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The Analysis of Requirements and Designing of a Software 'Identifications of Products Pipe Lines Corrosion States on the Basis of Graph Models'

Local models for Different Corrosion Process

- **Simple models: Bikkaris, Vellner, Godart, Denison, Drum, Johnson, Martin, Mor, Suterland, Tornes, Upham, Faradej, Hejnik, Shvank and others.**
- **More complex models with exponent : Azis, Mitkalf, Tsikerman L.J., Champion, and others.**
- **Math models with logarithm of an independent variable: Vittaker, Demin J.V., Bug N.P., Liddiard, Hok, TSihal, etc.**
- **Algebraic multifactorial models: Agniboti U.S., Dorofeev A.G., Kats A.S., Luchina M.A., Nalimov S.M., Nanda N.N., Shrejber G.K.**
- **Dynamic models of corrosion process: Agafonov V.V., Berukshtis G.K., Buraja M.V., Golubev A.I., Bug Y.M., Zhuravlev N.P., Kadyrov M.H., Klark G.B., Mihajlovskij J.N., Pritula V.A., Taisi, Turkovskaja A.V., Tsikerman L.J., Shturman Y.P., Kerimov A.M. and others.**
- **Models of target variable y‘ speed: Gorman I.V., Kuper A.S., Lysaja A.I., Sereda, Palmer I.D., Tsikerman L.J., etc.**
- **Models of a target variable y“ acceleration : Tsikerman L.J., etc.**

$$y = A \cdot t^{\alpha} \qquad y = y_0[1 - \exp(-\alpha \cdot t)];$$

$$y = y_0[1 - A_1 \exp(-\frac{t}{T_1}) - A_2 \exp(-\frac{t}{T_2})],$$

$$y = y_0 \lg(t_0 + t);$$

$$y = a_n \ln^n t + a_{n-1} \ln^{n-1} t + \ldots + a_0 \ln t + d$$

$$y = x_1(a_1 + a_2 x_2 + \ldots + a_7 x_7);$$

$$y = a_0 + a_1 x_1 + \ldots + a_7 x_7,$$

$$y = y_0 \frac{t}{t+T};$$

$$y = -A + (A^2 + Bt)^{1/2};$$

$$y = [A + B(t-D)]t - [a_1 - a_2(t - t_1) + a_3(r - E) - F];$$

$$y = \frac{A}{t_1} a_1 + \frac{B}{t_2} a_2;$$

$$y = A_1 t_1 + A_2 t_2;$$

$$y = y_0 \frac{A}{BC} t;$$

$$y = C_1 e^{A_1 t} + C_2 e^{A_2 t} + \alpha + \beta t + (\gamma + \theta t) \cos wt + (\varepsilon + K t) \sin t,$$

$$\frac{dy(t)}{dt} = \frac{dy(0)}{dt} \exp(-\alpha \cdot t); \quad y' = \frac{t}{At^2 + Bt + C};$$

$$y' = A \cdot \exp(-\frac{t}{T}) C_{H_2S}^{D} p^{E}; \quad y' = y'_0 \frac{A}{t+A};$$

$$\lg(y') = Ay' + By + c.$$

$$y'' = \frac{C - At^2}{(At^2 + Bt + C)^2}; \; y'' = A \sin\frac{t}{T} \cdot \exp(-C\frac{t}{T})$$

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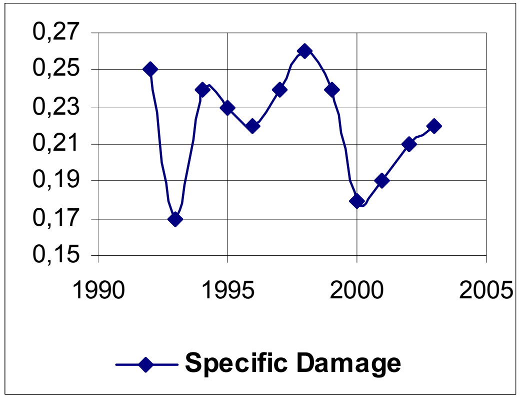
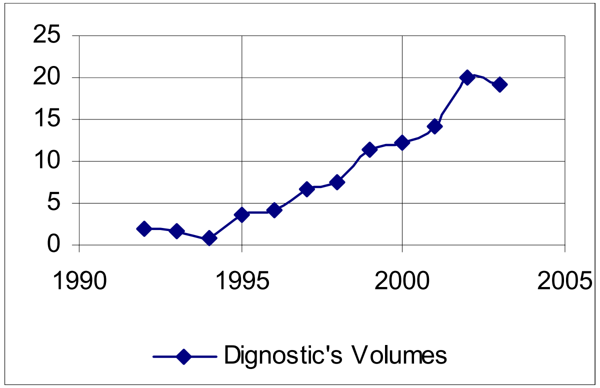
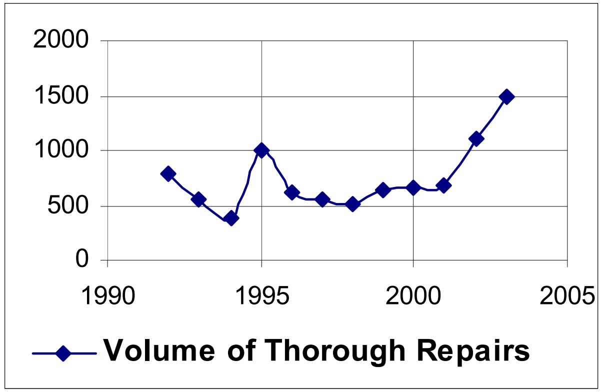
Pipelines Corrosion State Forecasting







■Diagnostic volumes and capital repairs impact on breakdown susceptibility of pipelines (Gasprom)

- **На этапе эксплуатации, превышающем 30 лет, для поддержания удельной повреждаемости на среднем уровне вынуждены существенно повышать объемы ВТД и объемы различного типа ремонтов.**
- **Статистика причин, приводящих к повреждению, показала, что коррозионные процессы в металле ТП составляют более 80 %.**
- **At an 30 years operation phase, for maintenance of breakdown susceptibility on an average level they are compelled to raise essentially defectoscopy and repairs volumes.**
- **The statistics of the reasons leading to failures showed that corrosion processes of metal damage consist of more than 80 %.**

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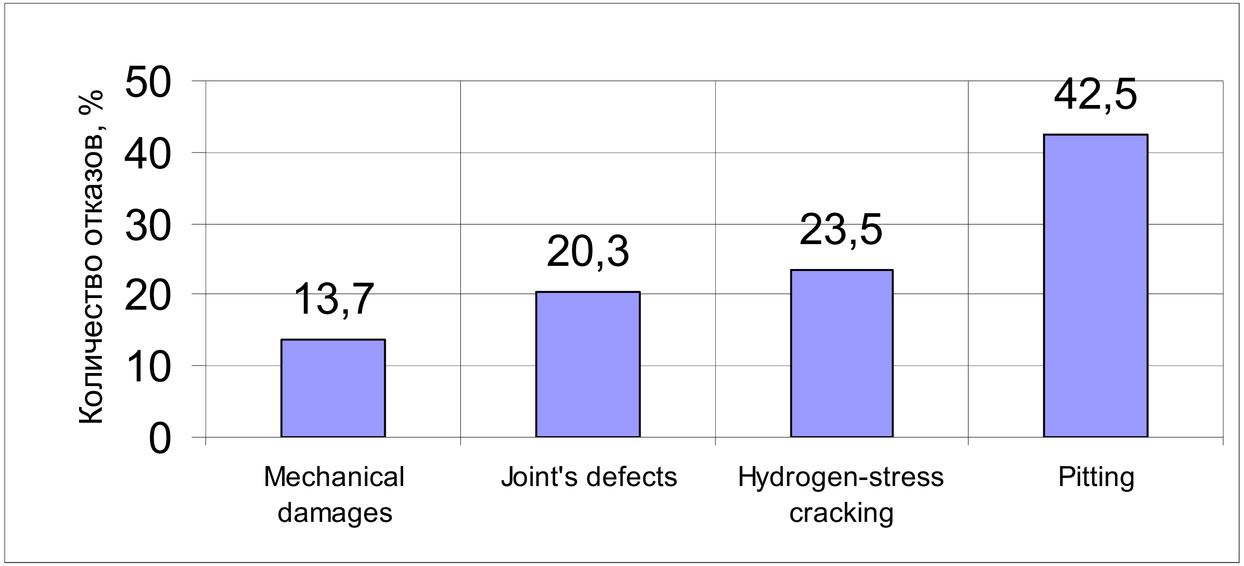
The reasons of pipelines corrosion refusals



The analysis* of a plenty cumulated datas for the operational period of OrenburgGasprom from 1974 till 2005, allows to allocate corrosion process as a determining type of pipeline damages. And pitting is the main component of this process.

The basic problem is forecasting of actual condition for long-term exploited steel pipelines and creation of schedules diagnostic and repairing for defective parts.

*** Dr. G. Vladov**

Hypothesis

- Suppose occurrence and development of defects are flows of random events for every pipeline.
- Let pittings classify by significant intervals (relative to residual wall's thickness) for every pipelines depends from its corrosion state.
- Number of significant intervals for long-term exploited pipelines is not more then 5. This define finite number of damage types.
- Let intensities dependence from time. This allows to forecast state probabilities for pipelines.

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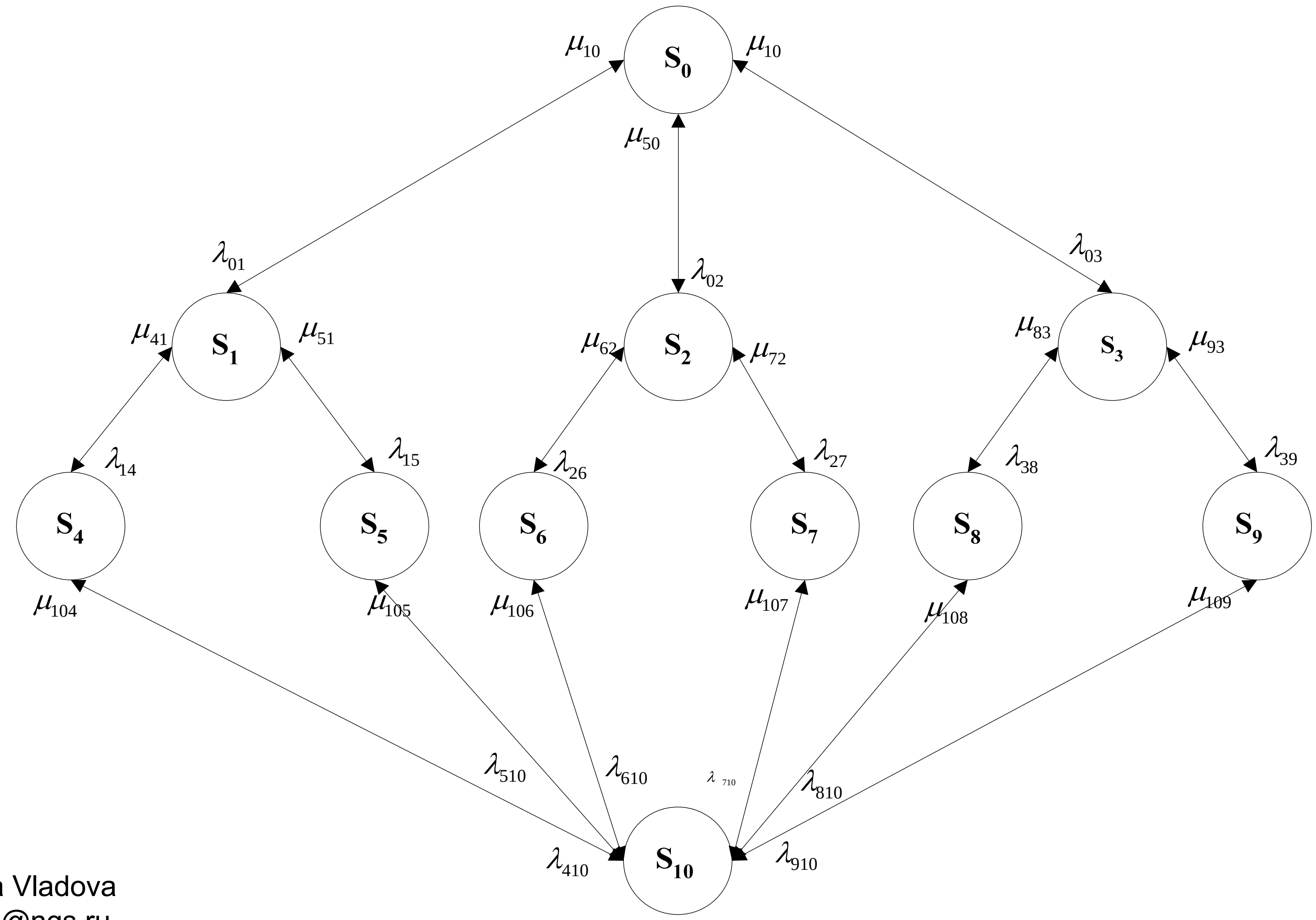
The graph model $G(S_0,\ldots S_{10})$ of pipeline state probabilities with 3 damage types



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The Math Model of Graph $G(S_0,\ldots S_{10})$

System of differential equations

$$
\begin{cases}
\frac{dp_1(t)}{dt} = p_0(t)\lambda_{01} + p_4(t)\mu_{41} + p_5(t)\mu_{51} - p_1(t)(\mu_{10} + \lambda_{14} + \lambda_{15}); \\
\frac{dp_2(t)}{dt} = p_0(t)\lambda_{02} + p_6(t)\mu_{62} + p_7(t)\mu_{72} - p_2(t)(\mu_{20} + \lambda_{26} + \lambda_{27}); \\
\frac{dp_3(t)}{dt} = p_0(t)\lambda_{03} + p_8(t)\mu_{83} + p_9(t)\mu_{93} - p_3(t)(\mu_{30} + \lambda_{38} + \lambda_{39}); \\
\frac{dp_4(t)}{dt} = p_1(t)\lambda_{14} + p_{10}(t)\mu_{104} - p_4(t)(\mu_{41} + \lambda_{410}); \\
\frac{dp_5(t)}{dt} = p_1(t)\lambda_{15} + p_{10}(t)\mu_{105} - p_5(t)(\mu_{51} + \lambda_{510}); \\
\frac{dp_6(t)}{dt} = p_2(t)\lambda_{26} + p_{10}(t)\mu_{106} - p_6(t)(\mu_{62} + \lambda_{610}); \\
\frac{dp_7(t)}{dt} = p_2(t)\lambda_{27} + p_{10}(t)\mu_{107} - p_7(t)(\mu_{72} + \lambda_{710}); \\
\frac{dp_8(t)}{dt} = p_3(t)\lambda_{38} + p_{10}(t)\mu_{108} - p_8(t)(\mu_{83} + \lambda_{810}); \\
\frac{dp_9(t)}{dt} = p_3(t)\lambda_{39} + p_{10}(t)\mu_{109} - p_9(t)(\mu_{93} + \lambda_{910}); \\
\frac{dp_{10}(t)}{dt} = p_4(t)\lambda_{410} + p_5(t)\lambda_{510} + p_6(t)\lambda_{610} + p_7(t)\lambda_{710} + \\
\quad + p_8(t)\lambda_{810} + p_9(t)\lambda_{910} - p_{10}(t)(\mu_{104} + \mu_{105} + \mu_{106} + \mu_{107} + \mu_{108} + \mu_{109})).
\end{cases}
$$

Analytical solution of system

$$
\begin{aligned}
p_0(t) &= 1 + h_{01}\, t + h_{02}\, t^2 + h_{03}\, t^3; \\
p_1(t) &= h_{11}\, t + h_{12}\, t^2 + h_{13}\, t^3; \\
p_2(t) &= h_{21}\, t + h_{22}\, t^2 + h_{23}\, t^3; \\
p_3(t) &= h_{31}\, t + h_{32}\, t^2 + h_{33}\, t^3; \\
p_4(t) &= h_{42}\, t^2 + h_{43}\, t^3; \\
p_5(t) &= h_{52}\, t^2 + h_{53}\, t^3; \\
p_6(t) &= h_{62}\, t^2 + h_{63}\, t^3; \\
p_7(t) &= h_{72}\, t^2 + h_{73}\, t^3; \\
p_8(t) &= h_{82}\, t^2 + h_{83}\, t^3; \\
p_9(t) &= h_{92}\, t^2 + h_{93}\, t^3; \\
p_{10}(t) &= h_{103}\, t^3;
\end{aligned}
$$

Analytical expressions for coefficients of system of differential equations

h_{ji}	t	t^2	t^3
h_{0i}	$-(\lambda_{01}+\lambda_{02}+ +\lambda_{03})$	$a_{01}(\lambda_{01}^2+2\lambda_{01}\lambda_{02}+\lambda_{01}\lambda_{03}+\lambda_{02}^2+2\lambda_{02}\lambda_{03}+\lambda_{03}^2+\lambda_{01}\mu_{10}+\lambda_{02}\mu_{20}+\lambda_{03}\mu_{30})$	$a_{02}(\lambda_{02}^3+\lambda_{02}^2(3\lambda_{01}+3\lambda_{03}+2\mu_{30})+(2\lambda_{01}\mu_{10}+\mu_{20}\lambda_{26}+2\lambda_{03}\mu_{30}+3\lambda_{01}^2+3\lambda_{03}^2+\lambda_{27}\mu_{20}+\mu_{20})\lambda_{02}+\mu_{10}\lambda_{01}\lambda_{15}+\lambda_{03}^3+\mu_{30}\lambda_{03}\lambda_{38}+\lambda_{01}^3+3\lambda_{01}\lambda_{03}+2\lambda_{03}\mu_{30}+3\lambda_{01}\lambda_{03}+2\mu_{10}\lambda_{01}^2+2\mu_{30}\lambda_{01}\lambda_{03}+\lambda_{03}\mu_{30}^2+\mu_{10}\lambda_{01}\lambda_{15})$
h_{1i}	λ_{01}	$a_{11}(\lambda_{01}\mu_{10}+\lambda_{01}\lambda_{14}+\lambda_{01}\lambda_{15}+\lambda_{01}^2+\lambda_{01}\lambda_{02}+\lambda_{01}\lambda_{03})$	$a_{12}(\lambda_{02}^2(\lambda_{02}+3\lambda_{01}+3\lambda_{03}+2\mu_{20})+\lambda_{01}^2(\lambda_{01}+3\lambda_{02}+3\lambda_{03}+2\mu_{10})+\lambda_{03}^2(3\lambda_{01}+\lambda_{03}+3\lambda_{02}+2\mu_{30})+\lambda_{03}(2\lambda_{01}\mu_{10}+2\lambda_{01}\mu_{30}+6\lambda_{01}\lambda_{02}+\mu_{30}^2+2\mu_{30}\lambda_{02}+2\lambda_{02}\mu_{30}+2\mu_{20}\lambda_{02}+\lambda_{39}\mu_{30}+\lambda_{38}\mu_{30})$
h_{2i}	λ_{02}	$a_{21}(\lambda_{02}\mu_{20}+\lambda_{02}\lambda_{26}+\lambda_{02}\lambda_{27}+\lambda_{01}\lambda_{02}+\lambda_{02}^2+\lambda_{02}\lambda_{03})$	$a_{22}(\lambda_{02}^2(\lambda_{02}+2\lambda_{01}+2\lambda_{03}+2\mu_{20}+\lambda_{26}+\lambda_{27})+\lambda_{02}\lambda_{01}(\lambda_{01}+\lambda_{26}+\lambda_{27}+\mu_{10}+\mu_{20}+\lambda_{03})+\lambda_{02}\lambda_{03}(\lambda_{26}+\lambda_{03}+\lambda_{27}+\mu_{30}+\mu_{20})+\lambda_{02}\lambda_{26}(\lambda_{26}+2\mu_{20}+2\lambda_{27}+\mu_{62})+\lambda_{02}\lambda_{27}(\lambda_{27}+\mu_{72})+\mu_{20}\lambda_{02}(\mu_{20}+\lambda_{27})$
…	…….	…………	……………….
h_{8i}		$a_{81}\lambda_{03}\lambda_{38}$	$a_{82}\lambda_{03}\lambda_{38}(\mu_{30}+\lambda_{38}+\lambda_{39}+\lambda_{01}+\lambda_{02}+\lambda_{03}+\lambda_{810}+\mu_{83})$
h_{9i}		$a_{91}\lambda_{03}\lambda_{39}$	$a_{92}\lambda_{03}\lambda_{39}(\mu_{30}+\lambda_{38}+\lambda_{39}+\lambda_{01}+\lambda_{02}+\lambda_{03}+\lambda_{910}+\mu_{93})$

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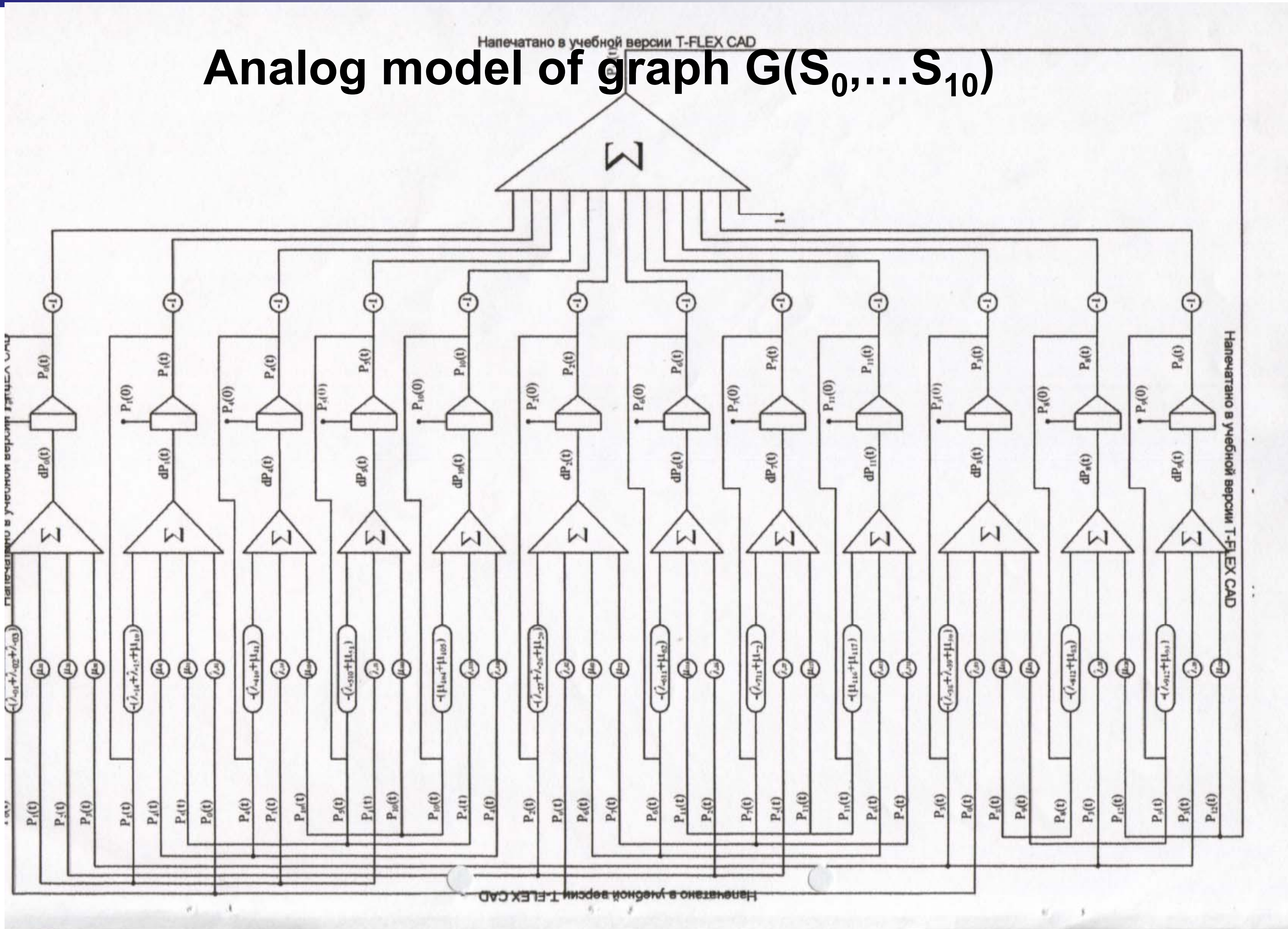
Analog model of graph $G(S_0,\ldots S_{10})$



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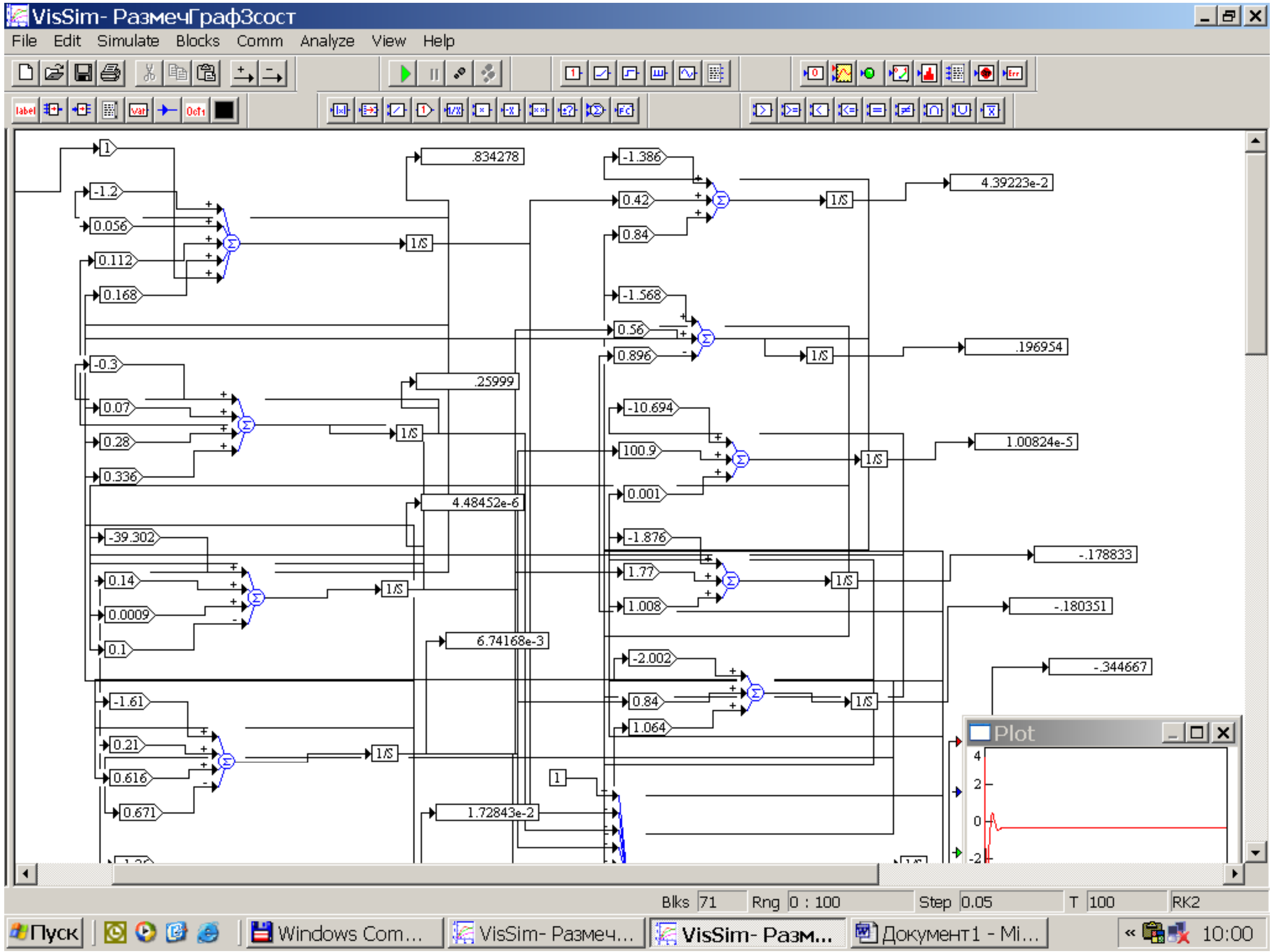
Analog model of analytic solution obtained in integrated system



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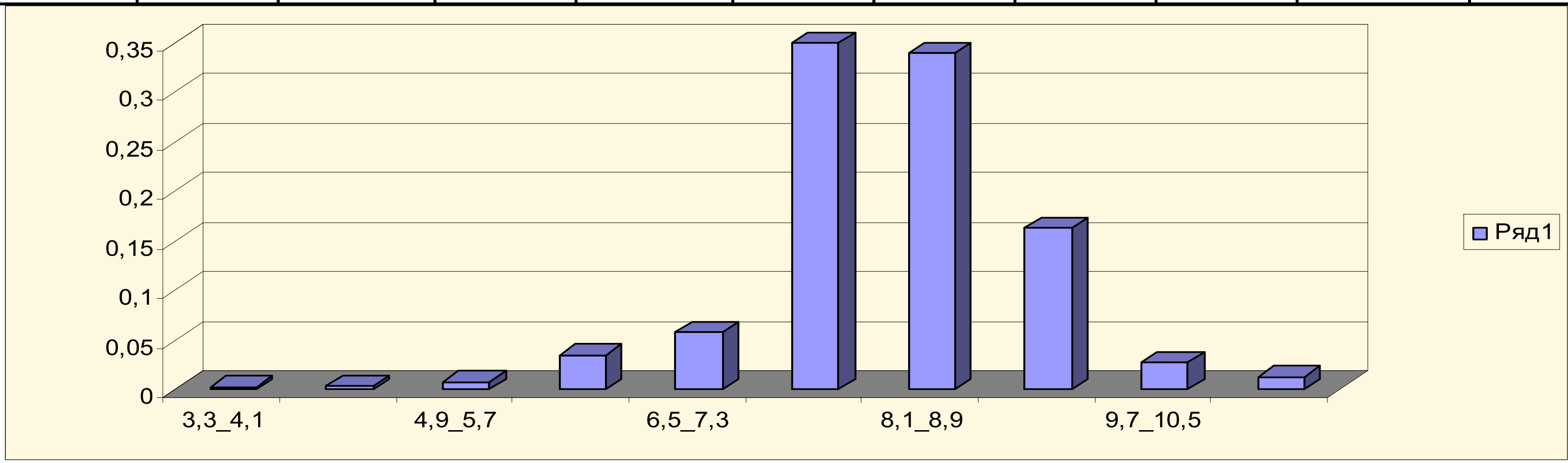
Determination of Damage types for Orenburg-Salavat pipeline

Number	1	2	3	4	5	6	7	8	9	10
Intervals	3,3_4,1	4,1_4,9	4,9_5,7	5,7_6,5	6,5_7,3	7,3_8,1	8,1_8,9	8,9_9,7	9,7_10,5	10,5_11,3
Class mark	3,7	4,5	5,3	6,1	6,9	7,7	8,5	9,3	10,1	10,9
Absolute frequency	2	3	6	27	45	269	261	126	21	10
Relative frequency	0,0026	0,0039	0,0078	0,0351	0,0584	0,3494	0,3389	0,1636	0,0273	0,013
Cumulative frequency	0,0026	0,0065	0,0143	0,0727	0,1312	0,4805	0,8195	0,9831	0,9844	1
Damage type					S0	S1	S2	S3		



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Numerical Determination of Graph Model Intensities for pipeline

Proper Intensities

Intensityof 1 diagnostic	1/year	Intensityof 2 diagnostic	1/year
λo2002abs	0,857	λo2005abs	2,29
λo2002otn	0,009	λo2005otn	0,004
λ1 2002 abs	1,25	λ1 2005abs	9,258
λ1 2002otn	0,013	λ1 2005otn	0,014
λ2 2002 abs	0,429	λ2 2005abs	2,452
λ2 2002otn	0,005	λ2 2005otn	0,004
λ3 2002 abs	0,179	λ3 2005abs	2,742
λ3 2002otn	0,002	λ3 2005otn	0,004

Transition absolute and relative intensities

Intensityof 1 diagnostic	1/year	Intensities of 2 diagnostic	1/year
λ01 2002abs/otn	2,107/0,022	λ01 2005abs/otn	11,548/0,018
λ02 2002 abs/otn	1,286/0,0135	λ02 2005abs/otn	4,742/0,007
λ03 2002abs/otn	1,0357/0,011	λ03 2005abs/otn	5,032/0,0085
λ14 2002abs/otn	2,536/0,027	λ14 2005abs/otn	14/0,022
λ15 2002abs/otn	2,286/0,024	λ15 2005abs/otn	14,29/0,022
λ26 2002abs/otn	1,463/0,015	λ26 2005abs/otn	7,484/0,012
λ27 2002abs/otn	2,536/0,027	λ27 2005abs/otn	14/0,022
λ38 2002abs/otn	2,286/0,024	λ38 2005abs/otn	14,29/0,022
λ39 2002abs/otn	1,464/0,015	λ39 2002abs/otn	14,29/0,012
λi10 2002abs/otn	1,857/0,028	λi10 2005abs/otn	16,742/0,026

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Numerical solution for identification problem of pipelines corrosion state

Graph model state probabilities for obtained transition intensities

$$p_0(t) = -0.00003 \cdot t^3 + 0.00135 \cdot t^2 - 0.047 \cdot t + 1$$

$$p_1(t) = 0.00004 \cdot t^3 - 0.00112 \cdot t^2 + 0.022 \cdot t$$

$$p_2(t) = 0.00002 \cdot t^3 - 0.0007 \cdot t^2 + 0.014 \cdot t$$

$$p_3(t) = 0.00002 \cdot t^3 - 0.00055 \cdot t^2 + 0.011 \cdot t$$

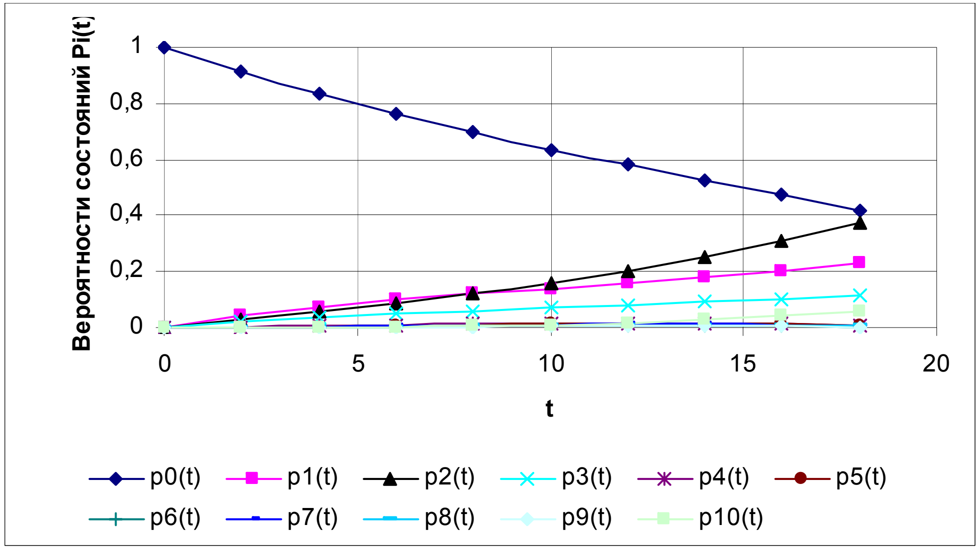
$$p_4(t) = -0.00002 \cdot t^3 + 0.00297 \cdot t^2$$

$$p_5(t) = -0.00001 \cdot t^3 + 0.000264 \cdot t^2$$

$$p_6(t) = 0.00012 \cdot t^2 \quad p_7(t) = 0.00019 \cdot t^2$$

$$p_8(t) = 0.00013 \cdot t^2 \quad p_9(t) = 0.00008 \cdot t^2$$

$$p_{10}(t) \approx 0$$



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Solution for forecasting problem of pipelines corrosion state with 3 types of damages and linear approximation

$\lambda_{ij}=a_{ij}t+b_{ij}$ **- linear approximation**

$$
\begin{cases}
p_0(t)=g_{02}t^2+g_{01}t+1 \\
p_1(t)=g_{12}t^2+g_{11}t \\
p_2(t)=g_{22}t^2+g_{21}t \\
p_3(t)=g_{32}t^2+g_{31}t \\
p_4(t)=g_{42}t^2 \\
p_5(t)=g_{52}t^2 \\
p_6(t)=g_{62}t^2 \\
p_7(t)=g_{72}t^2 \\
p_8(t)=g_{82}t^2 \\
p_9(t)=g_{92}t^2 \\
p_{10}(t)=g_{102}t^2
\end{cases}
$$

Coefficients

$$g_{02}=-0.5\cdot b_{01}(0.5b_{01}+b_{02}+b_{03}+0.5\mu_{10})-0.5(a_{01}+a_{02}+a_{03})+$$
$$+0.5(b_{02}+b_{03})^2+0.5(b_{02}\mu_{20}+b_{03}\mu_{30})$$

$$g_{12}=-0.5\cdot b_{01}(b_{01}+b_{02}+b_{03}+b_{14}+b_{15}+\mu_{10})+0.5a_{01}$$

$$g_{22}=-0.5\cdot b_{02}(b_{01}+b_{02}+b_{03}+b_{26}+b_{27}+\mu_{20})+0.5a_{02}$$

$$g_{32}=-0.5\cdot b_{03}(b_{01}+b_{02}+b_{03}+b_{38}+b_{39}+\mu_{30})+0.5a_{03}$$

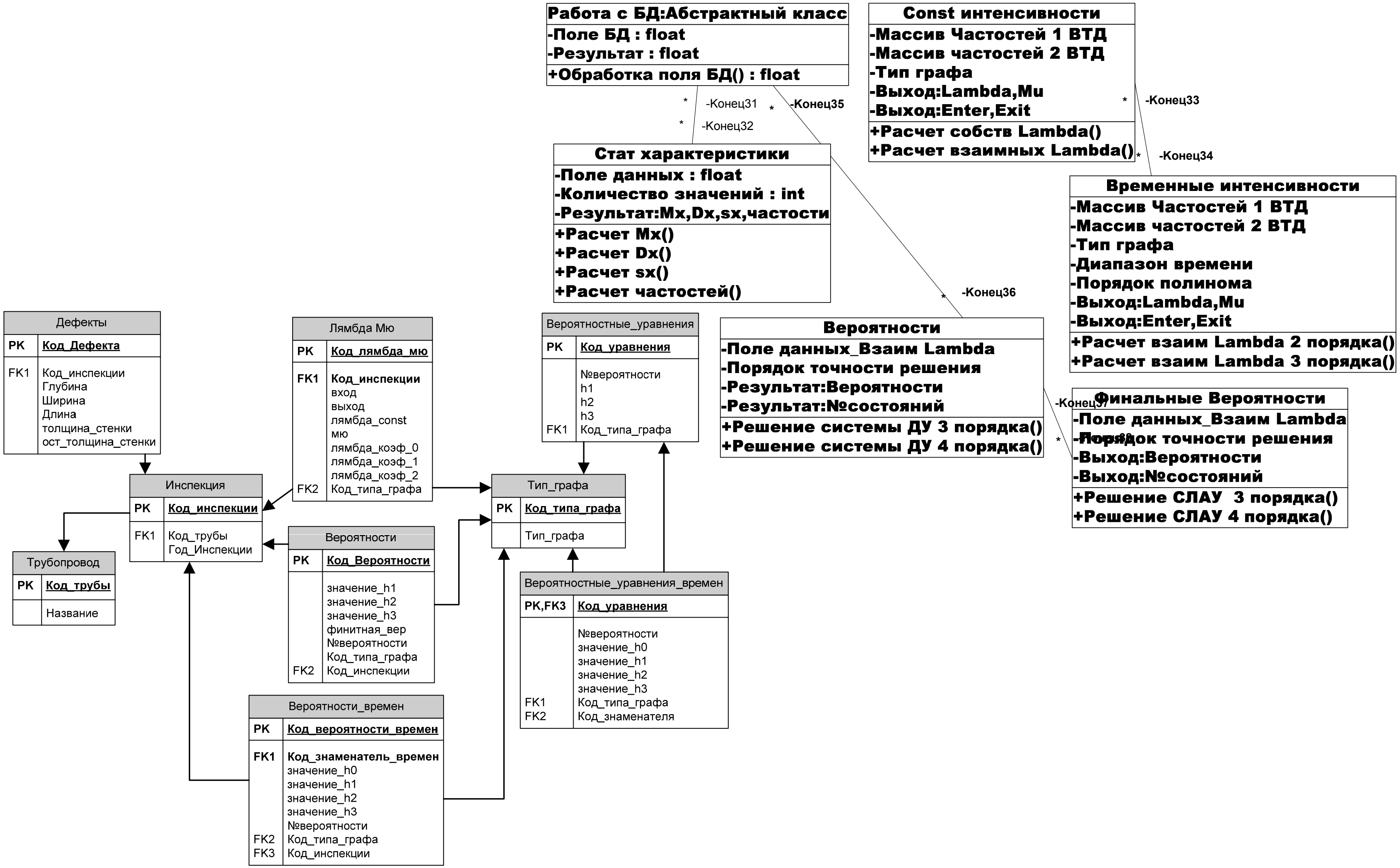
$g_{42}=0.5\cdot b_{01}b_{14}$ $g_{52}=0.5\cdot b_{01}b_{15}$ $g_{62}=0.5\cdot b_{02}b_{26}$ $g_{72}=0.5\cdot b_{02}b_{27}$

$g_{82}=0.5\cdot b_{03}b_{38}$ $g_{92}=0.5\cdot b_{03}b_{39}$ $g_{102}\approx 0$ $g_{01}=-(b_{01}+b_{02}+b_{03})$

$g_{11}=b_{01}$ $g_{21}=b_{02}$ $g_{01}=b_{03}$ $g_{41}=0.5\cdot b_{01}b_{14}$ $g_{51}=0.5\cdot b_{01}b_{15}$

$g_{61}=0.5\cdot b_{02}b_{26}$ $g_{71}=0.5\cdot b_{02}b_{27}$ $g_{81}=0.5\cdot b_{03}b_{38}$ $g_{91}=0.5\cdot b_{03}b_{39}$

Model of Database and Class Diagram



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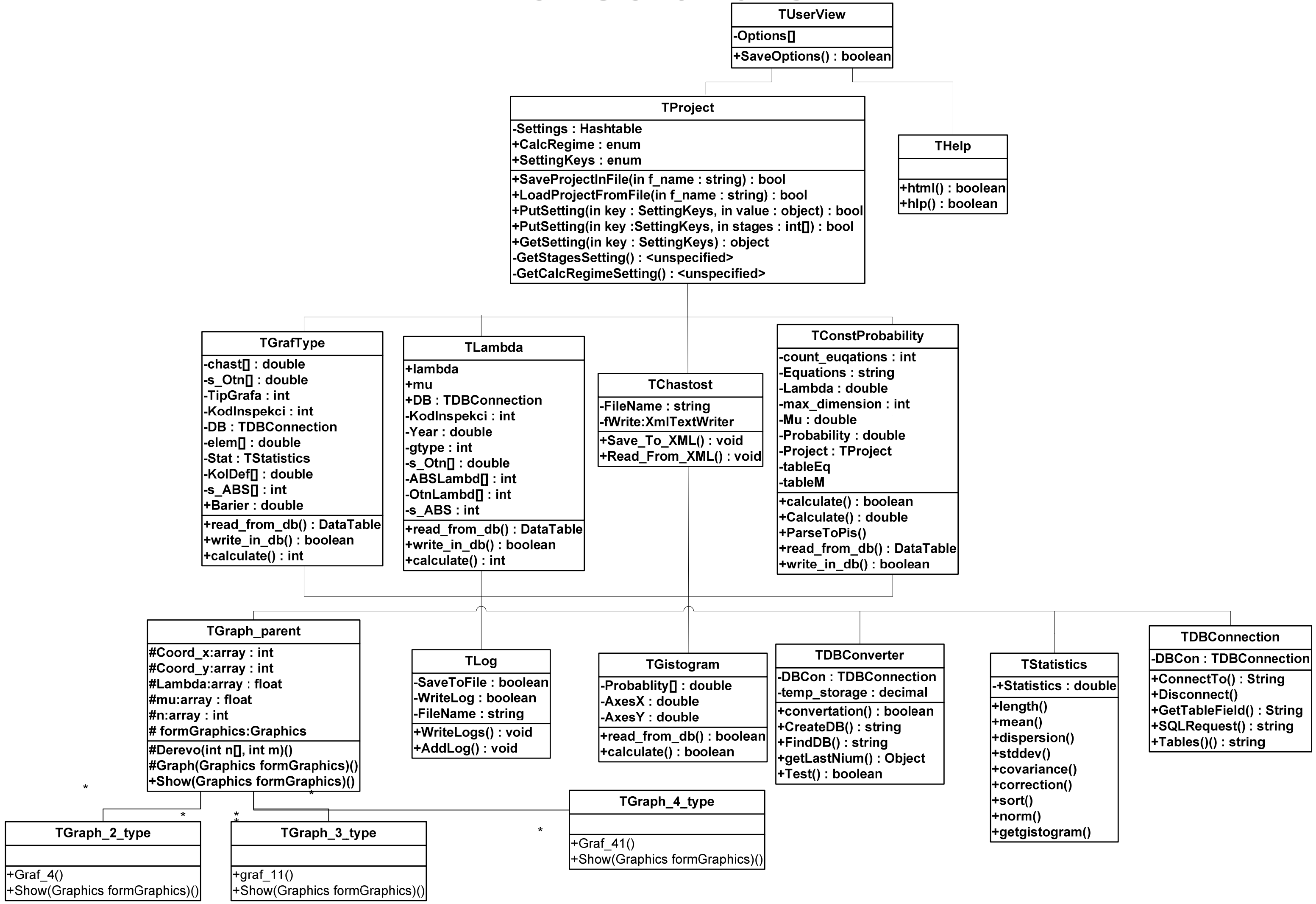
Hierarchical structure of main modules for client part of software



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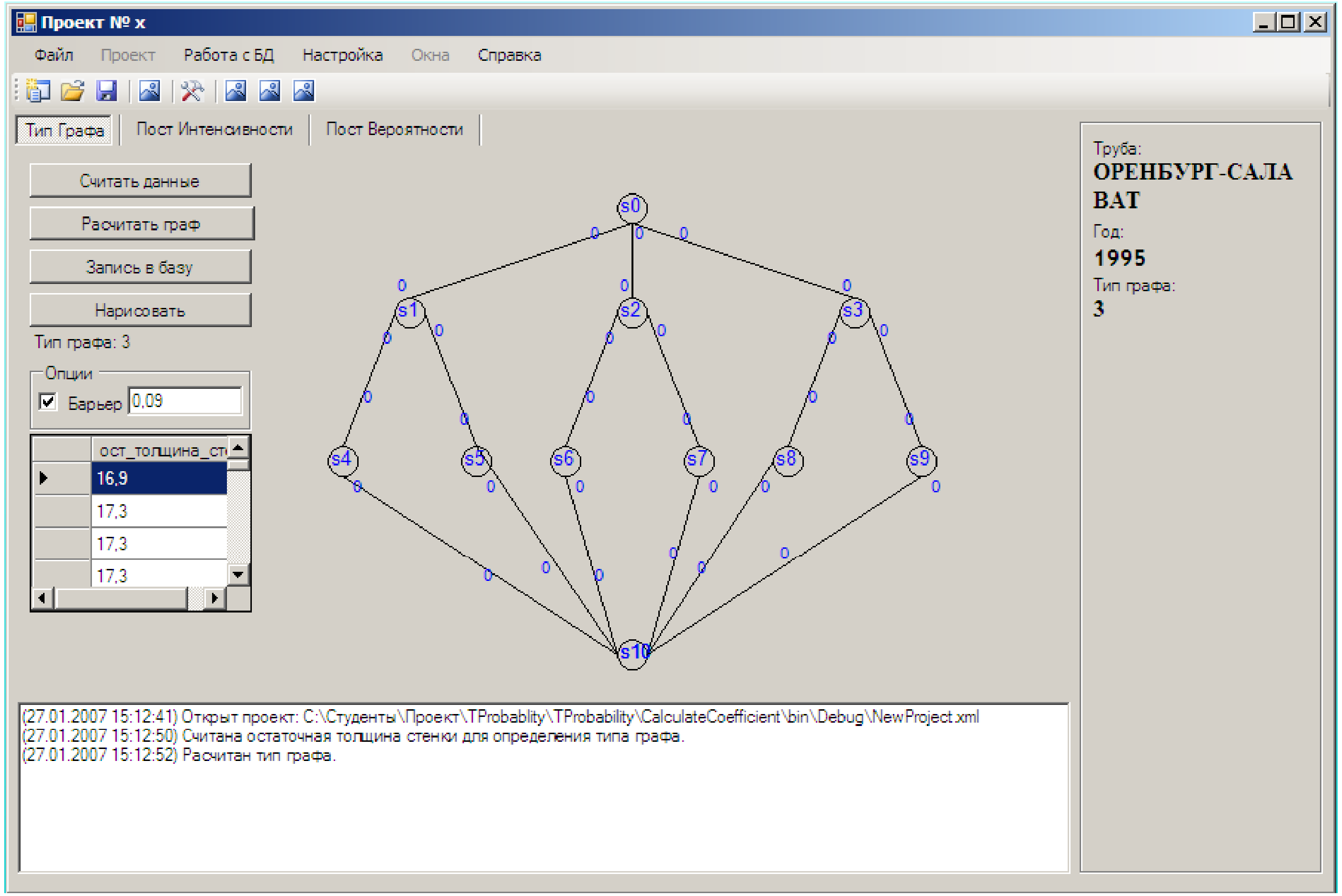
Definition of Graph Type. Test example of software calculation



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Conclusions

The analysis of publications and datas of companies extracting and transporting gas was conducted. This showed an insufficient efficiency of pipelines functioning because of absence of scientifically proved methodology of corrosion state forecasting.

The stated hypotheses are confirmed by results of research. In particular, occurrence and development of defects in every pipeline are represented by flows of casual events. This allows to use Markov processes and graph models.

Processing of big box units of data for trunk pipeline established 10 ranges, 4 from them are significant on 5 % barrier with following borders: 6,5_7,3; 7,3_8,1; 8,1_8,9; 8,9_9,7. Its corrosion state is represented by graph model with 3 types of damages.

Analytical decisions for 2, 3 and 4 types of pipeline damages are found. They are polynoms of 3 and 4 order of accuracy. Their coefficients are defined by transition intensities.

According to the developed techniques we define proper and transition absolute and relative intensities. For trunk pipeline proper absolute intensities belong [0,179; 1,25] for 1 diagnostic, and transition relative intensities belong [0,012; 0,026] for 2 diagnostic.

The developed theoretical positions are used in created software

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