 if\, m\neq j\, and\, r_m>1\, if\, m=j\}} + s_j A_{ij}(\bar{r}) + \\ &+ s_j C_{jj}(\bar{r}) I_{\{i=j+1, j\in I\}} + \left[\mu X_{i-1j}(\bar{r} + \bar{e}_{i-1}) + s_{i-1} C_{i-1j}(\bar{r})\right] I_{\{r_{i-1}=0\}}, \quad r_j > 0, r_m \geq 0 \ for\ m \neq j,\end{aligned} \tag{5}$$

$$\begin{aligned}(\lambda + 2\mu) X_{ij}(\bar{r}) &= \sum_{m=1}^{N} \lambda_m X_{ij}(\bar{r} - \bar{e}_m) I_{\{r_m>0 if\, m\notin\{i,j\} and\, r_m>1\, if\, m\in\{i,j\}\}} + s_i C_{ij}(\bar{r}) + \\ &+ s_j B_{ij}(\bar{r}) + \mu X_{ij}(\bar{r} + \bar{e}_i) + \mu X_{ij}(\bar{r} + \bar{e}_j), \quad r_i > 0, r_j > 0, r_m \geq 0 \ for\ m \notin \{i, j\},\end{aligned} \tag{6}$$

where $I_{\{E\}}$ is the indicator function of the event E.

In the next Section, we show how the balance equations (2)–(6) can be solved by applying of the power-series expansions to the stationary state probabilities in case of light traffic [6, 7].

4. Power-series Expansions for the Stationary State Probabilities

The basic idea of the power-series expansions is to express the stationary state probabilities as power series of $\rho = \sum_{i=1}^{N} \rho_i$ and to derive a computation scheme to calculate the coefficients of the power-series. Express the input intensities λ_i in terms of ρ as $\lambda_i = \tau_i \rho$, $i = \overline{1, N}$ and consider the following power-series expansions:

$$A_{ij}(\bar{r}) = \rho^{|\bar{r}|}\sum_{k=0}^{\infty}\rho^k a_{ij}(k,\bar{r}),$$
$$B_{ij}(\bar{r}) = \rho^{|\bar{r}|}\sum_{k=0}^{\infty}\rho^k b_{ij}(k,\bar{r}),$$
$$C_{ij}(\bar{r}) = \rho^{|\bar{r}|}\sum_{k=0}^{\infty}\rho^k c_{ij}(k,\bar{r}),$$
$$X_{ij}(\bar{r}) = \rho^{|\bar{r}|}\sum_{k=0}^{\infty}\rho^k x_{ij}(k,\bar{r}). \quad (7)$$

Replacing λ_i by $\tau_i\rho$ and substituting the expansions (7) into balance equations (2)–(6) with further equating the corresponding powers of ρ yield the following relations between the coefficients $a_{ij}(k,\bar{r})$, $b_{ij}(k,\bar{r})$, $c_{ij}(k,\bar{r})$ and $x_{ij}(k,\bar{r})$ of the power-series:

$$(s_i + s_j)a_{ij}(0,\bar{0}) = a_{i-1j}(0,\bar{0})s_{i-1} + a_{ij-1}(0,\bar{0})s_{j-1}, \quad (8)$$

$$(s_i + s_j)a_{ij}(k,\bar{0}) - a_{i-1j}(k,\bar{0})s_{i-1} - a_{ij-1}(k,\bar{0})s_{j-1} =$$
$$= -\tau a_{ij}(k-1,\bar{0}) + b_{i-1j}(k-1,\bar{e}_{i-1})\mu + c_{ij-1}(k-1,\bar{e}_{j-1})\mu,\ \ k \ge 1, \quad (9)$$

$$(s_i + s_j)a_{ij}(k,\bar{r}) - a_{i-1j}(k,\bar{r})s_{i-1}I_{\{r_{i-1}=0\}} - a_{ij-1}(k,\bar{r})s_{j-1}I_{\{r_{j-1}=0\}} = -\tau a_{ij}(k-1,\bar{r}) +$$
$$+\sum_{m=1}^{N}\tau_m a_{ij}(k,\bar{r}-\bar{e}_m) + b_{i-1j}(k-1,\bar{r}+\bar{e}_{i-1})\mu I_{\{r_{i-1}=0\}} + c_{ij-1}(k-1,\bar{r}+\bar{e}_{j-1})\mu I_{\{r_{j-1}=0\}}, \quad (10)$$

$$(\mu + s_j)b_{ij}(k,\bar{r}) - s_i b_{ii}(k,\bar{r})I_{\{j=i+1, i\in I\}} - s_{j-1}b_{ij-1}(k,\bar{r})I_{\{r_{j-1}=0\}} = -\tau b_{ij}(k-1,\bar{r}) + s_i a_{ij}(k,\bar{r}) +$$
$$+\sum_{m=1}^{N}\tau_m b_{ij}(k,\bar{r}-\bar{e}_m)I_{\{r_m>0 if\ m\ne i\ and\ r_m>1\ if\ m=i\}} + \mu x_{ij-1}(k-1,\bar{r}+\bar{e}_{j-1})I_{\{r_{j-1}=0\}}, \quad (11)$$

$$(\mu + s_i)c_{ij}(k,\bar{r}) - s_j c_{jj}(k,\bar{r})I_{\{i=j+1, j\in I\}} - s_{i-1}c_{i-1j}(k,\bar{r}) = -\tau c_{ij}(k-1,\bar{r}) +$$
$$+\sum_{m=1}^{N}\tau_m c_{ij}(k,\bar{r}-\bar{e}_m)I_{\{r_m>0 if\ m\ne j\ and\ r_m>1\ if\ m=j\}} + s_j a_{ij}(k,\bar{r}) + \mu x_{i-1j}(k-1,\bar{r}+\bar{e}_{i-1})I_{\{r_{i-1}=0\}}, \quad (12)$$

$$2\mu x_{ij}(k,\bar{r}) = -\tau x_{ij}(k-1,\bar{r}) + \sum_{m=1}^{N}\tau_m x_{ij}(k,\bar{r}-\bar{e}_m)I_{\{r_m>0 if\ m\notin\{i,j\}\ and\ r_m>1\ if\ m\in\{i,j\}\}} + s_i c_{ij}(k,\bar{r}) +$$
$$+ s_j b_{ij}(k,\bar{r}) + \mu x_{ij}(k-1,\bar{r}+\bar{e}_i) + \mu x_{ij}(k-1,\bar{r}+\bar{e}_j), \quad r_i>0, r_j>0, r_m \ge 0\ for\ m\notin\{i,j\}, \quad (13)$$

with

$\tau = \sum_{i=1}^{N}\tau_i$.

$$\sum_{i\in I\cup I_1}\sum_{j\in I\cup I_2}\sum_{\bar{r}\ge\bar{0}}\left(A_{ij}(\bar{r}) + B_{ij}(\bar{r})I_{\{r_i>0\}} + C_{ij}(\bar{r})I_{\{r_j>0\}} + X_{ij}(\bar{r})I_{\{r_i>0, r_j>0, i\ne j\}}\right) = 1$$

To complete the recursive scheme, we use the law of total probability that can be rewritten in the form of relations for the power-series coefficients

$$\sum_{i\in I\cup I_1}\sum_{j\in I\cup I_2}a_{ij}(0,\bar{0}) = 1, \quad (14)$$

$$\sum_{i\in I\cup I_1}\sum_{j\in I\cup I_2}\sum_{\bar{r}\ge\bar{0}}\left(a_{ij}(k,\bar{r}) + b_{ij}(k,\bar{r})I_{\{r_i>0\}} + c_{ij}(k,\bar{r})I_{\{r_j>0\}} + x_{ij}(k,\bar{r})I_{\{r_i>0, r_j>0, i\ne j\}}\right) = 0. \quad (15)$$

Note that the relation (15) is used together with (7)–(8) to calculate the coefficients $a_{ij}(k,\bar{0}),\ i\in I\cup I_1$, $j\in I\cup I_2$ under the fixed level *m*:

$$\sum_{i\in I\cup I_1}\sum_{j\in I\cup I_2}a_{ij}(m,\bar{0}) = -\sum_{i\in I\cup I_1}\sum_{j\in I\cup I_2}\sum_{\substack{|\bar{r}|+k=m\\ k<m}}a_{ij}(k,\bar{r}) -$$
$$-\sum_{i\in I\cup I_1}\sum_{j\in I\cup I_2}\sum_{|\bar{r}|+k=m}\left[b_{ij}(k,\bar{r})I_{\{r_i>0\}} + c_{ij}(k,\bar{r})I_{\{r_j>0\}} + x_{ij}(k,\bar{r})I_{\{r_i>0, r_j>0, i\ne j\}}\right] = 0 \quad (16)$$

given that the coefficients in the right-hand side of (16) are calculated as shown in Section 5.

5. Algorithm to Calculate the Coefficients of the Power-Series Expansions

The algorithm to calculate the stationary state probabilities through their power-series expansions (7) is based on the recursive relations (8)–(13) and is described as follows:

1. Calculate $a_{ij}(0,\overline{0})$ as the solution of (8) where one of the equations is replaced with (14).
2. Fix level $m = 1$.
3. Calculate the coefficients $a_{ij}(k,\overline{r})$, $b_{ij}(k,\overline{r})$, $c_{ij}(k,\overline{r})$ and $x_{ij}(k,\overline{r})$, $i \in I \bigcup I_1$, $j \in I \bigcup I_2$ for all $\overline{r} = (r_1,...,r_N)$ and k so that $|\overline{r}| + k = m$:
   a. Set $k = 0$.
   b. Calculate $a_{ij}(k,\overline{r})$, $i \in I \bigcup I_1$, $j \in I \bigcup I_2$ as solution of the system (10) for all $\overline{r}$ such that $|\overline{r}| = m - k$.
   c. Use the same procedure to calculate sequentially the coefficients $b_{ij}(k,\overline{r})$, $c_{ij}(k,\overline{r})$ and $x_{ij}(k,\overline{r})$ from (11), (12) and (13).
   d. Set $k = k + 1$.
   e. Repeat the steps 3.b-3.d until $k = m$.
   f. Solve (9) for $a_{ij}(m,\overline{0})$, $i \in I \bigcup I_1$, $j \in I \bigcup I_2$ where one of the equations should be replaced by (16).
4. Set $m = m + 1$ and go to the step 3.

The algorithm is stopped when the coefficients of the power-series expansions are calculated with the necessary accuracy. Thus, using the formulas (7), we get the stationary state probabilities.

Conclusions

We have considered the duplex polling system with two servers and multiple queues of M/M/1-type. In this paper, it is shown how the stationary state probabilities of the Markov chain describing the system's behaviour can be obtained through the power-series expansions in case of light traffic.

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Received on the 1st of December, 2009

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 40–49
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SERVICE QUALITY INDICATOR AT RIGA INTERNATIONAL COACH TERMINAL

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The level of service in „Rīgas Starptautiskā Autoosta" is studied. This enterprise provides the international, intercity and regional trips. Recent studies on the role of buses and coaches seem to confirm the already excellent safety, environmental and social record of bus and coach transport. The main attention was paid to the analyses of quality of service and its components. The theory of linear composite indicator constructing and statistical methods are used for definition of weights of aggregation function. The model was done on the basis of the questionnaire results of transport experts.

The model constructed for a scalar quality indicator, allows comparing analyzed service for the services given by other companies, to estimate influence of particular quality indicators on the overall quality estimation and to simplify monitoring of quality indicators.

***Keywords**: bus terminal, quality of service, scalar indicator, weights, regression models, restrictions*

1. Introduction

The entry of Latvia in the common European market and the political integration of Latvia in the EU have forwarded qualitatively new requirements to passenger transportation – high mobility support, intermodality, passenger's comfort and rights support, and also, new requirements to interaction of transport and environment. When examining a human being and his/her needs as a central part of any system, all these requirements must be analyzed in interaction as a single whole.

"Rīgas Starptautiskā Autoosta" being a leader in the area of passenger bus transportation services in Latvia provides the international, intercity and regional trips. Recent studies on the role of buses and coaches seem to confirm the already excellent safety, environmental and social record of bus and coach transport [1]. In Latvia this mode of transport is in competition with railway (and private cars also) in Latvia that's why the quality of services are very important from the all points of view [2].

The problems of the service quality provided by a terminal have been considered by the paper's authors many times [3, 4, and 5]. The theoretical basis of the quality system in public transport might be presented in a form of a "quality loop" (Fig. 1), which components might be divided in two parts: customers-passengers and service providers-carriers. Expected Quality is the level of quality, which is required by the customer.

Targeted Quality is the level of quality that service provider or manager of mobile system is aiming to provide to the customers as a consequence of his understanding of the customer expectation. Delivered Quality is the level of quality effectively achieved in the provision of mobility services by the different components of system. Perceived Quality – the level of quality perceived by the user-customer [6].

The difference between the Expected Quality and Perceived Quality reflects a measure of the customer satisfaction. The difference between the Targeted Quality and Delivered Quality reflects problems with the service design or anything else connected with the provision of services. In our case the Perceived Quality on top level consists of two parts: the Perceived Quality, which is provided by the direct service provider (companies) and the Perceived Quality, which is provided by a terminal. In this research we pay attention to the second part the AS "Rīgas Autoosta" is responsible for. The complexity of this particular case research is connected with the fact that a customer often doesn't divide the Perceived Quality in two parts and estimates the Perceived Quality as a single whole (placing own part and carrier's part on AS "Rīgas Autoosta").

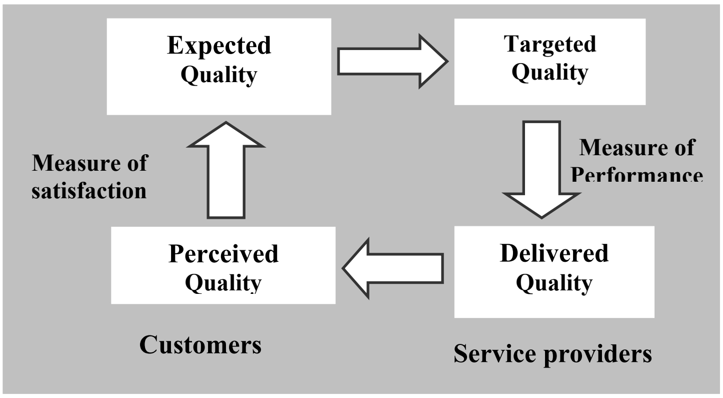

Figure 1. The parts of "Quality loop"

The main attention was paid to the analyses of Perceived quality of service and its components. When examine literature it becomes clear that it is no unique approach to measuring service quality. But, it is accepted that the quality of service is usually a function of several quality factors (attributes) and determining of each factor weight is one of the "corner-stone" of measuring quality. We took at the basis the approach that is developed in the works by D.Peña [7,8]. The theory of linear composite indicator constructing [9] and statistical methods are using for definition of weights of aggregation function.

Suppose that random sample with size denoted n from population of users involves estimates of overall quality of service – y_i, (i = 1, …, n) and estimates of attributes (particular quality indexes), which define quality of service – x_{ij}, for k concrete attributes (i = 1, …, n; j = 1, …, k). Assume that these estimates are made on the basis (0–5) scale. Let the quality of service to be unknown variable, which is measured by user's estimation y_i and determined as follow

$$y_i = \beta \mathbf{x}_i + u_i \,, \tag{1}$$

where $\boldsymbol{x_i} = (x_{i1},\ldots, x_{ik})$ – estimations of attributes, made by *i-th* user,
$\beta = (\beta_1, \ldots \beta_k)$ – vector of unknown weights,
u_i – error of measuring, which assume is normally distributed $u_i \sim N(0, \sigma_u^2)$.

A regression model assumes that overall service quality is determined by a linear combination of attribute evaluations with some unknown weights. The restrictions on a vector of weights are the next:

$$\beta_j \geq 0 \ \text{ for } j = 1, \ldots, k \ \text{ and } \sum_{j=1}^{k} \beta_j = 1 \,. \tag{2}$$

Therefore, the task is to get the estimation of the vector of unknown weights for function (1) with restrictions (2).

2. Considered Models for Weights Estimation

There were tested some variants of the weights searching in the research.

2.1. Least Squares Method for a Classical Linear Regression Model

The matrix form of the linear classical regression model is the next:

$$\boldsymbol{Y} = \boldsymbol{X\beta} + \boldsymbol{Z}, \tag{3}$$

where $\boldsymbol{X}$ is the matrix of independent variables, dimension ($n \times k$),
n is quantity of observations,
$\boldsymbol{Y}$ is the vector of dependent variable, dimension ($n \times 1$),
$\boldsymbol{Z}$ is the vector of dimension ($n \times 1$), which components $Z_1, Z_2, \ldots, Z_n$ are independent equally distributed random variables with mean zero and variance σ^2 and covariance matrix $Cov(\mathbf{Z}) = \sigma^2\mathbf{I}_n$,
$\boldsymbol{\beta}$ is the regression model vector of parameters, dimension ($k \times 1$), which needs to be estimated.

Least Square Estimation (LSE) $\boldsymbol{\beta}$ is calculated by formula**:**

$$\widehat{\boldsymbol{\beta}} = \left(\mathbf{X}^T\mathbf{X}\right)^{-1}\mathbf{X}^T\mathbf{Y} \tag{4}$$

and gives the smallest value of function

$$f(\beta) = \sum_{i=1}^{n}\left(Y_i - \sum_{i=1}^{k}\widehat{\beta}_i x_{i,j}\right)^2 = \sum_{i=1}^{n}\left(Y_i - \widehat{\beta}x_i\right)^2, \tag{5}$$

where $\boldsymbol{x_i} = (x_{i1}, ..., x_{ik})$ is the vector-column, dimension $k \times 1$.

Because of independent variables (partial quality attributes) can correlate between each other, that's why the stepwise regression model definition procedure is going to be applied (Forward Stepwise or Backward Stepwise) [10].

2.2. A Regression Model With Constrain on Parameters' Sign (a Restricted Least Squares Problem)

It is logical to assume that the increase in an estimation of partial attribute should lead to increase in an estimation of the general attribute of quality. In this case dependence between the general estimation of quality and partial attributes should be with a positive sign. Taking this condition into account let's enter the first restriction on parameters (weights for partial attributes of quality) into model (1):

$$\beta_j \geq 0 .$$

For an estimation of regression model parameters we will take the approach for the first time used by M.S. Waterman [11]. In a basis is the same method of the least squares, but with restrictions which are realized by below-mentioned iterative algorithm:

Step 1. Column vector with unknown parameters is estimated by the classical method of the least squares $\widehat{\boldsymbol{\beta}} = \left(\mathbf{X}^T\mathbf{X}\right)^{-1}\mathbf{X}^T\mathbf{Y}$. If the received vector has negative elements, transition to the step 2, if not, then transition to the step 3.

Step 2. In case of s negative elements presence in a vector of parameters $\boldsymbol{\beta}$ ($\beta_{\mathrm{I}} < 0$) the following updating (modification) of initial matrix **X** is made: the lines concerning negative estimations are excluded from consideration. Transformed matrix **X** dimension $(k - s) \times n$ goes on a repeated estimation of parameters, i.e. transition to the step 1 is made.

Step 3. In case of the component positivity in a vector of parameters $\boldsymbol{\beta}$ calculation of standard purpose function $f(\boldsymbol{\beta})$ in a method of the least squares which is necessary to minimize is made, by the formula (5).

Step 4 *(search of optimum value of the purpose function).* Assume that whole number of the remained positive parameters equals l. By serial zeroing (all possible combinations on one, on two, on three etc. on l remained positive parameters) and searching of all received values of the purpose function at given combinations of parameters such set is defined at which the purpose function $f(\boldsymbol{\beta})$ is minimum. Answering to the minimum value of the purpose function $f(\boldsymbol{\beta})$ the vector $\boldsymbol{\beta}$ which is not containing negative elements is the task decision.

The result of algorithm work is vector-column $\boldsymbol{\beta}$ (dimension $k \times l$), containing estimations of unknown regression model parameters only with nonnegative signs.

2.3. A Regression Model With Constrain On Parameters' Value

Let's consider other task setting, namely: algorithm of weights finding for particular quality attributes with constrain on value

$$\sum_{i=1}^{k}\beta_i = 1 .$$

Now to find coefficients $\boldsymbol{\beta} = (\beta_1, ... \beta_k)$, minimizing the function (5) providing

$$g(\beta) = \sum_{i=1}^{k}\beta_i - 1 = \beta e - 1 = 0 . \tag{6}$$

where **e** is vector-column, corresponding dimension, from ones.

Lagrange function for our problem will be

$$L(\beta,\lambda) = f(\beta) + \lambda g(\beta), \tag{7}$$

where $\lambda \geq 0$ is Lagrange coefficient.

It is necessary to minimize this function with respect to variables $\boldsymbol{\beta}$ and λ. It leads to system of the equations:

$$\frac{\partial}{\partial\beta} L(\beta,\lambda) = \frac{\partial}{\partial\beta} f(\beta) + \lambda \frac{\partial}{\partial\beta} g(\beta) = 0 \cdot$$

$$\frac{\partial}{\partial\beta} L(\beta,\lambda) = g(\beta) = 0, \tag{8}$$

The first of these equations looks like

$$\frac{\partial}{\partial\beta} L(\beta,\lambda) = -2\sum_{i=1}^{n}\left(Y_i - \beta x_i\right)x_i + \lambda e = 0 \cdot$$

Let's write down the equation in the matrix form

$$-2X^T Y + 2X^T X\beta + \lambda e = 0.$$

From here let's write down expression for $\boldsymbol{\beta}$

$$\beta = (X^T X)^{-1} X^T Y - \tfrac{1}{2}\lambda(X^T X)^{-1} e. \tag{9}$$

The Lagrange coefficient is from the second equality of system (8)

$$1 = e^T\beta = e^T(X^T X)^{-1} X^T Y - \tfrac{1}{2}\lambda e^T (X^T X)^{-1} e.$$

From here we find

$$\lambda = 2(e^T(X^T X)^{-1} X^T Y - 1)(e^T (X^T X)^{-1} e)^{-1}. \tag{10}$$

2.4. A Regression Model With Constrains On Parameters' Sign and Value

The algorithm, which is a combination of the algorithms, described in B and C is offered further. Key change consists that on step 1 the decision is searched not by a classical method of the least squares, but with use of formulas (9) and (10). Then it is applied the same procedures of an exception those vector β components which have a negative sign. Constrain on value and on a sign in this case remains.

Step 1. An estimation of a vector-column with unknown parameters β is finding by formulas (9) and (10) at which value of function (5) is minimal and the condition (6) is satisfied. If the received vector has negative elements, transition to the step 2, if not, then transition to the step 3.

Step 2. In case of s negative elements presence in a vector of parameters β ($\beta_I < 0$) the following updating (modification) of initial matrix **X** is made: the lines concerning negative estimations are excluded from consideration. Transformed matrix **X** dimension $(k - s) \times n$ goes on a repeated estimation of parameters, i.e. transition to the step 1 is made.

Step 3. In case of the component positivity in a vector of parameters β calculation of standard purpose function $f(\beta)$ in a method of the least squares which is necessary to minimize is made, by the formula (5).

Step 4 *(search of optimum value of the purpose function).* Assume that whole number of the remained positive parameters equals l. By serial zeroing (all possible combinations on one, on two, on three etc. on l remained positive parameters) and searching of all received values of the purpose function at given combinations of parameters such set is defined at which the purpose function $f(\beta)$ is minimum. Answering to the minimum value of the purpose function $f(\beta)$ the vector β which is not containing negative elements is the task decision. The result of algorithm work is vector-column β (dimension $k \times l$), containing estimations of unknown regression model parameters only with nonnegative signs and the sum of these parameters (weights) are equal 1.

3. Numerical Results of Weight Estimation

3.1. Initial Data

The model was constructed on the basis of questionnaire results of 44 transport experts that was performed in spring 2009. This fact, that respondents are the high-qualified transport specialists, allowed as to assume that the sample is homogeny and the assumption about equal variance of residual is fulfilled. The questionnaire included 7 groups of questions concerned the following groups of quality particular attributes: accessibility (availability); information; time characteristics of service; customer service; comfort; safety; infrastructure and environment (Table 1). Totally there were 22 particular attributes of quality distributed on these 7 groups. Also the overall quality of service was evaluated. As well as particular attributes of quality the overall quality service was estimated on a scale 0–5. In total 44 questionnaires have been returned but some questions remained without the answer in three questionnaires.

Table 1. Particular Attributes of Quality

Title of chapter in questionnaire	Coding	Description of variable	Coding
1. Accessibility	**W1**	Accessibility for external participants of traffic	X1
		Accessibility for terminal passengers	X2
		Ticket booking	X3
2. Information	**W2**	General information in terminal	X4
		Information about trips in positive aspect	X5
		Information about trips in negative aspect	X6
3. Time	**W3**	Duration of trip	X7
		Punctuality	X8
		Reliability/trust	X9
		Bus time schedule	X10
4. Customer service	**W4**	Customer trust to terminal employees	X11
		Communication with customer	X12
		Requirements to employees	X13
		Physical services providing	X14
		Process of ticket booking	X15
		Services provided by bus crews during boarding/debarkation	X16
5. Comfort	**W5**	Cleanness and comfort in terminal premises and on terminal square	X17
		Additional opportunities/services providing in coach terminal	X18
6. Reliability /safety	**W6**	Protection from crimes	X19
		Protection from accidents	X20
7. Environment	**W7**	Dirtying, its prevention	X21
		Infrastructure	X22
	W8	**Overall estimation**	X23

The analysis of coordination (consistency) of questionnaire questions was made by means of Cronbach alpha coefficient:

$$\alpha = \frac{k}{k-1}\left(1-\sum_{i=1}^{k}\frac{s_i^2}{s_{sum}^2}\right), \tag{11}$$

where k – amount of questions (in our case – particular quality attributes),

s_i^2 – variance of i question and s_{sum}^2 – variance of sum of questions.

The results of questionnaire (estimates of particular attributes of quality) have demonstrated high indices of the internal coordination. A value of Cronbach alpha coefficient is equal to 0.933 and the standardized value is 0.93. It has allowed making an assumption about reliability of results. The lowest value of correlation is between resultant estimate and variables x7 (“trip duration”) and x8 (“punctuality”).

Let's analyse the descriptive characteristics of estimates of particular attributes of quality. The lowest estimates the attributes connected with infrastructure ($\bar{x}_{22}$ = 3.035) and environment ($\bar{x}_{21}$ = 3.182) have received. It corresponds to a true situation: today the Coach Terminal is experiencing difficulties and looking for new squares for moving and further repair of the existing territory. The following low estimated attributes are „Cleanness and comfort in terminal premises and on terminal square" ($\bar{x}_{17}$ = 3.419), „Protection from crimes" ($\bar{x}_{19}$ = 3.500) and „Physical services providing" ($\bar{x}_{14}$ = 3.550). These attributes also depend directly on the state of the Coach Terminal's infrastructure. Experts have given the highest estimates to the private quality attributes of „Bus time schedule" ($\bar{x}_{10}$ = 4.409) and „Accessibility/Ticket booking" ($\bar{x}_{3}$ = 4.5) that is also explainable. The issues of accessibility (opportunity of ticket booking in the terminal ticket offices and in the Internet and via the mobile telephone) are considered by the management of the coach terminal as priority and therefore success of these attributes is obvious.

Let's investigate dependence between the particular quality attributes and the overall quality estimate given by experts. On the basis of the analysis of Kendall correlation values it is possible to make conclusions that the overall estimate of service quality in the coach terminal is correlated (connected) most with the following private criteria of quality:

- ✓ Protection from crimes (0.617)
- ✓ Cleanness and comfort in terminal premises and on terminal square (0.579)
- ✓ Additional opportunities/services providing in coach terminal (0.535)
- ✓ With attributes of quality characterizing the customer service: Customer trust to terminal employees (0.533) and Process of ticket booking (0.533)

It indicates the fact that the higher estimates are given to these attributes, the higher the overall quality estimate is.

In further research we will also consider other method of forming the independent variables for regression model, in particular: we will form 7 new variables corresponding to 7 groups of attributes (categories of questions) (Table 1, the left column). Values for each new variable (category of questions) have been received by calculation of a arithmetic mean of variables included in the composition of the given category. A reason of inputting the other set, that is the so called "clustered" variables, as the attending ones, lies in the following fact. All above mentioned models have assumed that the overall estimation and particular estimations are continuous variables. Very often variables are measured on categorical (on a discrete scale). Grouping of the initial attributes and calculation of new values on the basis of a mean arithmetic leads to a replacement of categorical variable x_{ij} by interval w_l (l = 1,..,7). In Table 2 the descriptive characteristics for new clusterized variables are presented, and in Table 3 – the lower triangle of the correlation matrix.

Table 2. Descriptive measures of the grouped variables (attributes of quality) and overall quality

	Valid N	Mean	Median	Mode	Frequency	Min	Max	Std.Dev.
W1	44	4.341	4.500	5.000	22	1.000	5.000	0.861
W2	44	4.064	4.000	4.670	13	2.000	5.000	0.678
W3	44	4.205	4.250	4.000	14	3.000	5.000	0.442
W4	44	4.031	4.170	Multiple		2.500	4.830	0.620
W5	44	3.557	4.000	4.000	18	1.000	5.000	0.916
W6	44	3.545	3.750	4.000	12	1.500	5.000	0.901
W7	44	3.119	3.000	3.000	12	1.000	5.000	0.845
W8	40	3.931	4.000	4.000	28	3.000	5.000	0.528

As it is shown in Table 2 the lowest estimates have been given by respondents to the attributes connected with infrastructure and environment (w_7), and the highest ones to Accessibility (w_1). Let's indicate important correlations between variables w_2, w_4, w_5 and w_6.

Table 3. Correlation matrix for grouped variables

	W1	W2	W3	W4	W5	W6	W7
W2	0.41						
W3	0.41	0.16					
W4	0.55	**0.74**	0.22				
W5	0.46	**0.71**	0.32	**0.72**			
W6	0.34	**0.78**	0.23	**0.75**	**0.77**		
W7	0.20	0.45	0.23	0.61	0.56	0.50	
W8	0.50	0.57	0.25	0.69	0.67	0.61	0.46

For elimination of the correlation effect between variables, it would be possible to use a method of main components for obtaining new orthogonal factors. However it would lead to a poor interpretation of the quality indicator model.

3.2. Results of Weights Estimation By Various Models

In Table 4 the results of estimating of weights on the basis of the above considered approaches for 8 various models are presented.

Table 4. Results of weights estimating

Attribute	Model A1	Model B1	Model C1	Model D1	Grouped attribute	Model A2	Model B2	Model C2	Model D2
X1	_	0.126	0.069	0.144	**1. Accessibility**	-	0.175	0.167	0.17
X2	_	_	0.134	_					
X3	0.218	0.035	0.166	_					
X4	_	0.102	0.174	0.082	**2. Information**	-	0.084	0.082	0.075
X5	_	_	-0.162	_					
X6	_	_	0.056	_					
X7	_	0.147	0.175	0.171	**3. Time**	0-337	0.255	0.232	0.235
X8	0.189	0.068	0.334	0.05					
X9	_	_	-0.217	_					
X10	_	_	-0.181	_					
X11	0.260	0.131	0.088	0.133	**4. Customer service**	0.620	0.406	0.346	0.338
X12	-	0.148	0.195	0.141					
X13	0.180	0.067	0.149	0.058					
X14	-	-	-0.011	-					
X15	-	-	-0.046	-					
X16	-	-	-0.147	-					
X17	-	-	-0.142	-	**5. Comfort**	_	0.031	0.074	0.056
X18	-	-	-0.011	_					
X19	-	0.107	0.317	0.128	**6. Reliability /safety**	_	_	-0.031	_
X20	-	_	-0.194	–					
X21	_	_	0.029	–	**7. Environment**	_	_	0.13	0.125
X22	0.103	0.137	0.225	0.093					
f(β)	5.221	4.133	2.274	4.355	f(β)	6.509	5.992	6.609	6.618
SEE2	0.366	0.349	0.322	0.353	**SEE2**	0.394	0.392	0.423	0.417
F	1024.400	564.953	304.867	625.669	**F**	2208	891.416	567.579	678.624

By ***model A1*** we indicate the classic regression model for the overall estimate of service quality as the dependent variable constructed with the help of procedure *Forward Stepwise* (SPSS package, replacing of the missed values by the mean ones). As a result of five steps an equation of regression with five significant corresponding variables has been received.

During testing of the hypothesis about insignificance, the F statistics is equal to 1024.4 (*p-level* < 0.00001), standard estimation error (SEE) is equal to .366; a model explains the dependent variable – the overall quality estimate on the level of 99%.

As to x_3 – attribute "Ticket Booking" of category "Accessibility" then, its entry is logical because a possible purchase of tickets in the ticket offices and in the Internet, and via the mobile telephone is highly estimated by customers. The significance of variable x_8 – attribute "Punctuality" of category "Time" is also logical because today a customer is exacting to a fulfilment of a time schedule and the coach terminal considers reliability of trips as a strategic task and conducts researches in this direction [5]. A significance of two other variables x_{11} – attribute "Customer trust to terminal employees" and x_{13} – attribute "Requirements to Employees" of category "Customer Service" speaks about a significance of this category of attributes. Therefore, it is possible to make a conclusion that increase of trust and conditions of services (especially, cleanness and comfort in premises) will lead to a considerable increase of the overall estimate. The last variable x_{22}, connected with the state of the Coach Terminal infrastructure also significantly influences on the overall quality estimate.

Model A2 (Table 4) – we indicate the classic regression model for the overall estimate of service quality as the dependent variable. The "grouped" variables cashiered as independent ones. An equation of regression with two significant independent variables has been received with the help of the *Stepwise* procedure. During testing of the hypothesis about insignificance the F statistics is equal to 2208.1 (*p-level* < 0.00001), standard estimation error (SEE) is equal to 0.394; a model explains the overall estimate of service quality on the level of 99%.

As it is shown in the constructed model (Table 4) the overall service quality estimate is influenced mostly by the quality of the passenger service process (w_4) – it is one of the most capacious categories including customers` trust to the terminal employees, communication with customers, help from the terminal's employees, organization of ticket booking etc. The "Time" category (w_3) including time schedule and reliability of its fulfilment is also an important category.

If to compare the results of model construction with the primary attributes and "grouped" attributes, then those entered ***model A2*** the "grouped" attributes of quality include three primary attributes, which entered ***model A1.*** Certainly, a positive character of the sign received in the ultimate equations is possible to consider being a "successful" result and with other input data it may be not like this.

For estimation of parameter of the regression model of the coach terminal services quality with restriction on signs (***model B1***) the interaction procedure has been applied described in Item 2.2. An algorithm has been realized in the MathCAD package. For the primary data (44 questionnaires and 22 private attributes) at the 1st step the results presented in Table 5 (the results coincide with the estimate of classic LSM, without a free member, in the SPSS package) have been received.

Table 5. Results of LSE-estimation at 1st step

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
0.058	0.135	0.177	0.174	-0.147	0.027	0.153	0.304	-0.171	-0.162	0.075
X12	**X13**	**X14**	**X15**	**X16**	**X17**	**X18**	**X19**	**X20**	**X21**	**X22**
0.221	0.158	-0.024	-0.016	-0.154	-0.164	-0.028	0.342	-0.209	0.0009	0.218

The second step of algorithm has been applied twice and the received final decision contains a value of only positive weights of 10 attributes. A value of the target function corresponding to the given decision – $f(\beta) = 4.133$. With availability of 10 positive parameters there are 1024 various combinations of the alternate nulling of parameters the result of search has shown that the minimum value of the target function saves with all 10 received parameters $f(\beta) = 4.133$. In Table 4 the final results of model ***B1*** estimating have been shown**.** The attributes characterizing the process of customer service – x_{11} and x_{12}, and also the trip duration – x_4. have the strongest influence on the overall quality estimate. By the way, in total the received weights (components of vector β) are equal to 0.968. Therefore, it is possible to assume that a weight of the rest 12 components is very small. The variables entered in the model **B1** include all the variables of **model A1.** For the grouped data the given algorithm also has been applied. In Table 6 the results of estimating after step 1 has been presented.

Table 6. Results of LSM-estimating on 1st step

W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**
0.164	0.098	0.253	0.434	0.078	-0.073	-5.4*10^-3

The second step of algorithm has been applied twice and the final decision – values of only positive weights of 5 grouped attributes (model ***B2***). With availability of 5 positive parameters there are 32 various combinations of alternate mulling of parameters. The result of search has shown that the minimum value of the target function saves with all 5 received parameters f(β) = 5.992. As it is obvious from the results of construction of ***model B2*** – grouped attributes 6 and 7 haven't entered it.

Let's use a procedure described in p.2.4 for finding weights, which values are limited by equality in amount 1. The considered algorithm has been realized in the Mathcad package. For the primary data the results submitted in Table 4 (***model C1***) have been received. As it is seen from the results, the negative value of weights relates to 9 attributes of quality, by the way, these attributes haven't entered **model A1** due to their insignificant influence on the resultant estimate or correlation with the earlier entered variables.

For the grouped attributes the given algorithm has been also applied and the results have been presented in Table 4 (***model C2***). As it is seen from the results – the negative value is just of 1 attribute – the sixth one corresponding to the „Reliability/Safety" category. It has also entered **model A2** because of the significant correlation with the earlier entered variables.

And, finally, the two-step procedure on the basis of combination of two algorithms has been applied – for decisions received with restrictions to values of parameters (***model C1*** and ***C2***) the procedure of removal of a parameter with the negative signs has been applied. The received results of estimating for models with 22 private attributes of quality (***model D1***) and the grouped attributes of quality (***model D2***) are presented in Table 4. Model ***D1*** has been received on the forth iteration and as the result of search of 512 decisions. Minimum value of the target function during the choice of 9 parameters is (f(β) = 4.355). ***Model D2*** includes 6 grouped attributes and minimum value of the target function f(β) = 6.618.

Conclusions and Discussion

As the final formula of the model for the input non-grouped data with observing all restrictions to weights it is possible to consider ***model D1***:

$$y_i^* = 0.144\,x_{1i} + 0.082\,x_{4i} + 0.171\,x_{7i} + 0.05\,x_{8i} + 0.133\,x_{11i} + 0.141\,x_{12i} + \\ + 0.058\,x_{13i} + 0.128\,x_{19i} + 0.093\,x_{22i}$$

and for the grouped data – ***model D2***:

$$y_i^* = 0.17w_{1i} + 0.075w_{2i} + 0.235w_{3i} + 0.338w_{4i} + 0.056w_{5i} + 0.125w_{7i},$$

For ***D1*** Standard Error of Estimate (SEE) compiles about 9% relatively a mean value of the overall estimate, for ***D2*** – a bit less than 11%.

A practical result of the given models is detecting of a significance of separate attributes of quality and their influence on the overall estimate of service quality provided by the coach terminal. It will allow the terminal's management to take more grounded measures for improvement of service quality. So, detecting the fact of the largest significance of factor w_4 corresponding to attributes of the customer service quality, once again stress a significance of measures of the staff management in the coach terminal. And, the second place according to significance x_1 – accessibility for external participants of traffic – in model ***D1*** confirms a correctness of a strategic goal of the terminal's management – to make it as a modern logistic passenger HUB with the high level of intermodality [1, 2]. Also it is confirmed from models the important role of planned reconstruction of infrastructure for improving the overall quality of service.

In a whole, the model constructed for a scalar quality indicator, allows estimating influence of particular quality indicators on the overall quality estimation and to simplify monitoring of quality indicators.

The models presented in this paper are based on a number of assumptions, which may be released later on and it will be a further development of the submitted approach.

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Received on the 1st of December, 2009

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 50–57
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MULTIDIMENSIONAL META-MODELLING FOR AIR TRAFFIC MANAGEMENT SERVICE PROCESSES

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Business Processes supported by IT Services is one of the mission critical factors of modern Air Traffic Control Providers (ATC). Particularly ATC companies are highly dependent on their technical process know how and to deliver a safe and efficient ATC Services. During research of dissertation by different ATC providers it was observed that no general meta-model for ATC technical services exists.

On the base of multidimensional modelling method the approach for modelling and design of a general ATC meta-model in context to ITIL Standard and ISO 20000 standard has been performed. The results of this research have been used for further optimisation and increasing of harmonization of the ATC technical service processes.

The focus of research is to develop a universal high level multidimensional model for technical ATC services, because over medium term period it will be essential on the European ATC market to change from a national oriented ATC provider to a global European ATC service provider which is able to support the ATC business on a standard technical service process model. With respect to the Single European Sky program from the European Commission and the activities of different national ATC service provide to create international functional airspace blocks a metaframe or meta multidimensional process model of technical services should be the basis for standardization of ATC technical services and be able to change from a national ATC-provider with their own best practices to a European global ATC provider.

An essential prerequisite for globalisation of European ATC market is to develop a global and standardized ATC process model. Based on the developed ATC meta-model technical services can be designed and described by dimension tables, information cubes. The ATC meta-model is to be the basis of high level description by scientific methods and can be used as input information for the specific ATC process management and monitoring.

The goal of meta frame model by multidimensional modelling is to investigate into standardization of ATC technical process landscape, to design specific key performance parameter for evaluation and benchmarking and to derive technical expertise for a migration of own specific technical processes to a general standardized meta process model of AIS Services. For that reason the research presents different number of data/information cubes and dimensional tables. The main result of the research is the developed Meta ATC Process model.

Keywords: *Multidimensional modelling, Modules of metaframe, Questionnaire and Dimension tables, ATC modelling cubes, Metric Controlled Meta Model Cubes*

1. Problem Description

Actual national ATC providers with focus to technical processes started to workout process models and design of a service model, based on own best practices; no international ATC standard exists, no industrial standard can be used. In order to harmonize and to move national ATC service provider it is necessary to develop an ATC high level Service model, which would be used by all European ATC providers and standard; and also to be able to compare and to harmonize the delivered ATC technical services. Because in a first step, for example, technical support processes like CNS services will be liberalized under market conditions.

On international ATC platform it has been observed that with respect to the Single European Sky Projects and activities of different ATC organization to design a multi-national ATC functional airspace block is depended on national borders and governances.

The future of ATC provider is now changing to a complete service provider with specific ATC related services on international level. In addition the European Commission will force this development on ATC market. Based that up to now each ATC organization develop different technical processes, taking into account national point of view; each organization has different approaches and different level of technical process description.

A general ATC related model doesn’t exist; single ATC organization only starts to perform a process description referring to ITIL de-facto standard. But for liberalization of ATC market and realization of the possibility of tendering for ATC services it is necessary to have a general meta-model of technical ATC services for comparing, assessment and benchmarking. So to design a meta-model there is a prerequisite of harmonization for ATC services and technical support services, the definition of standards for ATC technical processes must be measurable, so in a following step it is needed to define KPI for evaluation of Meta service model.

It is not a goal to reinvent all ATC technical process but it should be a large potential to use the different best practices and derive possible industrial standard for development and mathematical description of meta frame ATC technical service model.

Main goal is to design a common and harmonized Meta model, which can be used and can be valid for ATC technical support services on European level. Multidimensional modelling method should be used because it is necessary:

- to create service models and to perform a simulation before bring into the practice;
- to realize the modelling view from customer's and service point of view;
- to describe the processes in a complete and consistent way including the integration of different key performance indications into defined measurement points of model;
- to derive from the model and their processes the different task, rules and responsibilities;
- to detect pattern, which is reusable and repeatable from the meta model and to use the pattern for a following up more detailed process modelling and create process pattern.

2. Problem Analysis and Methodology Approaches

In comparison of characteristics between operational methods of modelling and multidimensional modelling that is described in Table 1.

Table 1. Comparison of main characteristics

Operational Modelling	Multidimensional Modelling	ATC related Findings
Data are particularized into detailed transaction data	Data are granular in form of time slices	Usage of time related information modelling by given time slots and events for technical processes
Consistent for local purposes	Global consistent	Data Modelling global consistent for the complete meta model of ATC technical Processes
Support the modelling processing of details	Support the modelling of relations	Usage of relation modelling between all technical service level processes
Explicitly modelling of relations	Implicitly modelling of relations	Focal point of relation modelling between processes and their interfaces

Based on the main basic ideas of multidimensional modelling there will be used modelling blocks:

- ✈ Dimension as the central basic term for information/data analysis, the dimension defined the following main axes of data cube –
  y-axe: process related metrics or key performance indicators
  x-axe: time relation
  z-axe: modelling research area
- ✈ Hierarchies are the summary of all defined different levels of dimensions. Based on hierarchies there can be defined different levels of data compressions.
- ✈ Elements are describing the different levels, elements are the features for analysing with help of data cubes, for example dimension: time; Level: year; elements: 2007, 2008, 2009; level: months; elements: Oct, Nov, Dec.
- ✈ Attributes are additional characteristics of elements for a defined hierarchies, they differ between classified and described attribute.
- ✈ Facts are metrics for the modelling.

For the multidimensional modelling on Meta level there is a main characteristic to find the related kind and operational Meta data. The meta data describe the operational systems, delivered data and data transformation, define the transformation algorithms of data into a data warehouse and contain structural information between data warehouse and meta data. So meta-data describes data and processes, contain data of data and processes.

The main characteristic criteria for a general meta-modelling are given on the following Figure 1.

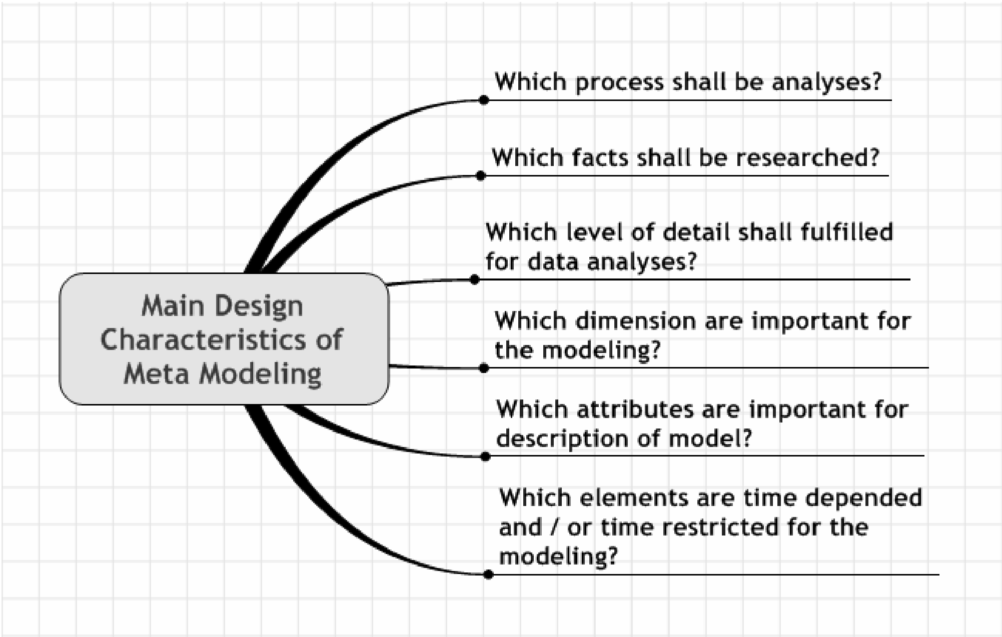

Figure 1. Mind Map of main characteristics for meta-modelling

A possible method to develop a meta-process model uses the business performance/process management. Because the business performance modelling performs align the strategic and operational object and services, which will be identified for ATC provider. So in a first step it is necessary to design the related main ATC processes, services, activity monitoring and corporate performance enabler for ATC purposes. Based on using the Business Process Management and Modelling for ATC the following benefits will be generated:

- Identification, harmonization and optimisation of ATC Business Processes
- Workflow and real time monitoring and visualization of ATC processes on meta level, which should be used as an ATC standard for all ATC providers
- Identification of process automation and integration, reduction of operational cost via process standardization and automation.

The ATC business process modelling generates also the possibility to implement service oriented architecture (SOA) for ATC technical services. So it is possible to close the contradiction between ATC busies and technical support based on SOA structure and be more depended on system technical view and specific technical systems.

The implementation and life-cycle of business process modelling can be oriented on the following proceeding after definition of goal of modelling:

Step 1: Definition of modelling methods.
Step 2: Development of actual business process model (as is status).
Step 3: Design of the full-size to be model.
Step 4: Definition of the related business key performance parameter, metrics, their method of measurement, identification of measurement point and measured units. The practical experiences show that it is very important to solve all mentioned topics of measurements in one step and before start to measure.
Step 5: Analysis and verification of developed model based of defined criteria's.
Step 6: Develop of workflows.
Step 7: Unit and Object Modelling.
Step 8: Design of services and integration of service chains.
Step 9: Definition of data and communication interfaces.
Step 10: Model Integration, harmonization.
Step 11: Implementation of Process Monitoring.
Step 12: Implementation of regular Process Optimisation.

3. Meta Modelling for ATC Business Processes

In the following chapter the main steps and approaches to develop a Meta ATC process model are described. This Meta process model is the basic model for each other business process models for ATC on more detailed level or specific variants.

The following goals are reached by developing of ATC Meta Business Process Model:

- Structuring of ATC Main Processes
- Standardization of ATC Business Process Models by given guidelines of modelling constructs
- Definition of a single modelling languages, because the Meta Model has been used for all European ATC Service Providers
- Definition of ATC Model Elements for description of terms of ATC Meta Model Elements
- The Meta Model fulfils the characteristics of universally using for further detailed and specific variants of models, so the Meta Model shall be in context to further detailed models and must be understand as an always relativity to other models.

The main structure and view of ATC Meta Model is the view from European Regulation Level and the national ATC Service Provider. Up to now the European Commission is given an overall ATC Safety Requirements to define a general European Safety Level of ATC. These Requirements are derived by National Service Provider into own national processes. A General ATC Meta Business Processes Model is not given on European Level.

Based on the described rules and requirements to a Meta Frame Model the following figure gives a view of the ATC Meta Model. This Meta process model describes the actual situation on European ATC market. The European Commission and Eurocontrol regulate the ATC service provider and have harmonized the needed ATC operational and technical service support and delivery.

For this regulation task it is necessary to use a multi level modelling approach because the meta model must be performed at first on meta level so that all regulations for ATC governance and compliance. Further that each ATC service provider has been derived and designed the own national ATC Process Model, which fulfils the national rules of governance and compliance based the requirements from national regulatory authority. So this ATC Service Provision Model describes the national characteristics and in a more detailed level.

The task is to develop an ATC Meta Model on European level and derive a general ATC Service Provider Model as a pattern for the different national ATC Company.

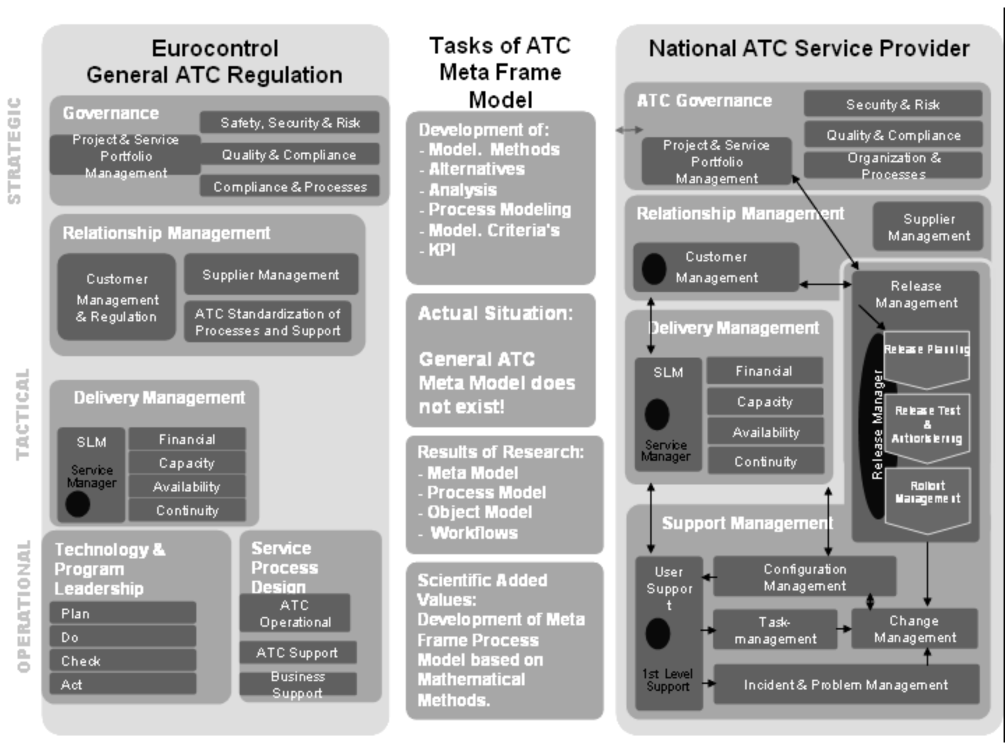

Figure 2. Overview of ATC Meta Model

With respect to further researches and analysis of modelling methods for the defined task of Meta modelling for ATC process model will be referenced to [1].

In summary the next figure describes the Promet-Meta Modelling Principles. These principles are recommended to be used in developing a specific ATC Meta Process Model. The PROMET Meta Process Modelling Principles are the most sophisticated method for using in modelling guidelines for development of an ATC Meta Models and for derived of ATC Process Models in more detailed level.

The benefits of PROMET can be summarized as follows:

- Process oriented Modelling Structure
- Complete Process Description by related tasks, applications, process goals, process typing.

Additional task is to manage and to control the modelled processes by defined critical success metrics, process leading, reporting and impact of organization structure.

4. Schematic View and Structure of Research Proceeding

The general proceeding of analysis and research is summarized in the following table. This schematic structure is used as guidelines for the further research of doctoral thesis.

Table 2. Schematic Structure of Meta modelling proceeding

1. Main Structure		
Problem Description, Task and Goals	Process Analysis and Support Actual - Optimisation	Composition and Structuring
Methods	Applications	Systems
2. Approaches and Procedures for Processing Support	**3. Processes Support into Applications**	**4. Basic Tools and Pattern**
Basics and Principles		
Meta-Modelling and Model Development	Definition and Guidelines of Process orientation	Multidimensional Modelling Tools
Methods of Process Modelling	Usage and derivations for ATC specific modelling	Meta and Process oriented Modelling Tools
Model Transformation		
Concepts of Model Design		
Conception		
5. Execution of Meta and Process Modelling	**6. Formation of Process Oriented Models**	**7. Conception Enhancements**
Definition of Meta Modelling Views: - European Level - General ATC Service Provider View	Usage and derivations for ATC specific process modelling: - ATC Main Operation Process - ATC technical Support Process - ATC specific Business Support Processes	Specification of data and metrics
Definition of Relationship between different model levels	Definition of Process Evaluation Criteria's and Metrics	Developments of measurements methods for KPIs
Mathematical description of Meta Model and General Service Provider Model	Development of Standard Process Interface and Information Transformation	
Implementation		
8. Integration of Meta Model and Process Model		
Realization and Alternatives of ATC Meta Model and their Evaluation based on defined criteria's	Realization and Alternatives of ATC Services Provider Process Model and Evaluation based on defined criteria's	
9. Conclusions and Expectations		
Description of further and practical implementation and more detail	Critical Appraisal and discourse	Discourse of Standardization and Automating

So the principles of ATC Meta model are interoperated by 3 points of view of the model. The highest level of the model interpretation is European Regulation Level. This level presents the Meta level and fulfils general requirements of using of all ATC service providers. For this Meta Model the multi-layer principle develops on, because the Meta Model describes the ATC Framework structure, the Meta Objects and Meta Process frame for ATC in general. Depending on general point of view the Meta Model has to describe also by given relations between Meta objects and processes and related attributes. The Meta Model fulfils the role as general Integration platform for ATC processes, objects and attributes. Deriving from this Meta model the specific ATC service provider model shall be developed, which is described by UML language and uses a specific modelling tool. The ATC service provider model will design the specific modelling domains for service provision of ATC services. This level of modelling is called the ATC application model and describes the specific ATC processes, parameter, relations and interfaces, UML class diagrams.

The development of ATC application model fulfils the following requirements:

- The focus is the process view.
- The modelling and configuration of processes are described by a domain specific model.
- The derivation from the ATC Meta Model to the ATC Application Model is described by a specific transformation process.
- The application model shall be used as a simulation for the development of the specific national ATC service provider model.
- Based on the ATC Meta Model and ATC Application Model shall be intensified and the pattern for repeated using is to be developed.

5. Development of Main Structure for ATC Meta Model and Data Cubes

The structure of ATC Meta Model is characterized by multi dimensions and different views. The main view to the model is the ATC service view with the main operational ATC services and support. The ATC Meta Model is described by different views, like Service View, Process View, and System View. The main services on general level are described and structured in the following Mind Map on Figure 3. The Meta Model describes categorical the dependency between different types of requirements to the service impact and the system impact. Especially the correlation between the dynamic of requirement level to the service and system view must be described on mathematical way.

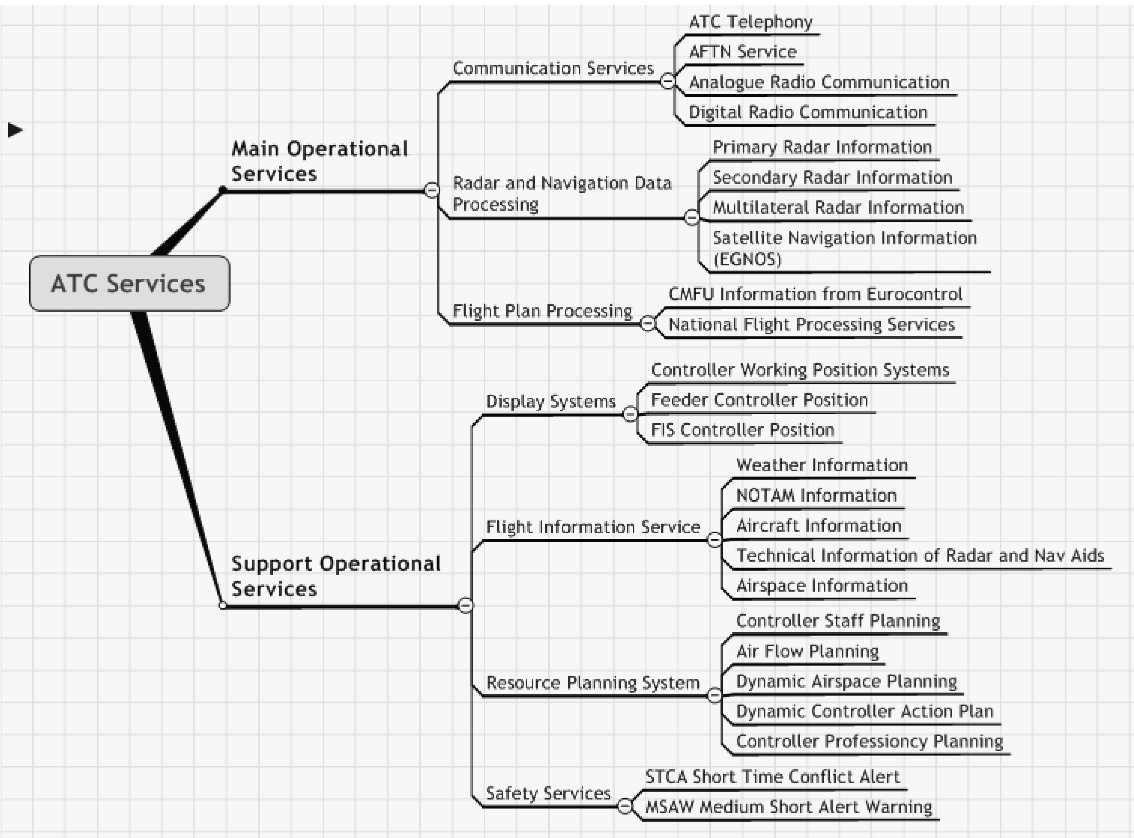

Figure 3. Mind maps of ATC Services

In general the Meta Model should be a 4-dimensional modelling system. The Meta Model fulfils the following dimensions:

1. The "How": ATC Processes, Organizational Structures
2. The " What": ATC Objects, Services, Systems
3. The "Time Focus": ATC Dynamic depending on Traffic Flow
4. The "Evaluation": Measurement Methods and Point, Metric System

Based on the time relevance and measurement capability it will be used for further optimisation of ATC Meta Model and it will perform a standardization approach to generate a Common European ATC Meta Model. Based on mathematical methods the standardization has been approved on scientific level. Mathematical methods will be further used for description of model limits and restrictions. For description the specific data cubes as part of multidimensional modelling method are used.

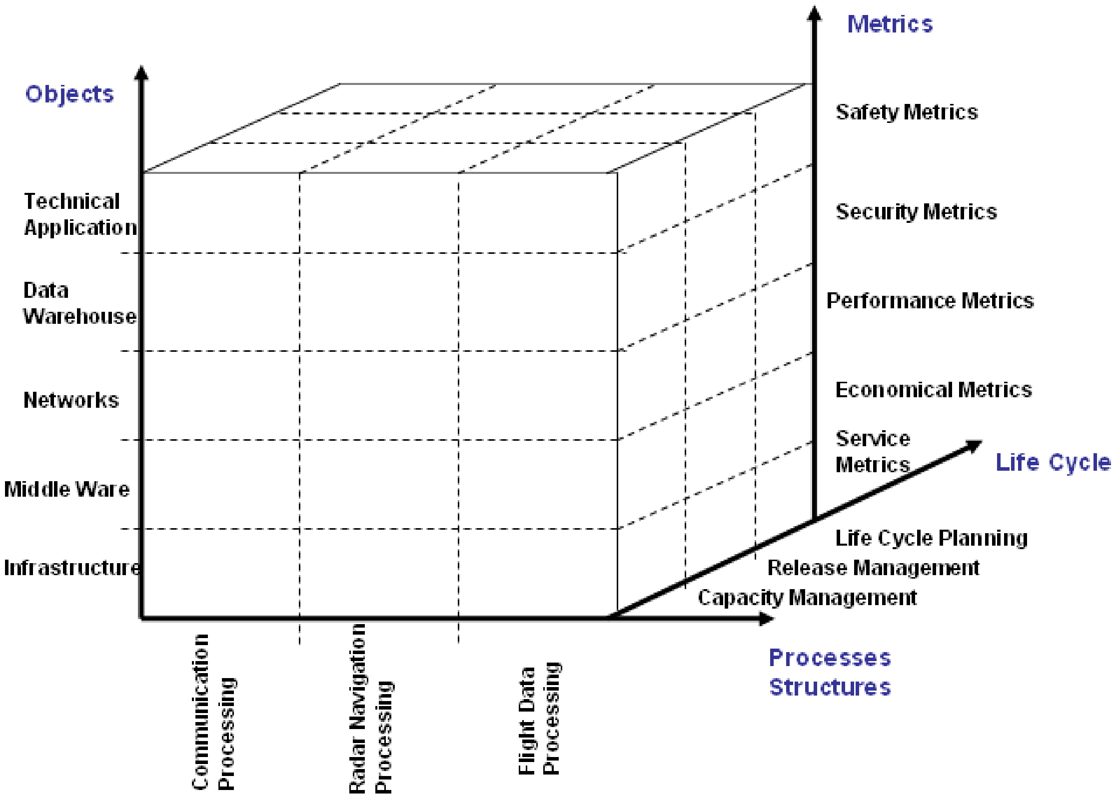

Figure 4. Data Cube for ATC Meta Model

The cubes have been developed on different levels. The main level is given the main structure for all more detailed data cubes:

y-axe: Objects, Services, Systems
x-axe: Processes, Organizational Structures
z-axe: Dynamic Time Slots
m-axe: Metrics for Measurements

The Main Data Cube is a part of the Meta Model. From this main level different diversification and individual Data Cubes for specific Services and Processes have been derived. The Data Cubes for the Meta Level are presented on Figure 4. Based on the level and on this proceeding it will generate on next detailed level more specific data cubes for description of ATC Meta Model.

Conclusions

The research and analysis gives a possible approach for development of ATC Meta Model on scientific level. The goal of the research is – to develop methods and structures of doctoral thesis. The following findings and conclusions have been derived:

- Basing on the multidimensional modelling methods it is possible to perform analysis and generation of ATC Meta Model with a 4-demensional description.
- The Modelling is performed on different levels, views and layer.
- From the point of view of investigation it is necessary to generate a general ATC Meta Model basing on a common European Regulation Layer and deriving from this layer a Meta ATC Service Provider Model, which can be used as a general tool from deriving of specific national service provision.
- Main description method will be used Data Cubes on different level for model description.
- From scientific point of view it is needed to find out mathematical methods for Meta models, and to perform and standardize process basing on mathematical methods for description of model limits and restrictions.

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Received on the 1st of December, 2009

Computer Modelling and New Technologies, 2010, Vol.14, No.2, 58–68
Transport and Telecommunication Institute, Lomonosova 1, LV-1019, Riga, Latvia

ASSESSING GROUNDWATER QUALITY FOR POTABILITY USING A FUZZY LOGIC AND GIS – A CASE STUDY OF TIRUCHIRAPPALLI CITY – INDIA

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Water quality management is an important issue in the modern times. In this paper, the application of fuzzy set theory for decision-making in the assessment of groundwater quality for drinking purposes. This is illustrated with seventy nine groundwater samples collected from Tiruchirappalli, S. India. These 79 samples were analysed for 12 physical and chemical parameters. Fuzzy groundwater classification rule base derivation from groundwater quality variation maps, which are based on twelve ions. These maps are obtained by geostatistical (Kriging) methodology and the results are presented in the form of MAPS as equal ion concentration lines. They help to visualize between desirable to Acceptable limits with twelve ions with linguistic interpretations. For this purpose four ions are separated into three linguistic categories, as 'Desirable', 'Acceptable' and 'Not Acceptable', which are characterized numerically by membership functions (MFs). Accordingly, the linguistic fuzzy 181 rules are presented for classification of quality based on different ions. In general, it is possible to run for the high data Volume of water quality. Simulink is used and the results are presented in GIS maps.

Keywords: *Fuzzy Logic, Simulation, Kriging, Water Quality, GIS, Tiruchirappalli*

1. Introduction

Water is an important resource for the sustenance of ecosystem, agriculture, human settlements. Ground water is one among the Nation's most important natural resources. Very large volumes of ground water are pumped each day for industrial, agricultural, and commercial use. Also, ground water is a drinking-water source for about one-half of the Nation's population, including almost all residents in rural areas. Ground water is important as a drinking-water supply in every State.

Information on the quality and quantity of ground water is important because of the Nation's increasing population and dependency on this resource. The population dependent on public water systems that used ground water for drinking-water supplies increased between 1950 and 2000, and the estimated withdrawal increased about five-fold during that time period.

The quality and availability of ground water will continue to be an important environmental issue for the Nation's citizens. Long-term conservation, prudent development, and management of this natural resource are critical for preserving and protecting this priceless national asset.

As per the international norms of [26] if per capita water availability is less than 1700m^3 per year then the country is categorized as water stressed and if it is less than 1000m^3 per capita per year then the country is classified as water scarce. Now our country, India is water stressed and is likely to be water scarce by 2050 [15].

Continued research, guidance and regulations by government agencies and pollution abetment programmes are necessary to preserve the Nation's groundwater quality and quality for future generations by industry are necessary to preserve the Nation's groundwater quality and quantity for future generations [1–30].

2. Groundwater Quality

Generally the quality of the groundwater is affected in two ways:

(a) It is inherent in the form of contamination caused by the very nature of the geological formation. Excess fluoride, arsenic and iron fall and (b) Groundwater pollution caused by human intervention (anthropogenic), like over exploitation of shallow groundwater in the coastal area resulting in saltwater intrusion and discharge of untreated domestic sewerage and industrial effluents.

The impact of Industrial effluents is also responsible for the deterioration of the physical and chemical and bio-chemical parameters of groundwater [24]. The environmental impacts on the groundwater contaminations may seriously affect the socio-economic conditions of the country. Knowledge on water chemistry is important to assess the quality of aquatic resources for understanding its suitability for various needs [23].

3. Spatial Data Analysis Using Spatial Statistics

Geographic Information systems (GIS) are powerful computer aided tools for varied applications ranging from sophisticated analysis and modelling of spatial data to simple inventory and management. In groundwater studies, the spatial statistics can be applied to study the distributions of non point source contamination of groundwater on a regional scale. Spatial statistics method has also been used for various purposes such as groundwater potential, quality mapping and determination of spatial distribution of major and minor ions present in the water and has been applied in diversified applications in medical diagnosis, geology and other fields. These maps are being used as preliminary screening tools for policy and decision-making in groundwater management strategies on a regional scale.

4. Study Area

The Base map of Tiruchirappalli city was drawn from Survey of India Topo sheets Nos. 58 J/9, 10, 13 and 14 and satellite imagery (IRS-1C and LISS III) is lies between 10° 48' 18" North: 78° 41' 7" East. The general topology of Tiruchirappalli is flat and lies at an altitude of 78 m above sea level. Tiruchirappalli is fed by the rivers Cauvery and Kollidam. There are reserve forests along the river Cauvery. Golden Rock and the Rock Fort are the prominent hills. The southern/south-western part of the district is dotted by several hills which are thought to be an offset of the Western Ghats Mountain range and the soil is considered to be very fertile. For the sample collection, seventy nine bore well locations were identified. These locations were identified in such a way that the bore wells were evenly distributed over the study area. The water samples were collected for periods between March 2006 and December 2008. The water from these bore wells were used for drinking, house hold utilities and bathing by the residents. The Laboratory tests were conducted on these samples for 16 different physical and chemical potable water quality parameters using [1, 3, 26].

The study area with sampling locations as on Figure 1.

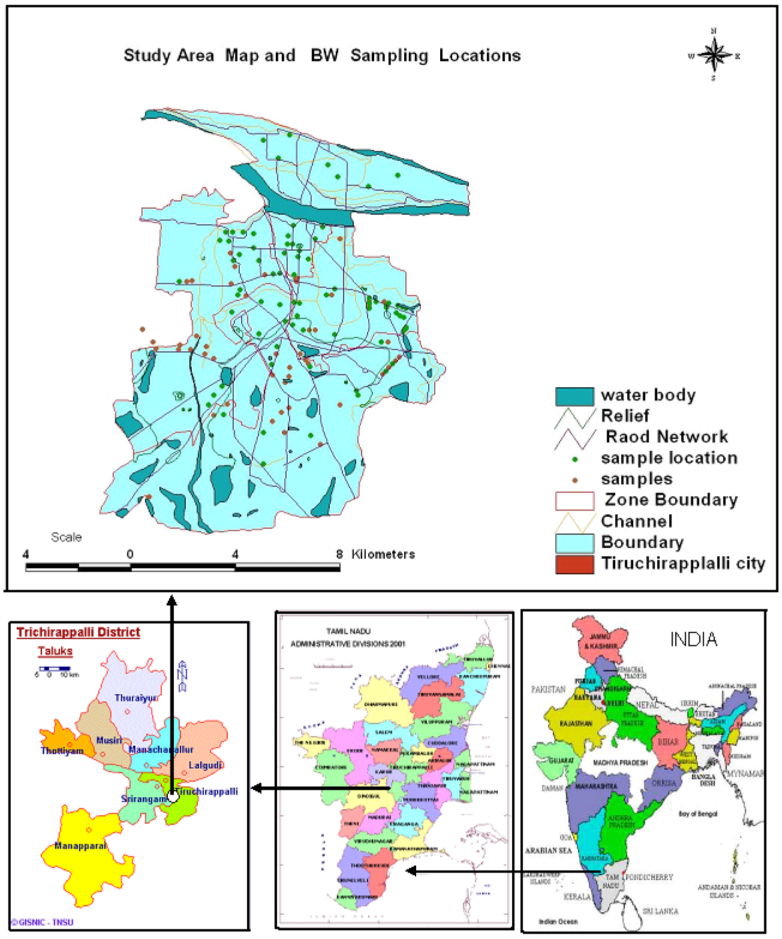


Figure 1. Study area map with sampling locations

5. Materials and Methods

The Base map of Tiruchirappalli area was drawn from Survey of India topographic map No. Topo sheets 58 J/9, 10, 13, 14-IRC-1C-LISS III and the bore well locations were identified and samples were collected from 79 boreholes of selected locations. The samples collected were water used for drinking, house hold utilities and bathing. The same were collected between March 2006 and December 2008. The most used 16 different physical and chemical water quality parameters as per the standard procedure [1, 2, 3, 26] criteria were adopted for testing the samples.

The groundwater hydrochemistry records of the Tiruchirappalli city corporation were used for the preparation of maps. These maps are obtained by geostatistical (Kriging) methodology and the results were presented in the form of equal ion concentration lines [30]. The MATLAB software was also used to analyse the data.

The groundwater quality data were used as the hidden layer for the preparation of base maps. These features were the boundary lines between mapping units, other linear features (streets, rivers, roads, etc. or point features like sampling bore well points, etc.). The contours were developed for pH, EC, Cl^-, Na^+, Ca^{++}, Mg^{++}, Total Hardness, Alkalinity, SO_4^-, Coliform and NO^-_3 values for the pre monsoon and post monsoon values and were stored in a grid file.

6. Groundwater Quality Monitoring Using Fuzzy Logic Controller and Simulink for Governing the Quality State in the Study Area

The theory of fuzzy sets was first introduced by [28] to model uncertainty in subjective information. Fuzzy sets are defined as sets whose members are vague objects. Data can generally be received in terms of linguistic judgments and beliefs (natural language), which can then be converted to the form of fuzzy sets in order to provide a base for logical and mathematical reasoning [29]. Simulink models were framed and used for selected parameters and providing pre constructed sub models which are linked to represent the complex interaction of the various parameters. The block diagrams, created for testing three groups of samples, were used in the present study and fuzzy model used is as shown on the Figure 2.

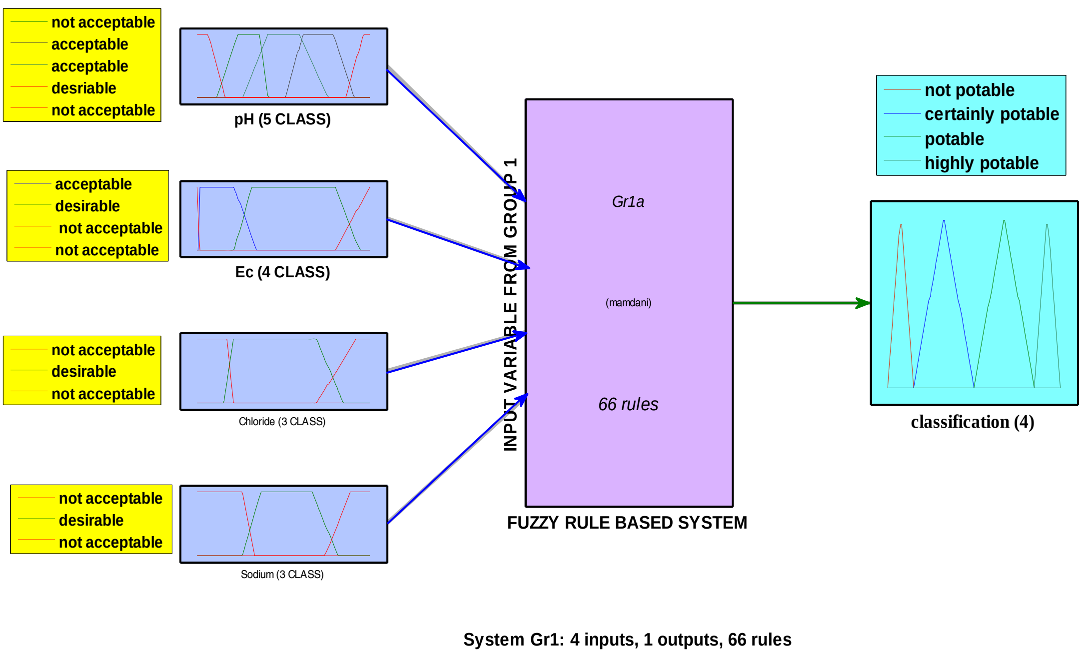


Figure 2. Block Diagram and Fuzzy Logic model for First Group water quality parameters

The simulation was used for the collected data for seasonal variations. Similarly the block diagrams were created for group II and group III in which the cation and anion were used as inputs. The 66 rules designed on the expert knowledge basis for the physical and chemical water quality parameters in group 1. In case of group 2, 73 rules fired for the classification of drinking water quality. This classification was based on the parameters studied in the second group. Results from group one and two were combined with group three to assess the final classification of water [13]. A total of 27 rules were fired for the final assessment of groundwater quality. The results from all the three groups were aggregated to assess the final classification of water as shown in the Figure 3.

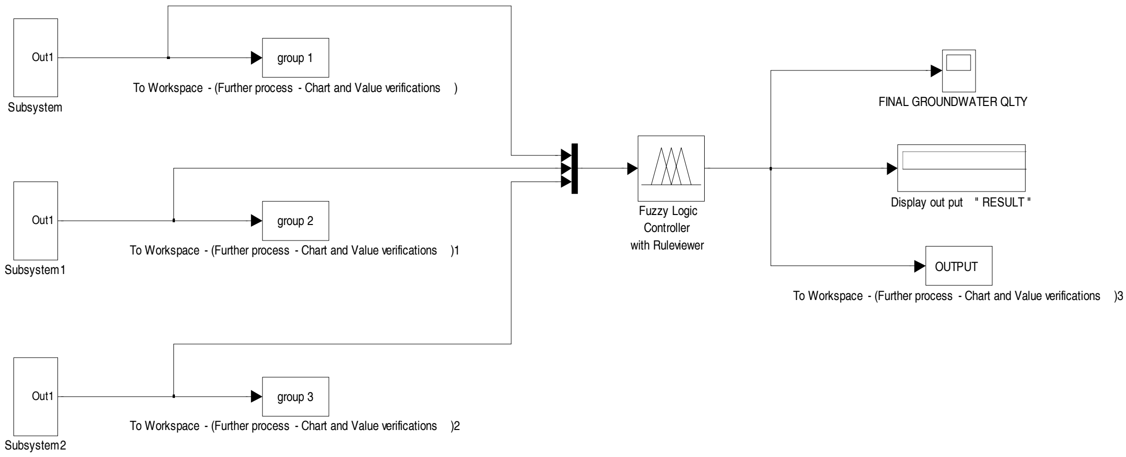


Figure 3. Block Diagram for the fuzzy Simulink process of FIP for Water quality assessment

7. Results and Discussion

7.1. The Major Findings of the Research Study Areas Follows

1) The accuracy of chemical analysis was verified by ionic balance errors and was found with in ± 5 %.
2) The hydro chemical analyses revealed that water samples in the study area is characterized by hard to very hard, fresh to brackish and alkaline in nature. The highly turbid water may cause health risk as excessive turbidity can protect pathogenic micro-organisms from the effects of disinfectants and also stimulate the growth of bacteria during storage.
3) Characteristic by pH values, most of the water samples were alkaline in nature which were well within permissible limit (6.5–8.5) and some of the samples have been found acceptable for usage and the ranges were between 6.5 and 9.2 meeting BIS standards of IS:10500:1991 and [26] guidelines.
4) Based on EC values measured in, all of the bore well water samples (Zone I) and plant water sample were desirable (< 1 mS/cm).
5) The microbial results indicated that all the samples exceeded the acceptable limit of drinking water purposes. *Salmonella* and *Shigella* presence was also detected.
6) Although, the water samples contain significant percentages or concentrations of calcium, magnesium, sulphate, alkalinity ($HCO_3 + CO_3$) and potassium ions, predominant presence of two ions, sodium and chloride were found in the samples.
7) It was found that about 60% of drinking water samples were found desirable for drinking purpose and the remaining 40% of samples could also acceptable for drinking in the absence of alternate water sources.
8) DEM diagrams are constructed directly from major anions and cations, so as to consider common behaviours within the study area. For instance, the DEM concentrations based on Cl^- and HCO_3^- values is presented on Figure 4.
9) Pre-monsoon and Post-monsoon contour potable water quality maps were constructed directly from major anions and cations, so as to consider twelve major anions and / or cations common behaviours within the study area. For instance, the contour maps of the equal concentrations based on regulatory body conditions is illustrated below (see Figures 5, 6, 7, 8).

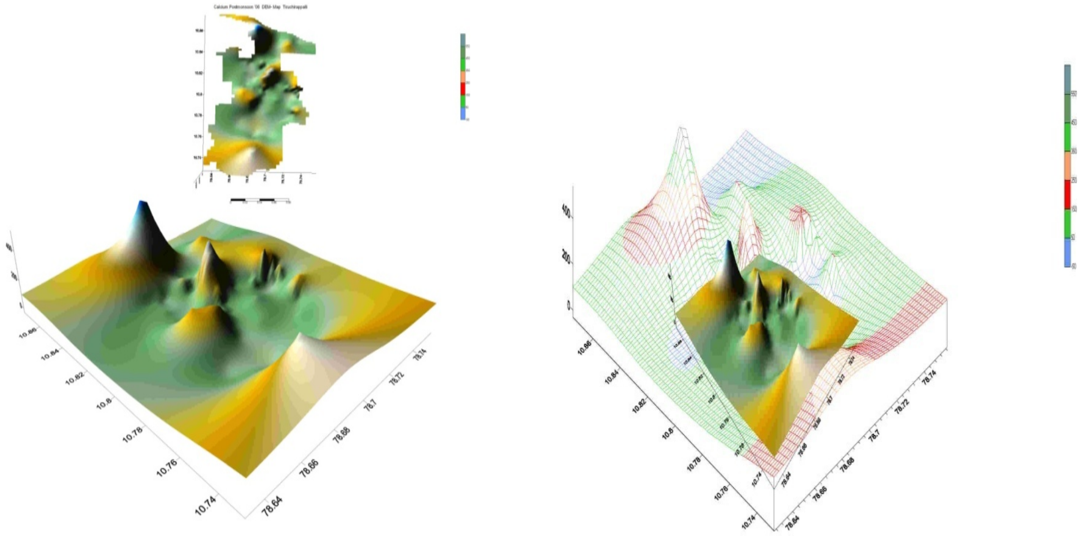


Figure 4. DSM generated for Chloride showing the Dispersion towards the zone IV of Tiruchirappalli city

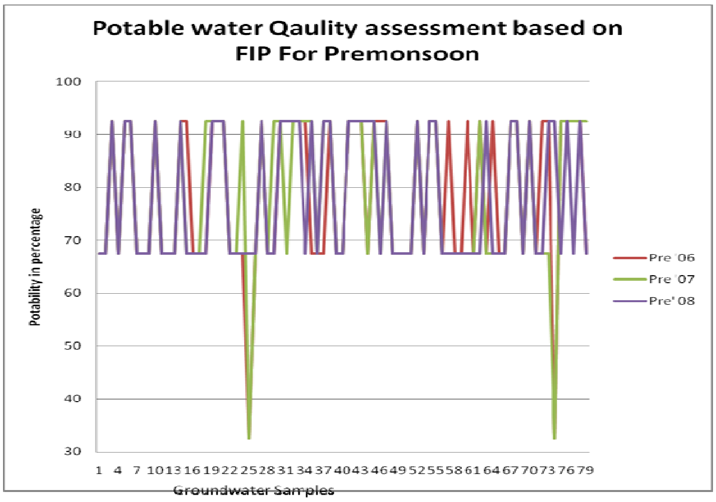


Figure 5. Post monsoon seasonal variations of potable water quality using Fuzzy Logic model results

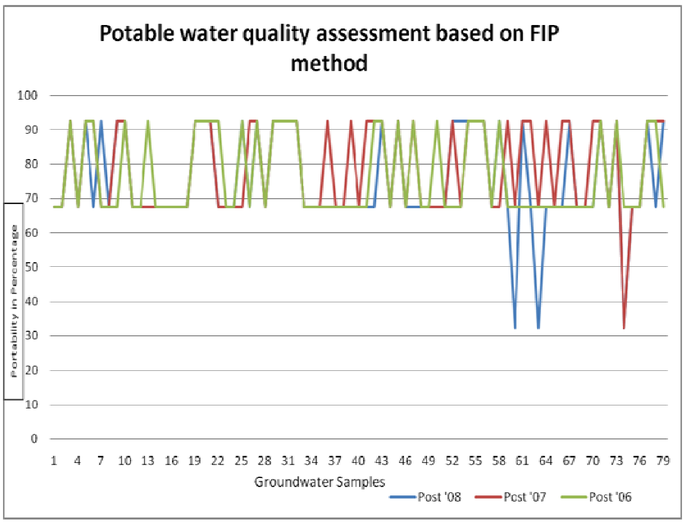
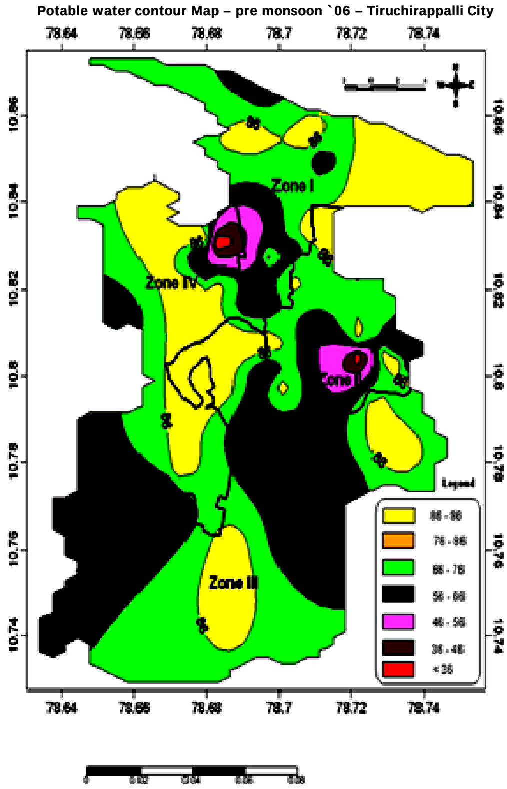


Figure 6. Pre monsoon seasonal variations of potable water quality using Fuzzy Logic model results

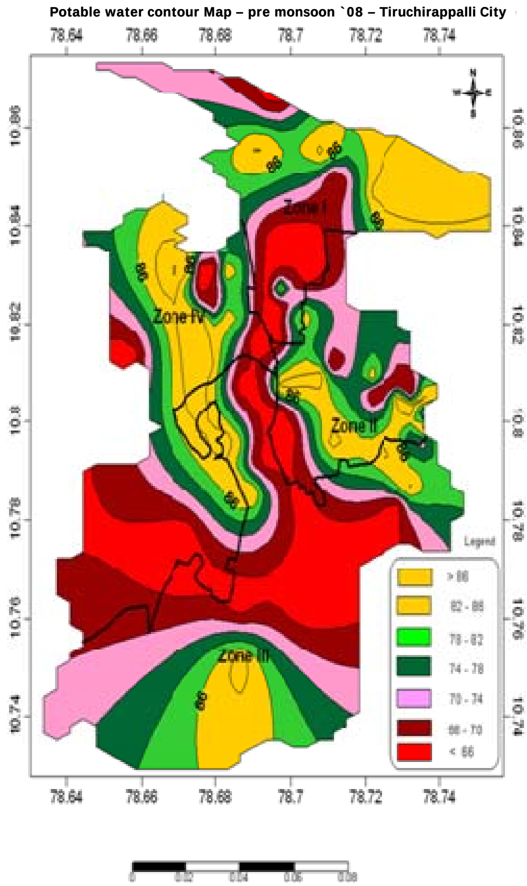


Potable Water Contour Map

Fuzzy Information Processing for Groundwater Quality Assessment

Fig. Potable Water Contour Map (in %)

During Pre monsoon 2006



Potable Water Contour Map

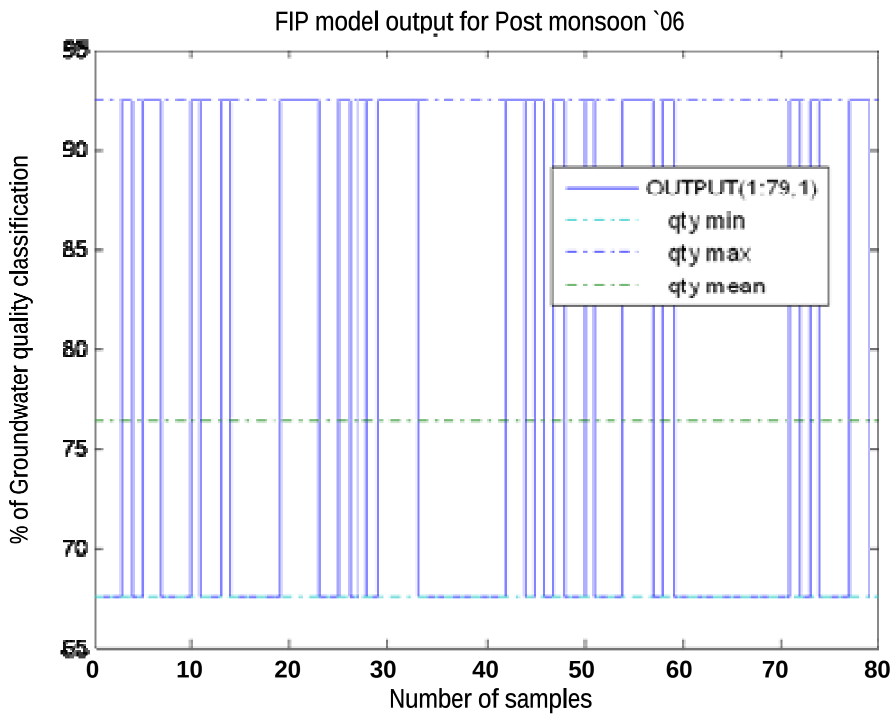
Fuzzy Information Processing for Groundwater Quality

Fig. Potable Water Contour Map (in %)

During Pre monsoon 2008

Figure 7. FIP generated Potable Water Contour Map for Pre Monsoon of Tiruchirappalli City

Groundwater classification based on FIP during Post monsoon-2006



Groundwater classification based on FIP during Post monsoon-2007

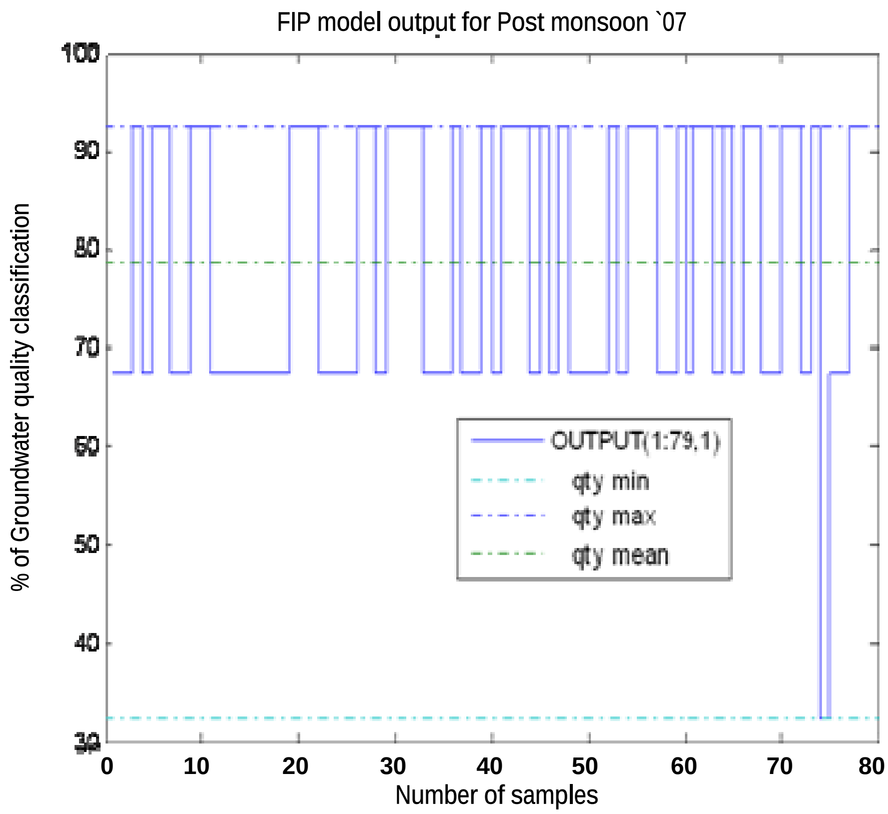


Figure 8. FIP Groundwater quality Classifcation during Post Monsoon 2006 and 2007

8. Artificial Neural Network Model for Predicting the Electrical Conductivity when Sulphates, Chlorides, Total Dissolved Solids and Ph are Available

Artificial Neural Network models learn from examples and captures clever functional relationships among the data even if the underlying relationships are unknown or hard to describe. Thus ANNs are well suited for problems whose solutions require knowledge that are difficult to specify but for which there are enough data or observations. Any forecasting model assumes that there exists an underlying (known or unknown) relationship between the inputs (the past values of the time series and / or other relevant variables) and the outputs (the future values). Frequently, traditional statistical forecasting models have limitations in estimating this underlying function due to the complexity of the real system. ANNs can be a good alternative method to identify this function.

Ground water modelling involves voluminous data, and accuracy of results depends on the availability of data on various input parameters based on the model developed as on Figure 9 shows the performance of the present study with ANN model. From the graph it can be said that value of correlation coefficient R is 0.9.

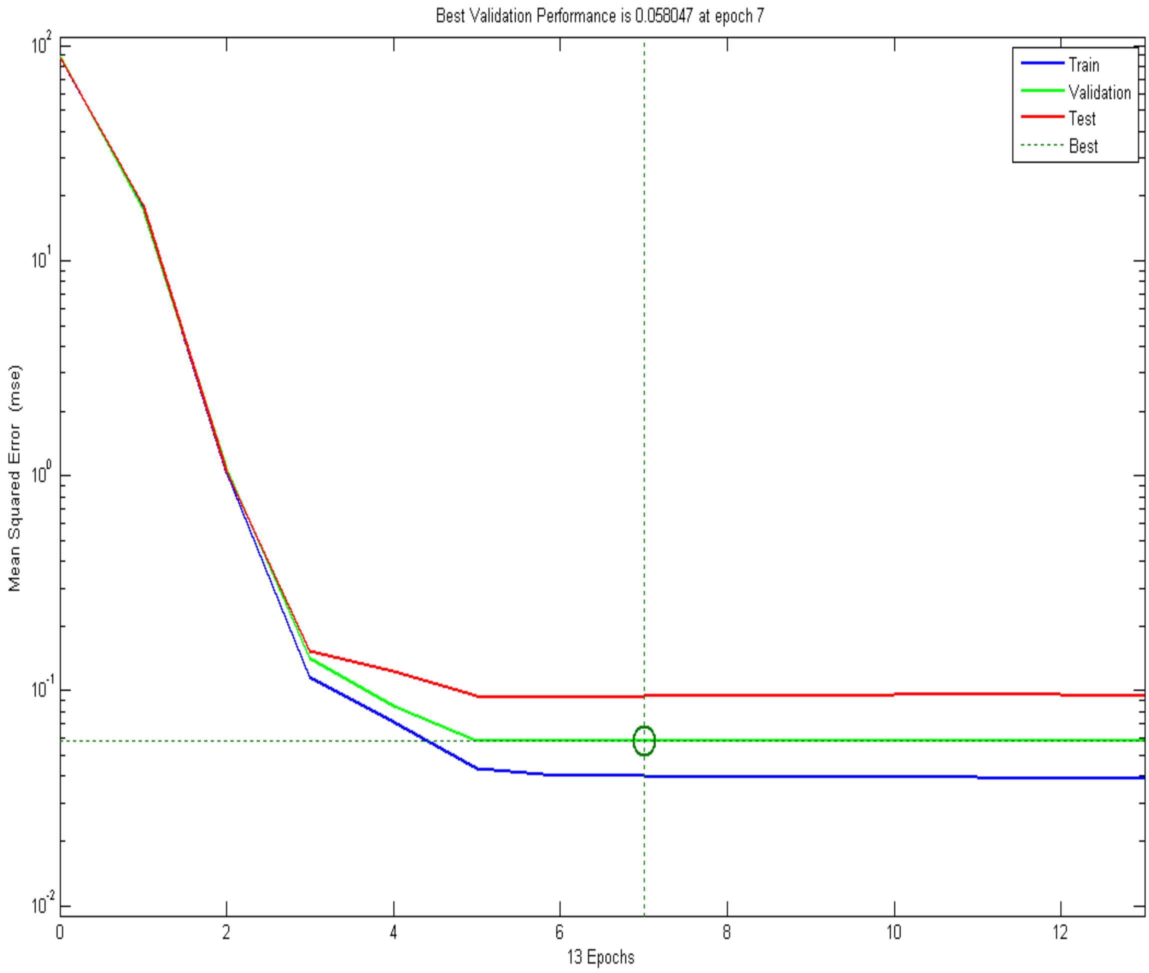


Figure 9. The output error variability of the ANN with epochs

An ANN model working on the principle of back propagation is confirmed to be a reliable method for the prediction of Groundwater quality as it is able to predict the Electrical Conductivity with a confidence level of 93.07%. It also predicts the pH and Total Dissolved Solids with a high confidence level Model (II) pH = 94.44% and TDS = 95.1%; Model (III) TDS = 85.71%). The optimum correlation R = 0.8973 was obtained during the performance and illustrated on Figure 10.

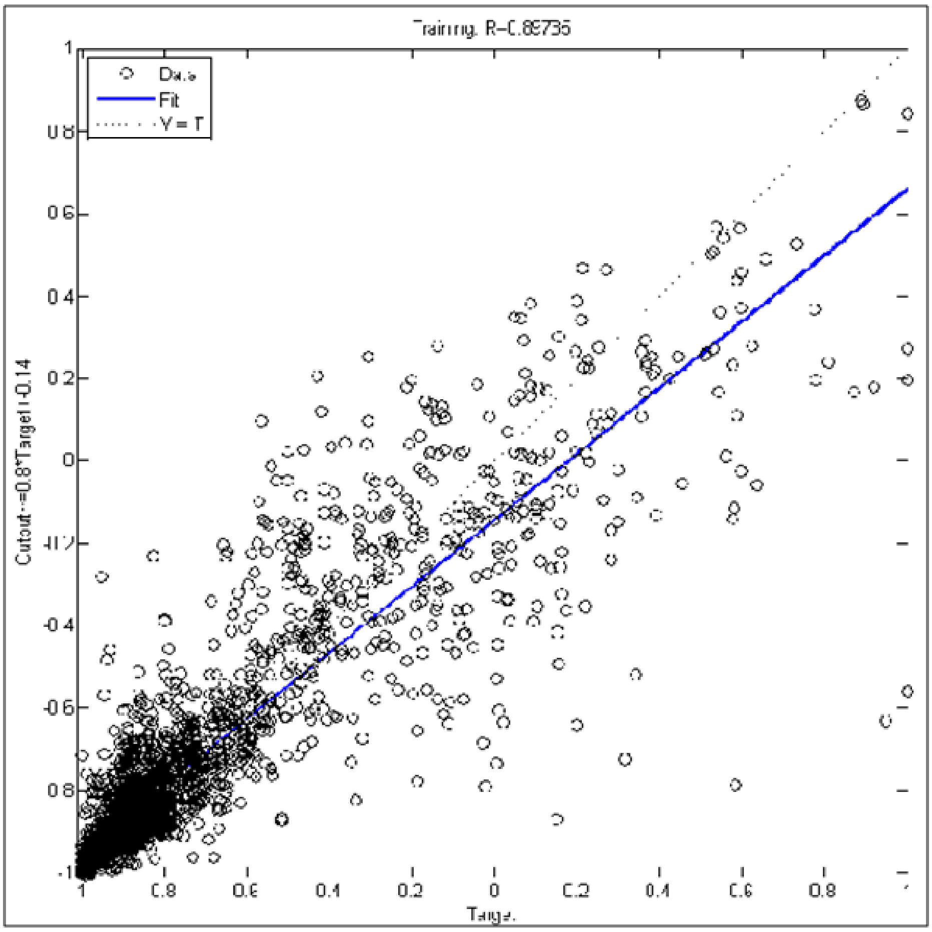


Figure 10. The relationship between target Value and training value

Conclusions

The quality of the groundwater of the Tiruchirappalli city was monitored in 79 sampling wells for 3 years and recorded data revealed that the concentrations of cations and anions were above the maximum, desirable for human consumption. The Electrical Conductivity was found to be the most significant parameter within input parameters used in the modelling. The developed model enabled well to test the data obtained from 79 samples of bore wells of Tiruchirappalli city. Therefore, with the proposed model applications, it is possible to manage groundwater resources in a more cost-effective and easy way.

Ground water quality modelling involves voluminous data, and accuracy of results depends on the availability of data. The various input parameters based on the developed model and its observation, the following points have been arrived as conclusions.

It is difficult to understand the issues related to epidemic diffusion simply by groundwater quality analysis as it lacks spatial information. Therefore, combination of groundwater quality parameters, fuzzy logic and GIS methods is very useful to all and to model the water quality related issues as GIS provides efficient capacity to visualize the spatial data.

The dynamic nature of ANN allows modifying the predictor with the help of new test data generated to grab the new features associated with the environment and developments in the water quality parameter over time. This saves time and experimental efforts required to generate new models.

Acknowledgements

The first author gratefully acknowledges the support by Fellowship under TEQIP, MHRD, and Govt. of India for his Doctoral study. The authors wish to express their sincere appreciation to the anonymous reviewers for their valuable comments to enhance the quality of this paper. Special thanks to Sarva Mangala Preveena, Doctoral Student, University of Malaysia, Saba Malaysia for her constant support in preparation of this manuscript. Special thanks go to M. Kannan (SASTRA) in the GIS field activities and in the laboratory measurement of this study. Sincere thanks to Professor K. Palanichamy, Civil Engineering Department, National Institute of Technology, Tiruchirappalli-15, India for providing constant encouragement throughout his study of the research. The authors wish to express many thanks to the anonymous reviewers for their valuable comments to enhance the quality of this paper.

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Received on the 22nd of June, 2010

Computer Modelling & New Technologies, 2010, Volume 14, No. 2
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CUMULATIVE INDEX

COMPUTER MODELLING and NEW TECHNOLOGIES, volume 14, No. 2, 2010 (Abstracts)

Yu. N. Shunin, Yu. F. Zhukovskii, N. Burlutskaya, V. I. Gopeyenko, S. Bellucci. Theoretical Resistance Simulations for Junctions of SW and MW Carbon Nanotubes with Metal Substrates in Nanoelectronic Devices, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 7–19.

In the current study, basic attention is paid to the junctions of carbon nanotubes (CNTs) with contacting metallic elements of a nanocircuit. Numerical simulations on the conductance and resistance of these contacts have been performed using the multiple scattering theory and the effective media cluster approach. Two models for CNT-metal contacts have been considered in this paper: a) first principles "liquid metal" model and b) empirical model of "effective bonds" based on Landauer notions on ballistic conductivity. Within the latter we have simulated both single-wall (SW) and multi-wall (MW) CNTs with different morphology. Results of calculations on resistance for different CNT-Me contacts look quantitatively realistic (from several to hundreds kOhm, depending on chirality, diameter and thickness of MW CNT). The inter-wall transparency coefficient for MW CNT has been also simulated, as an indicator of possible 'radial current' losses.

Keywords: *carbon nanotubes, single-wall and multi-wall morphology, nanotube-metal (CNT-Me) junction, scattering theory, electronic structure calculations, conductance and resistance in CNT-Me contact, inter-wall transparency in CNTs*

I. Klevecka. Forecasting Traffic Loads: Neural Networks vs. Linear Models, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 20–28.

The main aim of the research was to produce the short-term forecasts of traffic loads by means of neural networks (a multilayer perceptron) and traditional linear models such as autoregressive-integrated moving average models (ARIMA) and exponential smoothing. The traffic of a conventional telephone network as well as a packet-switched IP-network has been analysed. The experimental results prove that in most cases the differences in the quality of short-term forecasts produced by neural networks and linear models are not statistically significant. Therefore, under certain circumstances, the application of such complicated and time-consuming methods as neural networks to forecasting real traffic loads can be unreasonable.

Keywords: telecommunications, packet-switched networks, traffic forecasting, neural networks, ARIMA, exponential smoothing

E. Revzina. Stochastic Models of Data Flows in the Telecommunication Networks, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 29–34.

One of the successful applications of the stochastic models in engineering lies in the field of telecommunications. There are several branches of telecommunications that use different types of stochastic models. The study of multivariate character of the telecommunication processes is an important aspect for many applications. The aim of the given paper is to overview the use of BMAP-flows in stochastic queueing systems.

The BMAP-flow was described in detail and explained the importance of the generating function for this flow. The family of frequently used by researchers BMAP-flows is considered: Markovian Arrival Process (MAP), Markov-Modulated Poisson Process (MMPP) and PH – Phase Type process (PH).

Keywords: *Poisson flow, Markov's chains, stochastic queueing systems*

V. Vishnevsky, O. Semenova. Algorithm to Calculate Stationary Distribution for Duplex Polling System, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 35–39.

We consider the duplex system presented by two independent servers and multiple M/M/1-type queues to model the operation of cyclic polling systems in very high throughput wireless mesh-networks.

Each server polls its own group of queues. Some queues are common, i.e. accessible for service by both servers. To obtain the joint queue length distribution, we analyse the Markov chain describing the system states by means of the power-series algorithm which is a tool for numerical evaluation of the performance of a broad class of multi-queue models.

Keywords: *wireless mesh-network, duplex system, polling system, power-series algorithm.*

I. Yatskiv, V. Gromule, N. Kolmakova, I. Pticina. Service Quality Indicator at Riga International Coach Terminal, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 40–49.

The level of service in „Rīgas Starptautiskā Autoosta" is studied. This enterprise provides the international, intercity and regional trips. Recent studies on the role of buses and coaches seem to confirm the already excellent safety, environmental and social record of bus and coach transport. The main attention was paid to the analyses of quality of service and its components. The theory of linear composite indicator constructing and statistical methods are used for definition of weights of aggregation function. The model was done on the basis of the questionnaire results of transport experts.

The model constructed for a scalar quality indicator, allows comparing analyzed service for the services given by other companies, to estimate influence of particular quality indicators on the overall quality estimation and to simplify monitoring of quality indicators.

Keywords*: bus terminal, quality of service, scalar indicator, weights, regression models, restrictions*

J. Kundler. Multidimensional Meta-Modelling for Air Traffic Management Service Processes, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 50–57.

Business Processes supported by IT Services is one of the mission critical factors of modern Air Traffic Control Providers (ATC). Particularly ATC companies are highly dependent on their technical process know how and to deliver a safe and efficient ATC Services. During research of dissertation by different ATC providers it was observed that no general meta-model for ATC technical services exists.

On the base of multidimensional modelling method the approach for modelling and design of a general ATC meta-model in context to ITIL Standard and ISO 20000 standard has been performed. The results of this research have been used for further optimisation and increasing of harmonization of the ATC technical service processes.

The focus of research is to develop a universal high level multidimensional model for technical ATC services, because over medium term period it will be essential on the European ATC market to change from a national oriented ATC provider to a global European ATC service provider which is able to support the ATC business on a standard technical service process model. With respect to the Single European Sky program from the European Commission and the activities of different national ATC service provide to create international functional airspace blocks a metaframe or meta multidimensional process model of technical services should be the basis for standardization of ATC technical services and be able to change from a national ATC-provider with their own best practices to a European global ATC provider.

An essential prerequisite for globalisation of European ATC market is to develop a global and standardized ATC process model. Based on the developed ATC meta-model technical services can be designed and described by dimension tables, information cubes. The ATC meta-model is to be the basis of high level description by scientific methods and can be used as input information for the specific ATC process management and monitoring.

The goal of meta frame model by multidimensional modelling is to investigate into standardization of ATC technical process landscape, to design specific key performance parameter for evaluation and benchmarking and to derive technical expertise for a migration of own specific technical processes to a general standardized meta process model of AIS Services. For that reason the research presents different number of data/information cubes and dimensional tables. The main result of the research is the developed Meta ATC Process model.

Keywords: *Multidimensional modelling, Modules of metaframe, Questionnaire and Dimension tables, ATC modelling cubes, Metric Controlled Meta Model Cubes*

M. Samson, G. Swaminathan, N. Venkat Kumar. Assessing Groundwater Quality for Potability Using a Fuzzy Logic and GIS – a Case Study of Tiruchirappalli City – India, *Computer Modelling and New Technologies*, vol. 14, No 2, 2010, pp. 58–68.

Water quality management is an important issue in the modern times. In this paper, the application of fuzzy set theory for decision-making in the assessment of groundwater quality for drinking purposes. This is illustrated with seventy nine groundwater samples collected from Tiruchirappalli, S. India. These 79 samples were analysed for 12 physical and chemical parameters. Fuzzy groundwater classification rule base derivation from groundwater quality variation maps, which are based on twelve ions. These maps are obtained by geostatistical (Kriging) methodology and the results are presented in the form of MAPS as equal ion concentration lines. They help to visualize between desirable to Acceptable limits with twelve ions with linguistic interpretations. For this purpose four ions are separated into three linguistic categories, as 'Desirable', 'Acceptable' and 'Not Acceptable', which are characterized numerically by membership functions (MFs). Accordingly, the linguistic fuzzy 181 rules are presented for classification of quality based on different ions. In general, it is possible to run for the high data Volume of water quality. Simulink is used and the results are presented in GIS maps.

Keywords: *Fuzzy Logic, Simulation, Kriging, Water Quality, GIS, Tiruchirappalli*

COMPUTER MODELLING and NEW TECHNOLOGIES, 14.sējums, Nr. 2, 2010 (Anotācijas)

J. Šuņins, J. Žukovskis, N. Burlutskaja, V. Gopejenko, S. Beluči Teorētiskās rezistences imitācijas karbona nanocauruļu *SW* un *MW* mezgliem ar metāla pamatiem nanoelektroniskajās ierīcēs, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 7.–19. lpp.

Dotajā pētījumā pamatuzmanība tiek veltīta karbona nanocauruļu mezgliem (*carbon nanotubes – CNTs*), kontaktējoties ar metāla elementiem nano-riņķojumā.Tiek veikti neskaitāmas šo kontaktu vadītspējas un pretestības imitācijas, pielietojot multiplo izkliedes teoriju un efektīvo mēreno klasteru pieeju. Šajā rakstā tiek izskatīti divi *CNT* metāla kontaktu modeļi: pirmais – „šķidrā metāla” modelis un otrais – empīriskais „efektīvo saišu” modelis.

Pretestības dažādiem *CNT-Me* kontaktiem aprēķinu rezultāti izskatās kvantitatīvi reāli (no dažiem līdz simtiem kOhm, atkarībā no *MW CNT* atspulga, diametra un blīvuma).

Atslēgvārdi: *karbona nanocaurules, SW* un *MW morfoloģija, nanocaurules metāla mezgls, izkliedes teorija, elektroniskie struktūras aprēķini, CNT-Me kontaktu vadītspēja un pretestība*

I. Klevecka. Satiksmes kravnesības prognozēšana: neironu tīkli vs. lineārie modeļi, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 20.–28. lpp.

Pētījuma galvenais mērķis ir radīt īstermiņa prognozes satiksmes kravnesībai, pielietojot neironu tīklus un tradicionālos lineāros modeļus, tādus kā autoregresīvos-integrētos kustošos vidējos modeļus un eksponenciālo izlīdzināšanu.

Darbā tiek analizēts parastā telefonu tīkla trafiks, kā arī pakešu IP-tīkls. Eksperimentālie rezultāti pierāda, ka vairumā gadījumu atšķirības īstermiņa prognožu kvalitātē, ko rada neironu tīkli un lineārie modeļi, statistiski ir mazsvarīgi. Tādēļ pie noteiktiem apstākļiem šādu sarežģītu un laikietilpīgu metožu pielietošana kā neironu tīkli, prognozējot reālo satiksmes kravnesību, var izrādīties nesaprātīga.

Atslēgvārdi: *telekomunikācijas, pakešu IP-tīkli, trafika prognozēšana, neironu tīkli, eksponenciālā izlīdzināšana*

E. Revzina. Datu plūsmu stohastiskie modeļi telekomunikāciju tīklos, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 29.–34. lpp.

Viens no stohastisko modeļu veiksmīgākajiem pielietojumiem inženierzinātnēs ir telekomunikāciju joma. Pastāv dažas telekomunikāciju nozares, kas lieto atšķirīgus stohastisko modeļu tipus. Telekomunikāciju procesu daudzšķautnainā rakstura pētīšana ir svarīgs aspekts daudziem pielietojumiem. Dotā raksta mērķis ir apskatīt *BMAP*-plūsmas stohastiskajās rindošanas sistēmās.

BMAP-plūsmas ir aprakstītas detalizēti, un bez tam arī ir izskaidrota šīs plūsmas ģenerējošās funkcijas svarīgā loma.

Atslēgvārdi: *Puasona plūsma, Markova ķēdes, stohastiskās rindošanas sistēmas*

V. Višņevskis, O. Semenova. Stacionārās sadales aprēķina algoritms dupleksai aptaujas sistēmai, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 35.–39. lpp.

Autori savā rakstā izskata duplekso sistēmu, kas tiek parādīta kā divi neatkarīgi serveri un multipla *M/M/1*-veida rindas, lai modelētu ciklisku aptaujas sistēmu ļoti augstas caurteces bezvadu sazobes tīklos. Katrs serveris aptaujā savu rindu grupu. Dažas rindas ir kopējas, t.i., pieejamas abiem serveriem. Lai iegūtu savienotas rindas garuma sadali, autori analizē Markova ķēdes aprakstošas sistēmas stāvokļus, ar spēka-sērijas algoritma palīdzību, kurš ir līdzeklis skaitliskai izvērtēšanai daudzrindu modeļu plašās klases darbībai.

Atslēgvārdi: *bezvadu sazobes tīkls, dupleksa sistēma, aptaujas sistēma, spēka-sērijas algoritms*

I. Jackiva, V. Gromule, N. Kolmakova, I. Pticina. Servisa kvalitātes rādītājs Rīgas strarptautiskajā autobusu terminālī, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 40.–49. lpp.

Regulāri tiek pētīts pasažieru apkalpošanas līmenis Rīgas starptautiskajā autoostā. Uzņēmums nodrošina starptautiskos, starppilsētu un reģionālos pasažieru pārvadājumus. Nesenie pētījumi rāda, ka minētajā autoostā tiek nodrošināta lieliskas drošības, videi draudzīga un sociāli atbilstīga autobusu un starptautisko autobusu pakalpojumu sniegšana. Veicot pētījumu, lielākā uzmanība tika veltīta servisa sniegšanas kvalitātes analīzei. Statistiskās funkcijas noteikšanai tiek izmantots uzbūves lineārās kompozīta teorijas rādītājs, kā arī statistiskās metodes. Modelis ir izveidots, pamatojoties uz ekspertu aptaujas rezultātiem.

Modelis ir izveidots skalāram kvalitātes rādītājam, kas ļauj salīdzināt analizējamos pakalpojumus, sniegtus citām kompānijām, novērtēt konkrētos kvalitātes rādītājus, kā arī vienkāršot kvalitātes rādītāju monitoringu.

Atslēgvārdi: *autobusu terminālis, servisa kvalitāte, skalārais rādītājs, regresijas modeļi, ierobežojumi*

J. Kundlers. Multidimensionāla meta-modelēšana gaisa satiksmes servisa procesu menedžmentam, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 50.–57. lpp.

Mūsdienu Gaisa satiksmes kontroles provaideru (*ATC*) misijas kritiskie faktori ir biznesa procesu nodrošināšana ar IT pakalpojumiem. Minētās *ATC* kompānijas ir lielā mērā atkarīgas no to tehniskā nodrošinājuma, lai sniegtu drošu un efektīvu *ATC* servisu.

Pētījumā tiek izstrādāta, pamatojoties uz multidimensionālu modelēšanas metodi, vispārēja *ATC* meta-modeļa modelēšanas un dizaina pieeja kontekstā ar *ITIL* standartu un ISO 2000 standartu.

Pētījuma mērķis ir izveidot universālu augsta līmeņa multidimensionālu modeli tehniskajiem *ATC* servisiem tāpēc, ka pēc kāda laika tas būs būtiski Eiropas *ATC* tirgū, lai mainītos no nacionāli-orientētu ATC provaidera uz globālo ATC provaideru, kurš ir spējīgs nodrošināt ATC biznesu kā standarta tehniskā servisa procesa modelis.

Darbā tiek sniegti neskaitāmi datu/informācijas kubi un dimensionālās tabulas. Pētījuma galvenais rezultāts ir izstrādātais *Meta ATC* procesa modelis.

Atslēgvārdi: *multidimensionālā modelēšana, meta uzbūves moduļi, ATC modelēšanas kubi, aptaujas un dimensijas tabulas, metriskie kontrolētie meta modeļa kubi*

M. Samson, G. Swaminathan, N. Venkat Kumar. Novērtējot pazemes ūdeņu kvalitāti pārnesamībai, lietojot faziloģiku un *GIS* – Tiručirapali pilsētas izpēte Indijā, *Computer Modelling and New Technologies,* 14.sēj., Nr.2, 2010, 58.–68. lpp.

Mūsdienās ūdens kvalitātes pārvaldība ir ļoti svarīgs pasākums. Šajā rakstā autori parāda fazi rindu teorijas pielietojumu lēmumu pieņemšanā dzeramā ūdens kvalitātes noteikšanā. Darbā tas tiek ilustrēts ar 79 pazemes ūdens piemēriem, kas savākti Tiručirapali pilsētā Dienvidindijā.. Tie tika analizēti 12 fizioķīmiskiem parametriem. Fazi pazemes ūdeņu klasifikācijas noteikums pamato atvasinājumu no pazemes ūdens kvalitātes variāciju kartēm, kas pamatojas uz 12 joniem. Šīs kartes ir iegūtas ar ģeostatistisko (Kriginga) metodoloģiju, un rezultāti ir parādīti karšu veidā līdzīgi jonu koncentrācijas līnijām. Tie palīdz vizualizēt starp vēlamajiem uz Pieņemamajiem limitiem ar divpadsmit joniem ar lingvistiskajām interpretācijām. Šim nolūkam četri joni tiek atdalīti trijās lingvistiskajās kategorijās, kā "Vēlamie", "Pieņemamie" un "Nepieņemamie", kas tiek raksturoti skaitliski ar piederības funkcijām (*MFs*). Tādējādi lingvistiskais fazi 181 noteikums tiek parādīts kvalitātes klasifikācijas, kas pamatojas uz dažādiem joniem. Kopumā ir iespējams dabūt ūdens kvalitātes augstos datu apjomus. *Simulink* tiek pielietota un rezultāti tiek parādīti *GIS* kartēs.

Atslēgvārdi: *fazi loģika, simulācija, Krigings, ūdens kvalitāte, GIS, Tiručirapali*

COMPUTER MODELLING & NEW TECHNOLOGIES

ISSN 1407-5806 & ISSN 1407-5814(on-line)

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Transport and Telecommunication Institute

Supporting Organizations:
Latvian Transport Development and Education Association
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COMPUTER MODELLING AND NEW TECHNOLOGIES, 2010, Vol. 14, No.2

Scientific and research journal of Transport and Telecommunication Institute (Riga, Latvia)
The journal is being published since 1996.

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