ISSN 1407-6160

TRANSPORT AND TELECOMMUNICATION

Volume 7. No 1

2006

Transporta un sakaru institūts
(Transport and Telecommunication Institute)

Transport and Telecommunication

Volume 7, No 1 - 2006

ISSN 1407-6160

Proceedings

Part 1

The 5th International Conference

RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION

(RelStat'05)

13–14 October 2005. Riga, Latvia

ISBN 9984-668-98-3

Riga – 2006

EDITORIAL BOARD:

Prof. Igor Kabashkin (Editor-in-Chief), *Transport & Telecommunication Institute, Latvia*
Prof. Irina Yatskiv, *Transport & Telecommunication Institute, Latvia*
Prof. Adolfas Baublys, *Vilnius Gedeminas Technical University, Lithuania*
Dr. Brent Bowen, *University of Nebraska at Omaha, USA*
Prof. Olgierd Dumbrajs, *Helsinki University of Technology, Finland*
Prof. Arnold Kiv, *Ben-Gurion University of the Negev, Israel*
Prof. Anatoly Kozlov*, Moscow State University of Civil Aviation, Russia*

***T&T* Personnel:**
Literary editor – Lucija Paegle
Technical editor – Irina Mihnevich

Host Organizations:
Transport and Telecommunication Institute, Latvia – Eugene Kopytov, Rector
Telematics and Logistics Institute, Latvia – Igor Kabashkin, Director

Co-Sponsor Organization:
PAREX Bank, Latvia – Valery Kargin, President

Supporting Organizations:
Latvian Transport Development and Education Association – Andris Gutmanis, President
Latvian Academy of Sciences – Juris Ekmanis, President
Latvian Operations Research Society – Igor Kabashkin, President
Telecommunication Association of Latvia – Janis Lelis, Executive Director

Articles and review are presented in the journal in English (preferably), Russian and Latvian (at the option of authors).

EDITORIAL CORRESPONDENCE

Transporta un sakaru institūts (Transport and Telecommunication Institute)
Lomonosova iela 1, LV-1019, Riga, Latvia. Phone: (+371)-7100594. Fax: (+371)-7100535.
E-mail: kiv@tsi.lv, http:// www.tsi.lv

TRANSPORT and TELECOMMUNICATION, 2006, Vol. 7, No 1
ISSN 1407-6160
The journal of Transport and Telecommunication Institute (Riga, Latvia).
The journal is being published since 2000.

Copyright © Transport and Telecommunication Institute, 2006

CONTENTS

The 5th International Conference RELIABILITY and STATISTICS
in TRANSPORTATION and COMMUNICATION (RelStat'05),
13–14 October 2005, Riga, Latvia

PROGRAMME of the 5th International Conference RelStat'05 4

Proceedings. Part 1 8

Conference Authors Index 203

Cumulative Index 205

The 5th International Conference

RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION

(RelStat'05)

13–14 October 2005, Riga, Latvia

PROCEEDINGS

Part 1

Igor V. Kabashkin (ed.)

Riga – 2006

Proceedings of the 5th International Conference RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION (RelStat'05), 13–14 October 2005, Riga, Latvia, in 3 Parts. Riga: Transport and Telecommunication Institute, 2006, Part 1.

ISBN 9984-668-98-3

The aim of the journal is to acquaint the readers with the national experience and research activities of various countries in the fields of transport and telematics as well as with the working materials of the European thematic networks and the research projects in this area.

This special edition is devoted to the International Conference "Reliability and Statistics in Transportation and Communication" (October 13–14, 2005, Riga, Latvia). The edition includes texts of conference reports written by the authors in a special journal version.

The authors have submitted the material in English or Russian in accordance with the official languages of the Conference. Therefore, for the convenience of readers the editorial board has divided the selected materials into three editions – English (Vol.7, No1, No2, 2006) and Russian (Vol.7, No3, 2006).

ISBN 9984-668-98-3

Copyright © Transport and Telecommunication Institute, 2006

The 5th INTERNATIONAL CONFERENCE ORGANISED BY

Transport and Telecommunication Institute (Latvia)
The Kh. Kordonsky Charitable Foundation (USA)

in co-operation with

Latvian Transport Development and Education Association (Latvia)
Latvian Operations Research Society (Latvia)
Latvian Academy of Science (Latvia)

THE PROGRAMME COMMITTEE

Prof. Adolfas Baublys, *Vilnius Gedeminas Technical University, Lithuania*
Dr. Brent Bowen, *University of Nebraska at Omaha, USA*
Prof. Ernst Frankel, *Massachusetts Institute of Technology, USA*
Prof. Igor Kabashkin, *Transport & Telecommunication Institute, Latvia*
Prof. Eugene Kopytov, (Chairman) *Transport & Telecommunication Institute, Latvia*
Prof. Anatoly Kozlov, *Moscow State University of Civil Aviation, Russia*
Prof. Zohar Laslo, *Sami Shamoon College of Engineering, Israel*
Prof. Lauri Ojala, *Turku School of Economics and Business Administration, Finland*
Prof. Irina Yatskiv, *Transport & Telecommunication Institute, Latvia*
Prof. Edmundas Zavadskas, *Vilnius Gediminas Technical University, Lithuania*

ORGANIZATION COMMITTEE

Prof. Igor Kabashkin, Latvia – Chairman
Mrs. Inna Kordonsky-Frankel, USA – Co-Chairman
Prof. Irina Yatskiv, Latvia – Co-Chairman
Mrs. Elena Rutkovska, Latvia – Secretary

PROGRAMME

of the 5th International Conference

"RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION (RelStat'05)"

13–14 October 2005. Riga, Latvia

Thursday, October 13

Transport and Telecommunication Institute (Lomonosov str. 1, Library)

10:00–16:00 **Registration**

14:00 Opening Ceremony of the Literature Exhibition "Professor Kordonsky. Researcher and Educator" (Lomonosov str. 1, Library)

14:30–17:00 **Discussion Panel.**

Transport Development in the Baltic States: Transport Policy and Transport Research

Moderators: Igor Kabashkin (Latvia, Transport and Telecommunication Institute) *and Ramunas Palsaitis,* (Lithuania, Vilnius Gediminas Technical University)

- State and Legal Support of Intermodal Transport Development. *Ramunas Palsaitis,* (Lithuania, Vilnius Gediminas Technical University)
- Logistics Centres Networks in the Baltic Sea Region. *Igor Kabashkin, Irina Yatskiv* (Latvia, Transport and Telecommunication Institute)
- Main Establishment Conditions of Logistics Centre and Its Financing Facility. *Ieva Meidute* (Lithuania, Vilnius Gediminas Technical University)
- Probability of Reviving and Development of Local Public Transport in Lithuanian Regions**.** *Daiva Griskeviciene, Algirdas Griskevicius* (Lithuania, Vilnius Gediminas Technical University)
- Development of New Technologies in Lithuanian Customs. *Aldona Jarasuniene* (Lithuania, Vilnius Gediminas Technical University)
- Truck Haulage in Latvia and the EU after One Year – Problems and Outlook. *Alexander Medvedev, Vladimir Zvonarev* (Latvia, Transport and Telecommunication Institute)
- Prospective of Logistics Training in Lithuania. *Ramunas Palsaitis***,** *Darius Bazaras* (Lithuania, Vilnius Gediminas Technical University)

Friday, October 14

Maritim Park Hotel Riga (Slokas str. 1)

9:00–10:00 **Registration (**Maritim Park Hotel Riga)

10:00–10:45 **Opening Session (Hall "Berlin").** Session Chair – *Igor Kabashkin* (Latvia, TTI)

- *Igor Kabashkin,* Chairman of the Organising Committee, Vice-Rector of the Transport and Telecommunication Institute (Latvia)
- *Eugene Kopytov*, Rector of the Transport and Telecommunication Institute (Latvia)
- *Inna Kordonsky-Frankel*, President of the Kh. Kordonsky Charitable Foundation (USA)
- Professor Kordonsky – Researcher and Educator. *Alexander Andronov* (Latvia, Transport and Telecommunication Institute)

11:00–18:30 **Thematic Sessions**

Time	Hall #1	Hall #2	Hall #3	Hall #4	Hall #5
11:00–13:00	**Session 1** **Statistical Methods and Their Applications** Session Chair – ***Irina Yatskiv***	**Session 2** **Applications of Mathematical Methods in Logistics and Business** Session Chair – ***Eugene Kopytov***	**Session 3** **Intelligent Transport System** Session Chair – ***Igor Kabashkin***	**Session 4** **Modern Technologies in Aviation** Session Chair – ***Richard Klophaus***	**Session 5** **Transport Logistics** Session Chair – ***Darius Bazaras***
	1. Beta Characterization. *Max V. Moldovan, Nicholas A. Nechval* (Australia, Latvia) **2.** Weibull or Lognormal Distribution. *A. Paramonova, M. Kleinhof, Yu. Paramonov* (Latvia) **3.** On Some Modification of Seemingly Unrelated Regression Equation Models. *Alexander Andronov, Andrey Svirchenkov* (Latvia) **4.** Upper Prediction Limit for Future Observations from a Weibull Distribution and Its Applications. *Konstantin N. Nechval* (Latvia) **5.** Dynamic Classification of Multidimensional Objects. *Ilya Gertsbakh, Irina Yatskiv* (Israel, Latvia) **6.** Multi-Product Inventory Control Model with Constraints. *Eugene Kopytov, Fedor Tissen, Leonid Greenglaz* (Latvia)	**1.** Multicriteria Technique for Project Selection under Risk. *Maciej Nowak* (Poland) **2.** The Application of a General Mathematical Model to Multimodal Transportation in Logistics. *Olga Lingaitienė, Vytautas Lingaitis* (Lithuania) **3.** Parametric and Stochastic Models for Optimal Investment Strategy. *Sigute Vakriniene, Arnoldina Pabedinskaite* (Lithuania) **4.** Urbanistic Evaluation of City Compactness on the Basis of GIS Applying COPRAS Method. *Edmundas Kazimieras Zavadskas, Zenonas Turskis, Jurgis Zagorskas* (Lithuania) **5.** Application of Saw Method for Multi-Criteria Comparative Analysis of Investments Alternatives Risk in Construction. *Leonas Ustinovichius, Zenonas Turskis, Galina Shevchenko* (Lithuania) **6.** Markov Reward Model for Decision Making about the Best Configuration of the Refrigeration System. *Lev Khatskin, Ilia Frenkel and Anatoly Lisnianski* (Israel)	**1.** Modelling of Indirect Visual Transfer Collected by Car Driver. *Krzysztof Olejnik* (Poland) **2.** Survey of the International Standards of the Information Security. *Wladimir Freund* (Germany) **3.** IT Security Protection and Audit Concept for ATC IT-Systems. *Jörg Kundler* (Germany) **4.** Prospects of Development of the Road Traffic's Automated Management Systems. *Eduard Vorobeu, Dzianis Kapski, Vladimir Sedzukevich* (Belarus) **5.** Location and Control of Cargo and Vehicles with New Technologies. *Nijolė Batarlienė* (Lithuania) **6.** Application of Intelligent Transport Systems in Urban Public Transport. *Gražvydas Jakubauskas* (Lithuania)	**1.** Airline Revenue Management in a Changing Business Environment. *Richard Klophaus* (Germany) **2.** Airport Slot Information Logistics as Dynamic Web-Pages. *Genady Gromov, Valery Pustinsky, Eduard Zinovjev* (Latvia) **3.** Crew Readiness Influence on a Navigation Complex Application Efficiency. *Andrey Troyanovsky, Boris Tsilker* (Latvia) **4.** Investigation of Navigator Activity Algorithms as an Instrument for Test Flights Number Reducing at the Estimation of Reliability of Navigation. *Andrey Troyanovsky, Boris Tsilker* (Latvia) **5.** The Analysis of the Commercial Sector of Lithuania Aviation. *Jonas Lazauskas* (Lithuania) **6.** Comparative Analysis of Statistical Data of Linear and Learning Crew Activity on Aircraft Simulators. *Victor Feofanov, Alexander Medvedev* (Latvia)	**1.** Outsourcing Logistics Criteria and It's Impact to Supply Channel Structure. *Andrius Jarzemskis* (Lithuania) **2.** Analysis of Problems with Containers as Intermodal Loading Unit. *Aidas Vasilis Vasiliauskas, Darius Bazaras* (Lithuania) **3.** Reliability, Logistics and Quality Management in Production Systems. *Wacław Szymonik, Mieczysław Dziubiński* (Poland) **4.** The Factors Having Influence of Freight Flows. *Michail Litvinenko* (Lithuania) **5.** Analysis of Transport Performance Measurement System. *Margarita Isoraite* (Lithuania) **6.** Main Cost Factors' Significance Definition to the Development Stability of the Enterprise Activity. *Rostislav Kopitov, Vladimir Labeyev* (Latvia)

Time	Hall #1	Hall #2	Hall #3	Hall #4	Hall #5
14:00-16:00	**Session 1** **Statistical Methods and Their Applications** Session Chair – ***Alexander Andronov***	**Session 2** **Applications of Mathematical Methods to Logistics and Business** Session Chair – ***Leonas Ustinovichius***	**Session 3** **Intelligent Transport System** Session Chair – ***Jonas Butkevičius***	**Session 6** **Reliability in Applications** Session Chair – ***Larisa Zaitseva***	**Session 5** **Transport Logistics** Session Chair – ***Ramunas Palsaitis***
	1. Resampling Approach to the Estimation of the Aircraft Circulation Plan Reliability with One Sample for Service Time. *Maxim fioshin* (Latvia) **2.** Multiperiod Project Portfolio Investment Strategy. *Gundars Berzins, Nicholas A. Nechval, Edgars K. Vasermanis* (Latvia) **3.** Statistical Methods in Logistics Systems of Transport. *Helen Afanasyeva* (Latvia) **4.** New Information Criterion and Its Applications to Multiple Regression. *Jury Krasts, Nicholas A. Nechval, Kristine Rozite, Natalie Zolova* (Latvia) **5.** Bayesian Approach to Forecasting Damage to Buildings from Accidental Explosions on Railway. *Egidijus R. Vaidogas* (Lithuania) **6.** On One Theorem Concerning a Weibull Distribution. *Konstantin N. Nechval, Nicholas A. Nechval* (Latvia)	**1.** The Analysis of Apartment House Construction Investments Efficiency Applying Mathematical Modelling. *Leonas Ustinovichius, Edita Šarkienė* (Lithuania) **2.** The Operation of the Gauge Changing Facility of the New Railway Line Rail Baltica. *Jonas Jonaitis* (Lithuania) **3.** Retrofitted Rear Suspension Efficiency. *M. Bogdevičius, R. Junevičius* (Lithuania) **4.** Multi-Criteria Comparative Analysis of Building Materials Export. *Artūras Kaklauskas, Zenonas Turskis, Mindaugas Krutinis* (Lithuania) **5.** Using the Judgment Coherence Evaluation Apparatus when Choosing a Hosting Provider. *Victor Siperkovsky* (Latvia) **6.** Cluster Analysis as the Method of Subject Segmentation of European Development Funds of Small and Medium-Sized Business in Latvia. *Ludmila Bakhmane* (Latvia)	**1.** Ways of Realization of the Coordinated Main Management of Traffic in Minsk. *Eduard Vorobeu, Yuri Vrubel, Dzianis Kapski* (Belarus) **2.** Selection and Analysis of Quality Indices for the Automated Urban Traffic Management and Control System Efficiency Estimation. *Alexander Berezhnoy, Igor Smirnov* (Latvia) **3.** Introduction of Electronic Card System in Lithuanian City Passenger Transport. *Jonas Butkevičius* (Lithuania) **4.** An Integrated System for the Safe Handling of Hazardous. *Zohar Laslo, Michael Hanani* (Israel) **5.** Recommendations on Development of Modes Traffic Regulations on Pedestrian Crossings. *Dzianis Kapski, Yauheni Kot* (Belarus) **6.** Modelling as a Means to Solve the Problem of City Traffic Optimization. *Nadezda Kolmakova, Elena Yurshevich, Irina Yatskiv* (Latvia) **7.** Generative Programming for Web-Services Simulation**.** *Sergey Orlov, Dmitry Morozov* (Latvia)	**1.** Logical Differential Calculus in Reliability Analysis. *Elena Zaitseva, Stefan Kovalik, Karol Matiasko* (Slovakia) **2.** Neural Networks Application for Analysis of Flight Information in Aircraft Engine Diagnostic System. *Eugene Kopytov, Vladimir Labendik, Arvid Osis, Alexey Tarasov* (Latvia) **3.** Comparison Sequential Testing on Reliability: Exact Computation of OC and ASN. *Y. H. Michlin, G. Grabarnik* (Israel, USA) **4.** Statistical Representation of Turbofan Throttling Characteristics by Thrust Parameter. *Sergey Yunusov, Vladimir Labendik, Eugene Kopytov* (Latvia) **5.** Multidimensional Spectral Measurements in Technical Diagnosis. *B.Greenstein, E.Ostrovsky, L.Sirota* (Israel)	**1.** Modelling Freight Flows at Transport Terminal and Vehicle Fleet of Optimal Carrying Capacity. *A.Baublys* (Lithuania) **2.** Substantiation of Transport Infrastructure Investments. *Ramunas Palšaitis* (Lithuania) **3.** Analysis of Expenses in Passenger Transportation by Railroad. *Vytautas Lingaitis, Olga Lingaitienė* (Lithuania) **4.** Mechanism of Allocating Expenses on Capital Repair and Technical Maintenance. *Nataly Podolyakina* (Latvia) **5.** Significance of Logistics Centres for Development of Intermodal Transport Services in Lithuania. *Ieva Meidutė, Aidas Vasilis Vasiliauskas* (Lithuania) **6.** Financial Stability of Transport Enterprises in Realities of the Latvian Market. *Marinicole Lopes-Errera* (Latvia)

Time	Hall #1	Hall #2	Hall #3	Hall #4
16:30-18:30	**Session 1** **Statistical Methods and Their Applications** Session Chair – ***Boriss Misnevs***	**Session 7** **Modelling and Simulation** Session Chair – ***Alexander Grakovski***	**Session 3** **Intelligent Transport System** Session Chair – ***Valery Kutev***	**Session 6** **Reliability in Applications** Session Chair – ***Andrzej Niewczas***
	1. Reliability of Management Decisions under Stochastic Demand. *Arnoldina Pabedinskaite* (Lithuania) **2**. Research of a Statistical Process Control in Software Engineering Project. *Jurijs Senbergs, Boriss Misnevs* (Latvia) **3.** Network Probabilistic Characteristics Direct Measurement System. *R. Platonov, A.Latkov, A. Savchenko, Y. Svirchenkov* (Latvia) **4.** Using the Package Means for the Solving Some Problems of Actuarial Mathematics. *Victor Lyumkis, Dina Lvovich* (Latvia) **5.** Problems of Statistical Maintenance of Models of Economic Growth. *Evgeni Makarov, Alexander Stetjuha* (Latvia) **6.** The Econometric Analysis of the Influence of Foreign Direct Investment on Domestic Investment Processes in Latvia. *Deniss Titarenko* (Latvia)	**1.** Hydrodynamic Processes of the Impulse Fire Extinguishing. *M. Bogdevicius, V.Suslavicius* (Lithuania) **2.** Nanodevices Modelling and Quantum Computing. *Yuri Shunin, Victor Gopeyenko and Alexey Gopeyenko* (Latvia) **3.** One Inverse Hyperbolic Heat Transfer Problem for Intensive Steel Quenching. *A.Buikis, Sh.Guseinov* (Latvia) **4.** Algebraic Method of Optimum on Speed Computer Management of Neutrally Steady and Conservative Objects Synthesis. *Valery Nikolsky, Alexander Iscenko* (Latvia) **5.** Image Processing Mistakes Elimination on the Basis of the Four Dimension Spline-Binarization Method. *Natalia Odnakish, Alexander Grakovski* (Latvia) **6**. Cellular Automata Application in Image Processing Tasks. *Alexander Grakovski, Sergey Ovchinnikov* (Latvia)	**1.** Supporting of Forecasting Models in Information-Analytical Systems of Railway Transportation. *Eugene Kopytov, Vasilijs Demidovs* (Latvia) **2.** Integrated Information Systems as a Factor of Reliability of Logistic Systems in Supply Chain Oriented Business. *Irina Osobskaya, Vitaly Skaredov* (Latvia) **3.** Relational Approach to Information Security in Temporal Databases. *Nataly Petukhova* (Latvia) **4.** Signal Analysis and Modelling to Global Navigation System. *Valery Kutev, Anatoly Pozdnyakov* (Latvia) **5.** Space-Temporal Signal Processing for Subsurface Radar Sounding of Earth Covers. *Alexander Krainyukov, Valery Kutev* (Latvia) **6.** The Modelling of Communication Channel with Relay's Fading by Usage of Adaptive Filters. *Marina Konovalenko, Yury Sikerzhitsky* (Latvia)	**1.** Laboratory Reliability Research Method of Automotive Diesel Engine. *Andrzej Niewczas, Paweł Kordos, Grzegorz Koszałka* (Poland) **2.** Reliability of Combustion Engine Electric Equipment. *Dziubiński Mieczysław* (Poland) **3.** Inspection Program for Fatigue Crack Growth Model with Two Random Parameters. *A. Kuznetsov, Yu. Paramonov* (Latvia) **4.** Model of the Multi-Site Fatigue Damage in the Thin-Walled Structure. *Vitaly Pavelko, Julija Timoshtchenko* (Latvia) **5.** Simulation of Lamb's Waves Propagation from Structural Damage. *Eric Ozolinsh, Ilmar Ozolinsh, Igor Pavelko, Vitaly Pavelko* (Latvia)

CONTENTS

Session 1. Statistical Methods and Their Applications

Testing for Crack Initiation in Fatigue-Sensitive Aircraft Structures with Repair under Type I Censored Sampling
Konstantin N. Nechval, Nicholas A. Nechval 11

Approximation Technique for Finding a Probabilistic Assessment of the Fatigue Reliability
Konstantin N. Nechval 16

Dynamic Classification of Multidimensional Objects
Ilya Gertsbakh, Irina Yatskiv 21

Multi-Product Inventory Control Model with Constraints
Eugene Kopytov, Fedor Tissen, Leonid Greenglaz 28

Bayesian Approach to Forecasting Damage to Buildings from Accidental Explosions on Railway
Egidijus R. Vaidogas 34

Prediction Limits for Future Samples from a Weibull Distribution
Konstantin N. Nechval, Nicholas A. Nechval 44

Normal, Lognormal, Weibull or P-Sev Distribution of Ultimate Strength of Strands and Composite Specimens
A. Paramonova, M. Kleinhof, Yu. Paramonov 50

Multiperiod Project Portfolio Investment Strategy
Gundars Berzins, Nicholas A. Nechval, Edgars K. Vasermanis 60

New Information Criterion and It's Applications to Multiple Regression
Jury Krasts, Nicholas A. Nechval, Kristine Rozite, Natalie Zolova 66

Research of a Statistical Process Control in Software Engineering Project
Jurijs Senbergs, Boriss Misnevs 70

The Influence of Foreign Direct Investment on Domestic Investment Processes in Latvia
Deniss Titarenko 76

Session 2. Applications of Mathematical Methods in Logistics and Business

Multicriteria Technique for Project Selection under Risk
Maciej Nowak 85

Application of a General Model of Multimodal Transportation in Logistics
Olga Lingaitienė, Vytautas Lingaitis 92

The Analysis of Apartment House Construction Investments Efficiency Applying Mathematical Modelling
Leonas Ustinovichius, Edita Šarkienė 97

The Operation of the Gauge Changing Facility of the New Railway Line Rail Baltica
Jonas Jonaitis 106

Retrofitted Rear Suspension Efficiency
Marijonas Bogdevičius, Raimundas Junevičius 110

Session 3. Intelligent Transport System

Modelling of Indirect Visual Transfer Collected by Car Driver
Krzysztof Olejnik 118

IT-Security Protection and Audit Concept for ATC IT-Systems (SAIFIT)
Jörg Kundler 125

Location and Control of Cargo and Vehicles with New Technologies
Nijole Batarliene 144

Introduction of Electronic Card System in Lithuanian City Passenger Transport
Jonas Butkevičius 149

Modelling as a Means of Solving the Problem of City Traffic Optimisation
Nadezda Kolmakova, Elena Yurshevich, Irina Yatskiv 156

Supporting of Forecasting Models in Information-Analytical Systems of Railway Transportation
Eugene Kopytov, Vasilijs Demidovs 165

Integrated Information Systems as a Factor of Reliability of Logistic Systems in Supply Chain Oriented Business
Irina Osobskaya, Vitaly Skaredov 173

The Modelling of Communication Channel with Relay's Fading by Usage of Adaptive Filters
Marina Konovalenko, Yury Sikerzhitsky 178

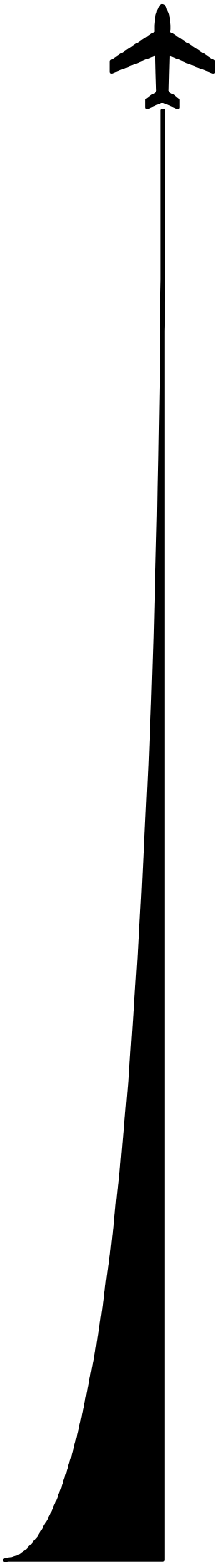
Session 4. Modern Technologies in Aviation

Airline Revenue Management in a Changing Business Environment
Richard Klophaus 183

Crew Readiness Influence on Navigation Complex Using Efficiency
Andrey Troyanovsky, Boris Tsilker 189

Investigation of Navigator's Activity Algorithms as an Instrument for Test Flights Number Reducing at the Estimation of Reliability of Navigation
Andrey Troyanovsky, Boris Tsilker 193

The Analysis of the Commercial Sector of Lithuania Aviation
Jonas Lazauskas 196



Session 1

Statistical Methods and Their Applications

TESTING FOR CRACK INITIATION IN FATIGUE-SENSITIVE AIRCRAFT STRUCTURES WITH REPAIR UNDER TYPE I CENSORED SAMPLING

Konstantin N. Nechval[1], Nicholas A. Nechval[2]

[1]*Transport and Telecommunication Institute*
Applied Mathematics Department
Lomonosov Str. 1, LV-1019, Riga, Latvia
E-mail: konstan@tsi.lv

[2]*Mathematical Statistics Department, University of Latvia*
Raina Blvd. 19, LV-1050, Riga, Latvia
E-mail: nechval@junik.lv

Inferences concerning the location and scale parameters of a two-parameter exponential distribution of time to crack initiation due to fatigue, when crack is repaired, are discussed for samples censored at a fixed value. The procedures considered are uniformly most powerful unbiased if the tests are performed with repair. An example is given.

Keywords: f*atigue crack, repair, two-parameter exponential distribution, censored sampling*

1. INTRODUCTION

In this paper, we discuss the case of the testing with repair. Suppose that *n* items are tested, each having failure time with density function of the two-parameter exponential distribution,

$$f(x;\mu,\sigma)=(1/\sigma)\exp\{-(x-\mu)/\sigma\},\quad \mu\le x<\infty,\sigma>0, \tag{1}$$

and that these failure times are independent. This model is useful in life testing experiments; in these situations the location parameter μ is often called a guarantee or threshold parameter. In the case being considered, an item, which fails before the termination time, is repaired and tested again. We suppose that the repaired items have an exponential distribution with the same scale parameter σ as the original items but with location parameter 0. Since a repaired part would not be expected to perform as long as a new part, some assumption like this one would be appropriate. Even if defective parts were replaced, such an assumption might be reasonable if the original parts or system were sealed or treated in a special manner. This assumption was also used by Mann, Schafer, and Singpurwalla [1] to obtain the model they considered for testing with replacement for type I and type II censoring. Based on (possibly) censored data, Mann, Schafer, and Singpurwalla [1] discuss point estimates of μ and σ. They also present tests of hypotheses and confidence intervals for these parameters in the case of type II censoring (in which the number of failures is fixed) but not in the case of type I censoring (in which the duration of the experiment, as measured by time or some other appropriate quantity, is fixed). Such inferences based on type I censored data are discussed here for testing with repair. To be specific, we assume that the failures are occurring with time and that the duration of the experiment is some fixed time, say t units ($t > 0$). However, in the fatigue example discussed below, the failure times are measured in terms of load cycles. We also assume $\mu < t$ since there will be no failures otherwise and assume that the lifetimes of the original and repaired parts are mutually independent.

For a specific example, we consider the results of a fatigue test conducted by Butler and Rees [2] to determine the suitability of various metals for aircraft construction. In one phase of the study, titanium and steel specimens were tested for crack initiation due to fatigue. Each specimen was subjected to stresses in varying amounts and patterns similar to those occurring in flight. These stress patterns were repeated until a crack was detected, the number of load cycles (which can be thought of as a laboratory measure of flight time) until crack detection was recorded, the crack was repaired, the test was resumed until another crack was detected, the total number of load cycles to this failure was

recorded, etc. The data given in their report (Butler and Rees [2]) definitely indicate that the number of load cycles before the first failure is considerably larger than the number of load cycles between successive failures. In the data considered here in Section 3, the number of load cycles to the first failure is about six times that of the largest successive difference. Also, the chi-squared goodness-of-fit test indicates that for this data the exponential distribution provides a reasonable model for the inter-failure times in the range that these tests were conducted.

In type I censoring the number of failures before time t is a random variable, which we denote by R. Because of the lack-of-memory property of an exponential distribution with location parameter μ, R has, in this case, a Poisson distribution with mean $n(t-\mu)/\sigma$. Given that $R = r > 0$, the ordered failure times $X_{(1)}, X_{(2)}, \ldots, X_{(r)}$ have the same distribution as the ordered values of a random sample from a uniform distribution on the interval (μ, t). Hence these ordered failure times and R have likelihood function

$$f(x_{(1)}, x_{(2)}, \ldots, x_{(r)}, r; \mu, \sigma, t, n) = f(x_{(1)}, x_{(2)}, \ldots, x_{(r)}; \mu, t, R = r) \Pr\{R = r; \mu, \sigma, t, n\}$$

$$= (n/\sigma)^r \exp[-n(t-\mu)/\sigma],$$

$$\mu < x_{(1)} < x_{(2)} < \ldots < x_{(r)} < t, \quad r = 1, 2, \ldots, \tag{2}$$

where

$$f(x_{(1)}, x_{(2)}, \ldots, x_{(r)}; \mu, t, R = r) = \frac{r!}{(t-\mu)^r}, \tag{3}$$

$$\Pr\{R = r; \mu, \sigma, t, n\} = \frac{[n(t-\mu)/\sigma]^r}{r!} \exp[-n(t-\mu)/\sigma], \tag{4}$$

and

$$\Pr\{R = 0\} = \exp[-n(t-\mu)/\sigma]. \tag{5}$$

Since R, the number of failures is random; the likelihood function has been written as a function with a variable number of arguments. Applying the factorization criterion for a family of distributions dominated by a σ-finite measure, we see that $X_{(1)}$ and R are jointly sufficient for (μ, σ), that $X_{(1)}$ is sufficient for μ with σ fixed, and that R is sufficient for σ with μ fixed (see Lehmann [3]). The dominating measure is defined on the union of $\{0\}$ and the sets $\{(x_{(1)}, \ldots, x_{(r)}, r): x_{(1)} < \ldots < x_{(r)} < t\}$ for $r = 1, 2, \ldots$). Although (2) is not a member of the regular exponential class, as shown in Section 2, the tests obtained from the appropriate conditional tests are uniformly most powerful unbiased and consequently, they give rise to optimal confidence limits.

2. TESTING WITH REPAIR

As noted in Section 1, $X_{(1)}$ and R are sufficient in the case being considered. For convenience we will define $X_{(1)}$ as the time of the first failure if this is less than t, and $X_{(1)} = t$ otherwise. First, optimal conditional tests will be developed and then shown to be optimal when viewed as unconditional tests for one of the parameters with the other considered as a nuisance parameter.

For inferences about σ with μ a nuisance parameter, we first need the conditional distribution of R given $X_{(1)}$. If $X_{(1)}=t$, then $R = 0$, and if $X_{(1)}=x_{(1)}<t$, then "restarting" the Poisson process at $x_{(1)}$, it is clear that $R-1$ has a Poisson distribution with mean $n(t- x_{(1)})/\sigma$. Since the density of $R-1$ is known to have a monotone likelihood ratio, the usual one-sided tests based on R are uniformly most powerful in this conditional framework. (If the uniformly most powerful unbiased two-sided test is preferred over the equal-tails test, then the rejection region must be chosen to satisfy the equality given in Lehmann [3]). In this procedure we randomize if $R = 0$. Note that in practice it may not be possible to obtain an exact α-level test since the test statistic R has a discrete distribution, so it may also be necessary to randomize for this reason.

For inferences about μ with σ viewed as a nuisance parameter, we obtain the conditional density of $X_{(1)}$ given R. If $R = 0$, then $X_{(1)}=t$, and if $R = r > 0$, then it is well-known that $X_{(1)}$ has the same distribution as the smallest order statistic of a random sample of size r taken from a uniform distribution on the interval (μ, t). So for $r > 0$ this conditional density is

$$f(x_{(1)};r) = r(t-\mu)^{-r}(t-x_{(1)})^{r-1}, \quad \mu < x_{(1)} < t. \tag{6}$$

Again this family of densities has a monotone likelihood ratio and the usual one-sided tests based on $X_{(1)}$ are uniformly most powerful in the conditional framework. The equal-tails test could be used in the two-sided case. It should be noted that given $R = r > 0$, $[(t-X_{(1)})/(t-\mu)]^r$ has a uniform distribution on the interval (0, 1). Since $[(t-x_{(1)})/(t-\mu)]^r$ is a decreasing function of $x_{(1)}$, inferences based on either $X_{(1)}$ or this pivotal quantity are equivalent but, of course, small values of $X_{(1)}$ correspond to large values of the pivotal quantity, and vice versa. Again this test is conditioned on $R > 0$.

The one-sided tests described in this section can also be viewed as unconditional tests. Appealing to Theorems 1 and 2 given by Ferguson [4], we see that these tests are uniformly most powerful unbiased provided

(i) every test of these hypotheses has power which is a continuous function of (μ,σ);
(ii) for each fixed μ, R is sufficient and complete for σ; and
(iii) for each fixed σ, $X_{(1)}$ is sufficient and complete for μ.

The required sufficiency of R and of $X_{(1)}$ follows by inspection of (2) and the completeness of R follows because it has a re-parameterized Poisson distribution. Next, $X_{(1)}$ is shown to be complete (with σ held fixed). Now $X_{(1)}$ has the same distribution as the smallest order statistic of a random sample of size n from (1) except that the probability that this order statistic exceeds t is assigned to t. That is, $X_{(1)}$ has a mixed discrete-absolutely continuous distribution with

$$\Pr\{X_{(1)} = t\} = \exp\{-n(t-\mu)/\sigma\} \tag{7}$$

and density

$$f(x) = (n/\sigma)\exp\{-n(x-\mu)/\sigma\} \quad \text{for} \quad \mu < x < t. \tag{8}$$

So for any function $h(\cdot)$, for which $E(h(X_{(1)})) = 0$ for all $\mu<t$

$$\int_{\mu}^{t} h(x)f(x)dx + h(t)\exp[-n(t-\mu)/\sigma] = 0, \tag{9}$$

and differentiating (9) with respect to μ, we see that $h(\cdot)$ is essentially zero.

Finally we establish (i). Denoting an arbitrary test function by $\varphi(r, x_{(1)}, ..., x_{(r)})$, we need only show that

$$g(\mu,\sigma) = \sum_{r=1}^{\infty}(n/\sigma)^r f(r,\mu), \tag{10}$$

where

$$f(r,\mu) = \int_{\mu<x_{(1)}<\ldots<x_{(r)}<t} \ldots \int \varphi(r, x_{(1)}, ..., x_{(r)}dx_{(1)}dx_{(2)}\ldots dx_{(r)}, \tag{11}$$

is a continuous function of (μ,σ). Letting (μ',σ') denote another parameter point with $\mu'>\mu$, $|g(\mu,\sigma) - g(\mu',\sigma')|$ is bounded above by

$$\sum_{r=1}^{\infty}(n/\sigma')^r \,|\, f(r,\mu') - f(r,\mu) \,| + \sum_{r=1}^{\infty} f(r,\mu) \,|\, (n/\sigma')^r - (n/\sigma)^r \,|\,. \tag{12}$$

To establish the desired continuity we bound both expressions in (12) by quantities, which converge to zero as $|\mu - \mu'|$ and $|\sigma - \sigma'|$ converge to zero.

Since $0 \le \varphi(\cdot) \le 1$, $0 \le f(r,\mu) \le (t-\mu)^r/r!$ and by the mean value theorem $\left|(n/\sigma')^r - (n/\sigma)^r\right| \le r\left|n/\sigma' - n/\sigma\right|(n/\sigma^\bullet)^{r-1}$, where $\sigma^\bullet = \min(\sigma,\sigma')$. Applying these two bounds to the second expression in (12), we see that it is bounded above by

$$(t-\mu)\left|n/\sigma' - n/\sigma\right|[\exp[n(t-\mu)/\sigma^\bullet]. \tag{13}$$

Since $|f(r,\mu') - f(r,\mu)|$ is bounded above by

$$\int_{\mu}^{\mu'} (t-x_{(1)})^{r-1}/(r-1)!dx_{(1)} \le |\mu' - \mu|(t-\mu)^{r-1}/(r-1)!, \tag{14}$$

the first expression in (12) is bounded by

$$(n/\sigma')|\mu' - \mu|\exp[n(t-\mu)/\sigma']. \tag{15}$$

Thus, these one-sided tests are uniformly most powerful unbiased and consequently the associated confidence limits are uniformly most accurate unbiased.

3. EXAMPLE

To illustrate the results for testing with repair we consider some data from the fatigue-testing example discussed in the introduction. Recall that specimens of titanium and steel were subjected to stresses similar to those occurring in flight until a crack was detected; the crack was repaired, and testing was then resumed. The total "time" to detection of each crack was recorded in load cycles. For the tests discussed in Butler and Rees [2], no two specimens of the same metal were tested at the same temperature and humidity level, so we consider only the results from the test on one specimen.

Table 1 contains the total number of load cycles for the successive crack initiations for the first steel specimen with a termination "time" of 60,000 load cycles. Ties in the data may be attributed to several factors; for example, cracks beginning to form might be detected while others are being repaired. Note that the first crack was detected at 35,143 load cycles and the largest of the next twenty times between

Table 1. Total Number of Load Cycles to Successive Crack Detections

Crack no.	Load cycles	Crack no.	Load cycles	Crack no.	Load cycles
1	35,143	8	50,750	15	54,111
2	41,250	9	50,750	16	54,940
3	43,150	10	50,750	17	55,600
4	46,950	11	52,052	18	56,750
5	47,900	12	52,646	19	58,000
6	48,750	13	52,850	20	59,506
7	50,250	14	53,476	21	60,000

failures was 6,107 load cycles. This data set, as well as the other seven presented by Butler and Rees indicates that a model should be chosen which tends to have longer times to the first failure than the times between successive failures. The inclusion of the threshold parameter μ provides such a model. A chi-squared goodness-of-fit test was performed on the 20 times between failures (not including the time to the first failure) to determine if the exponential assumption is reasonable. The chi-squared value with two degrees of freedom was 2.00, so the assumption of exponential seems reasonable.

First we test H_0: $\mu = 0$ versus H_1: $\mu > 0$. The conditional test rejects if

$$\left(\frac{t-X_{(1)}}{t}\right)^r < \alpha\,, \tag{16}$$

and for this example

$$\left(\frac{t-X_{(1)}}{t}\right)^r = 9.19\times10^{-9}. \tag{17}$$

Therefore, under the distribution assumptions of Section 2, the inclusion of a threshold parameter is definitely justified, and we will obtain a lower confidence bound for σ with μ a nuisance parameter. We wish to determine σ_L as a function of *r*, which satisfies

$$\Pr\{R^{\bullet} \geq r-1\} = 1-\alpha, \tag{18}$$

where $R^{\bullet}$ is a Poisson variable with mean $n(t-x_{(1)})/\sigma_L$. However,

$$\Pr[R^{\bullet} \geq r-1] = G(2n(t-x_{(1)})/\sigma_L;2(r-1)), \tag{19}$$

where G(*x*;*k*) denotes the cumulative distribution function of a chi-squared variable with *k* degrees of freedom. Denoting the 100(1−α)th percentile of such a distribution by χ^2(l−α; *k*), the desired lower confidence bound is given by

$$\sigma_L = 2n(t-x_{(1)})/\chi^2(1-\alpha;2(r-1)). \tag{20}$$

In the example considered, *r*=21, *n*=l, *t*= 60,000, and $x_{(1)}$= 35,143, so a 95 percent lower confidence bound for σ is σ_L = 891.65.

4. CONCLUSION

The purpose of the paper has been to present inferences concerning the location and scale parameters of an exponential distribution under type I censored sampling. It is the authors' hope that this study will stimulate others to study the problem of testing for crack initiation due to fatigue in fatigue- sensitive structures with repair or without repair under type I censored sampling.

ACKNOWLEDGMENTS

This research was supported in part by Grant No. 02.0918 and Grant No. 01.0031 from the Latvian Council of Science and the National Institute of Mathematics and Informatics of Latvia.

References

[1] Mann Nancy R., Schafer Ray E., Singpurwalla Nozer D. *Methods for Statistical Analysis of Reliability and Life Data.* New York: John Wiley & Sons, 1974.

[2] Butler J.P., Rees D.A. Exploration of statistical fatigue failure characteristics of 0.063-inch mill-annealed Ti6Al-4V sheet and 0.050-inch heat-treated 17-7 ph steel sheet under simulated flight-by-flight loading. In: *Technical Report AFML-TR-74-269.* Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, 1974.

[3] Lehmann E.L. *Testing Statistical Hypotheses.* New York: John Wiley & Sons, 1959.

[4] Ferguson Thomas S. *Mathematical Statistics: a Decision Theoretic Approach.* New York: Academic Press, 1967.

APPROXIMATION TECHNIQUE FOR FINDING A PROBABILISTIC ASSESSMENT OF THE FATIGUE RELIABILITY

Konstantin N. Nechval

Transport and Telecommunication Institute
Applied Mathematics Department
Lomonosov Str. 1, LV-1019, Riga, Latvia
E-mail: konstan@tsi.lv

Probabilistic assessments are a useful supplement to deterministic analyses and can also be used as an aid to decision making in areas such as safety analyses, design studies and deployment of resources on maintenance, inspection and repair. Because the initial crack size, the stress, the material properties and other factors that may affect the fatigue crack growth are statistically distributed, the first-order second-moment technique is often adopted to calculate the fatigue reliability of industrial structures. In this paper, a second-order third-moment technique is presented and a three-parameter Weibull distribution is adopted to reflect the influences of skewness of the probability density function. The proposed method that has more characteristics of those random variables that are concerned in reliability analysis is obviously more accurate than the traditional first-order second-moment technique.

Keywords: *Paris–Erdogan law, fatigue reliability, Weibull distribution*

1. INTRODUCTION

Several models based on the principles of fracture mechanics for the prediction of fatigue crack growth in components and structures under dynamic loads have been proposed, one of the best known is the Paris–Erdogan law [1]. From fracture mechanics, it is known that the fatigue crack propagation follows the Paris–Erdogan law

$$\frac{\mathrm{d}a}{\mathrm{d}N} = C(\Delta K)^b = C\beta^b S^b a^{b/2}, \tag{1}$$

where da/dN is the crack growth rate, $\Delta K = \beta S\sqrt{a}$, the range of the stress intensity factor, S, the stress range, β, a constant that depends on the type of load and geometry of the crack, C and b are material constants.

If we assume all parameters in Equation (1) are constants and deterministic, then the crack length, $a(N)$, after N cycles of stress can be obtained directly from Equation (1). Integrating Equation (1) from a deterministic initial crack size, $a(0)$, to crack size $a(N)$, one obtains

$$a(N) = \left([a(0)]^{(2-b)/2} + \frac{2-b}{2} C\beta^b S^b N \right)^{2/(2-b)} \qquad (b \neq 2), \tag{2}$$

$$a(N) = a(0)\exp\left(C\beta^2 S^2 N\right) \quad \text{(b=2)}. \tag{3}$$

However, $a(0)$, C, β and S may be all random variables with prescribed probability density functions in probabilistic fracture mechanics analysis. In practical applications of the stochastic crack growth analysis, either one of the following two distribution functions is needed: the distribution of the crack size at any given number of load cycles or the distribution of the number of load cycles to reach any given crack size. As a result, numerical simulation (Monte Carlo simulation) procedures have been used to obtain more accurate results [2-3]. The simulation approach is a very powerful tool, in particular with modern higher speed computers. However, in some situations, such as the preliminary analysis or design, simple approximate analytical solutions are very useful. The accuracy of such

solutions depends on the sophistication of the approximation. One of the widely used approximations is the first-order second-moment technique in which only the means and variances of random variables are considered, namely the random variables are assumed following normal distributions [4-5].

The fatigue life, N, at any given crack size $a(N)$, is also obtained from Equations (2) and (3).

2. APPROXIMATION TECHNIQUE

The first-order second-moment method only considers the means and variances of random variables. But probabilistic fracture mechanics problems generally involve non-normal distributions such as the lognormal, the exponential or the Weibull distribution. The skewness of a probability density function is sometimes used to measure the asymmetry of a probability density function about the mean. The second-order third-moment method considers not only the mean and variance of a probability density function, but also the influence of skewness (which is represented by the third moment) of a probabilistic distribution. Because more characteristics of random variables are concerned with reliability analysis, the precision of reliability analysis can be increased. Particularly when random variables are not normally distributed. It is very important for industrial structures with high reliability requirement.

The random variable Y is the function of several mutually independent random variables, $X_1, X_2, \ldots, X_n$, as follows:

$$Y = f(X_1, X_2, ..., X_n)\,, \tag{4}$$

where vector $\boldsymbol{\mu} = (\mu_1, \mu_2, \ldots, \mu_n)$ denotes the mean of vector $\boldsymbol{X} = (X_1, X_2, \ldots, X_n)$, namely μ_i is the mean of random variable X_i.

To obtain a better approximation, Y is expanded about $\boldsymbol{\mu}$ to second order

$$Y = f(\mu_1, \mu_2, ..., \mu_n) + \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\right)_{\boldsymbol{\mu}}(X_i - \mu_i) + \frac{1}{2}\sum_{i,j=1}^{n}\left(\frac{\partial^2 Y}{\partial X_i \partial X_j}\right)_{\boldsymbol{\mu}}(X_i - \mu_i)(X_j - \mu_j)\,, \tag{5}$$

Taking the first, the second and the third moment of both sides of Equation (5) respectively, one obtains

$$\mu_Y = f(\mu_1, \mu_2, ..., \mu_n) + \frac{1}{2}\sum_{i=1}^{n}\left(\frac{\partial^2 Y}{\partial X_i^2}\right)_{\boldsymbol{\mu}}\sigma_i^2, \tag{6}$$

$$\sigma_Y^2 = f^2(\mu_1, \mu_2, ..., \mu_n) + \sum_{i=1}^{n}\left[\left(\frac{\partial Y}{\partial X_i}\right)^2 + Y\frac{\partial^2 Y}{\partial X_i^2}\right]_{\boldsymbol{\mu}}\sigma_i^2 + \sum_{i=1}^{n}\left(\frac{\partial Y}{\partial X_i}\frac{\partial^2 Y}{\partial X_i^2}\right)_{\boldsymbol{\mu}}\gamma_i - \mu_Y^2\,, \tag{7}$$

$$\gamma_Y = f^3(\mu_1, \mu_2, ..., \mu_n) + \frac{3}{2}\sum_{i=1}^{n}\left[2Y\left(\frac{\partial Y}{\partial X_i}\right)^2 + Y^2\frac{\partial^2 Y}{\partial X_i^2}\right]_{\boldsymbol{\mu}}\sigma_i^2$$

$$+\sum_{i=1}^{n}\left[\left(\frac{\partial Y}{\partial X_i}\right)^3 + 3Y\frac{\partial Y}{\partial X_i}\frac{\partial^2 Y}{\partial X_i^2}\right]_{\boldsymbol{\mu}}\gamma_i - \mu_Y^3 - 3\mu_Y\sigma_Y^2\,, \tag{8}$$

where μ_Y and σ_Y^2 are the mean and variance of the random variable Y, and γ_Y is the third moment of the random variable Y, which measures the amount of skewness of the distribution, σ_i^2 is the variance of the random variable X_i and γ_i is the third moment of the random variable X_i. When $\gamma > 0$, the distribution is skewed to the right like the lognormal and exponential distributions do. When $\gamma < 0$, the

distribution is skewed to the left. When $\gamma = 0$, the distribution is a symmetrical distribution such as the normal distribution.

In this paper, Y may denote the crack length $a(N)$, and X_1, X_2, X_3 and X_4 may denote $a(0)$, C, β and S, respectively.

3. FINDING A PROBABILISTIC ASSESSMENT OF THE FATIGUE RELIABILITY

The Weibull distribution is one of the most widely used distributions in reliability calculations. The great versatility of the Weibull distribution stems from the possibility to adjust to fit many cases where the hazard rate either increases or decreases. Further, of all statistical distributions that are available the Weibull distribution can be regarded as the most valuable because through the appropriate choice of parameters (the location parameter, the shape parameter and the scale parameter), a variety of shapes of probability density function can be modeled [6]. Which include the cases of $\gamma > 0$, $\gamma = 0$ and $\gamma < 0$.

The three-parameter Weibull distribution pertains to a continuous variable Y that may assume any value $\mu < y < \infty$, and is defined in terms of its density function or distribution function as follows:

$$f(y) = \frac{\delta}{\sigma}(y-\mu)^{\delta-1}\exp\left[-(y-\mu)^{\delta}/\sigma\right] \quad (y \geq \mu), \tag{9}$$

$$\Pr\{Y \leq y^{\bullet}\} = 1 - \exp\left[-(y^{\bullet}-\mu)^{\delta}/\sigma\right], \tag{10}$$

where μ is the location parameter, δ and σ are the shape parameter and the scale parameter respectively;
δ, σ and μ are related to the mean value μ_Y, the variance σ_Y^2 and third moment γ_Y through the following:

$$\mu_Y = \sigma^{1/\delta}\Gamma\left(1+\frac{1}{\delta}\right)+\mu, \tag{11}$$

$$\sigma_Y^2 = \sigma^{2/\delta}\left[\Gamma\left(1+\frac{2}{\delta}\right)-\Gamma^2\left(1+\frac{1}{\delta}\right)\right], \tag{12}$$

$$\gamma_Y = \sigma^{3/\delta}\left[\Gamma\left(1+\frac{3}{\delta}\right)-3\Gamma\left(1+\frac{2}{\delta}\right)\Gamma\left(1+\frac{1}{\delta}\right)+2\Gamma^3\left(1+\frac{1}{\delta}\right)\right], \tag{13}$$

where $\Gamma(\cdot)$ is the gamma function.

If a variable X is normally distributed, the third moment of the random variable X is $\gamma_X = 0$ and its density function is

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-(x-\mu)^2/(2\sigma^2)\right]. \tag{14}$$

Then the mean and variance of the random variable X are given by

$$\mu_X = \mu, \tag{15}$$

$$\sigma_X^2 = \sigma^2. \tag{16}$$

If a variable X is exponentially distributed and its density function is given by

$$f(x) = \sigma^{-1}\exp\left[-(x-\mu)/\sigma\right], \tag{17}$$

then the mean, the variance and the third moment of the variable is given by

$$\mu_X = \mu + \sigma, \tag{18}$$

$$\sigma_X^2 = \sigma^2, \tag{19}$$

$$\gamma_X = 2\sigma^3. \tag{20}$$

If a variable X is lognormally distributed and its density function is given by

$$f(x) = \frac{1}{\sigma x\sqrt{2\pi}} \exp\left[-(\ln x - \mu)^2/(2\sigma^2)\right], \tag{21}$$

then the mean, the variance and the third moment of the variable is given by

$$\mu_X = \exp(\mu + 0.5\sigma^2), \tag{22}$$

$$\sigma_X^2 = \exp(2\mu + \sigma^2)\left[\exp(\sigma^2) - 1\right], \tag{23}$$

$$\gamma_X = \exp(3\mu + 4.5\sigma^2) - 3\exp(3\mu + 2.5\sigma^2) + 2\exp(3\mu + 1.5\sigma^2)\,. \tag{24}$$

If a variable X follows the Weibull distribution and its density function is defined by Equation (9), then the mean, the variance and the third moment of the variable X is calculated from Equations (11)–(13).

Thus, procedure for finding a probabilistic assessment of the fatigue reliability can be summarized as follows. If, $a(0)$, C, β and S in Equations (2) and (3) may be all random variables with prescribed probability density functions such as the normal, the lognormal, the exponential and the Weibull distributions, in which the means, the variances and the third moments can be calculated from Equations (14)–(24) (the Weibull distribution calculated from Equations (11)–(13)). Then the mean, the variance and the third moment of the crack length $a(N)$ at any given N cycles of stress can be calculated from Equations (6)–(8). The parameters, δ, σ and μ of the Weibull distribution are solved from Equations (11)–(13) and the reliability of the cracked structure after N cycles of stress are obtained from Equation (10).

4. NUMERICAL EXAMPLE

Let us assume that a cracked structure with the fatigue crack growth rates $\mathrm{d}a/\mathrm{d}N = 5 \times 10^{-5}$ mm/cycle is researched. The probability density function of the initial crack size $a(0)$ is exponential distribution function,

$$f(x)=\exp[-(x-2)]. \tag{25}$$

The critical crack length is $a^{\bullet}=10$ mm. The reliability of the cracked structure after $N=10^5$ cycles of stress is obtained as follows:

(i) Suppose that the constant of the Paris–Erdogan law is $b=0$ and only $a(0)$ is random variable. From Equation (2), one can obtain the crack size after $N=10^5$ cycles of stress:

$$a(N) = a(0) + 5\times 10^{-5} N = a(0) + 5 \quad \text{(mm)}. \tag{26}$$

(ii) From Equations (17)–(20), the mean, the variance and the third moment of the initial crack size $a(0)$ is calculated in which $\sigma=1$, $\mu=2$ mm; then from Equations (6)–(8), one can obtain the mean, the variance and the third moment of the crack size a after $N=10^5$ cycles of stress as follows:

$$\mu_{a(N)} = 8.0, \quad \sigma_{a(N)}^2 = 1.0, \quad \gamma_{a(N)} = 2.0. \tag{27}$$

(iii) Substituting $\mu_{a(N)}$, $\sigma^2_{a(N)}$, and $\gamma_{a(N)}$ into Equation (11), Equation (12) and Equation (13), respectively, these simultaneous equations for δ, σ and μ can be solved to obtain three parameters of the Weibull distribution as follows:

$$\delta=1.0, \quad \sigma=1.0, \quad \mu=7.0. \tag{28}$$

(iv) As the density distribution of the crack length $a(N)$ is defined as Equation (9), the reliability of the cracked structure after $N=10^5$ cycles of stress is calculated by Equation (10) as follows:

$$\Pr\{a(N) \le a^{\bullet}\} = 1 - \exp\left[-(a^{\bullet} - \mu)^{\delta} / \sigma\right] = 1 - \exp[-(10-7)] = 0.95. \tag{29}$$

Let us assume that we use the above technique to calculate the reliability of the cracked structure, where only the mean $\mu_{a(N)} = 8.0$ and the variance $\sigma^2_{a(N)} = 1.0$ of the crack size $a(N)$ are considered. The distribution of the crack size $a(N)$ is assumed to be a normal distribution. One can obtain

$$\Pr\{a(N) \le a^{\bullet}\} = \Phi\left(\frac{10-8}{1}\right) = \Phi(2) = 0.9772. \tag{30}$$

where $\Phi(\cdot)$ is the standard normal distribution function.

Actually the problem discussed has an analytical solution, which is given as follows:

$$\begin{aligned} \Pr\{a(N) \le a^{\bullet}\} &= \Pr\{a(0) + 5 \le 10\} = \Pr\{a(0) \le 5\} \\ &= \int_{2.}^{5.} \exp\left[-(x-2)\right] dx = 1 - \exp\left[-(5-2)\right] = 0.95, \end{aligned} \tag{31}$$

where the result is the same as the one of (29).

5. CONCLUSION

From the case discussed above, the second-order third moment technique is obviously more accurate than the traditional first-order second-moment technique.

ACKNOWLEDGMENTS

This research was supported in part by Grant No. 02.0918 and Grant No. 01.0031 from the Latvian Council of Science and the National Institute of Mathematics and Informatics of Latvia.

References

[1] Paris P.C., Erdogan F. A.Critical Analysis of Crack Propagation Laws, *J Basic Engng, Trans ASME*, Series D, 85,1963, pp.528-534.

[2] Mann N.R., Schafer R.E. and Singpurwalla N.D. *Methods for Statistical Analysis of Reliability and Life Data.* New York: Wiley, 1974.

[3] Oklin I., Gleser L.J. and Derman C. *Probability Models and Applications.* New York: Macmilian, 1980.

[4] Robert G.T., Thomas A.C. and Mahadevan S. Development of a Reliability Based Fatigue Life Model for Gas Turbine Engine Structures, *Engng Fracture Mech*, 53, 1996, pp.807-828.

[5] Zhao Z. and Haldar A. Bridge Fatigue Damage Evaluation and Updating Using Non-Destructive Inspections, *Engng Fracture Mech*, 53, 1996, pp.775-788.

[6] Provan J.W. *Probabilistic Fracture Mechanics and Reliability*. Dordrecht: Martinus Nijhoff, 1987.

DYNAMIC CLASSIFICATION OF MULTIDIMENSIONAL OBJECTS

Ilya Gertsbakh[1], Irina Yatskiv[2]

[1]Department of Mathematics,
Ben Gurion University, Beer-Sheeva, Israel

[2] Transport and Telecommunication Institute
Lomonosov Str. 1, Riga, LV-1019, Latvia
Ph: (+371)-7100650. Fax: (+371)-7100660. E-mail: ivl@tsi.lv

The goal of this paper is to develop the dynamic classification algorithm. This algorithm might be applied to any object whose state is described by a vector parameter with coordinates changing in time. This algorithm combines from standard clustering algorithms and Fisher discriminant analysis. The application of this algorithm allows transforming the vector process to scalar process. In article this algorithm is demonstrated in application to the economic development of EU countries and an Economic Welfare Growth Index to the EU countries is worked out in the research.

Keywords: *Economic Welfare Growth Index, cluster analysis, Fisher discriminant function*

1. INTRODUCTION

The principal idea of the suggested dynamic classification of objects with multidimensional state description $\mathbf{x(t)}=(x_1(t),\ldots,x_p(t))$ is replacing the vector process $\mathbf{x}(t)$ by a scalar process r(t) obtained by an "optimal" weighting of its coordinates as $r(t) = \sum x_i(t) w_i$, see[1], Chapter 4. Further on, object's evolution in time is based on observing and analysing the trajectory r(t).

In this article we consider the application of this approach to the study of the economic development of EU countries during the last decade. We develop a dynamic classification algorithm (DCA) which is used to work out the so-called Economic Welfare Growth Index (EWGI) for each EU country over the period 1995-2004. The use of this index makes it possible, for each year and each country in the study, to estimate and analyse its economic welfare, to compare the welfare growth for different countries and make the corresponding forecasts. Similar approach can be used also in other areas, such as transportation, education, health care, whenever the development in time is described by a multidimensional time series.

2. ALGORITHM OF DYNAMIC CLASSIFICATIONS

Step 1. Suppose we have a set of objects with vector description of attributes (parameters) $\boldsymbol{x(t)}=(x_1(t),\ldots,x_p(t))$. Since the parameters describing the objects have different dimensions and their variances differ significantly, the data are standardized (rescaled). There are different methods to make this rescaling, the most popular of which is standardization via the formula

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j}, \qquad (1)$$

where x_{ij} – is the value of j-th index for i-th country, $i = \overline{1,n}$, $j = \overline{1,p}$;

z_{ij} – is the standardized value of j-th index for i-th country, $i = \overline{1,n}$, $j = \overline{1,p}$;

$\bar{x}_j$ – average of j-th index over all countries, s_j – standard deviation of j-th index.

Step 2. We take data for one "typical" year as a training sample. For this year, all objects after being standardized are subject to cluster analysis to single out two "extreme" groups with "bad" and "good" values of parameters [2].

We use for cluster analysis hierarchical agglomerative algorithms, e.g. Ward's and Complete Linkage, and iterative k-means algorithm. Hierarchical Ward's method divides the objects into clusters on the basis of within cluster variance minimization:

$$\sum_{g=1}^{n}\left[\sum_{k=1}^{p}\left\{\sum_{i\in G_g}\left(x_{ik}-\frac{1}{|G_g|}\sum_{j\in G_g}x_{jk}\right)^2\right\}\right]\rightarrow \min, \tag{2}$$

where n – is the numbers of clusters,
G_g – set of numbers of objects in g-th cluster,
$|G_g|$ – numbers of objects in g-th cluster,
p – numbers of variables,
x_{ik} – value of k-th variable for i-th object.

In Complete Linkage method the distance between clusters is determined as the maximum distance between pair of objects. K-means method, introduced by MacQueen, has many various forms. The main algorithm proceeds iteratively and consists of two phases. One phase updates clusters according to the minimum distance between each object and the centroid. The other phase updates cluster centroids as the centres of clusters gravity [see 2, page 41].

Step 3. The results of cluster analysis data, namely the groups of "Good" and "Bad" objects are used to calculate the Fisher linear discriminant function (FDF):

$$r_i = w_1 z_{i1} + w_2 z_{i2} + ... + w_p z_{ip}, \tag{3}$$

where $w_1, w_2, ..., w_p$ – are the coefficients selected to maximize the Mahalanobis distance between the groups, see [1], Chapter 4; see [3], Chapter 11.

The best linear combination (3) maximizes the Fisher ratio – the squared distance between $\bar{r}^B$ and $\bar{r}^G$ divided by sample variance, sometimes called the Mahalanobis distance D^2:

$$D^2 = FR = \frac{(\bar{r}^B - \bar{r}^G)^2}{s_r^2}. \tag{4}$$

Here $\bar{r}^B$ and $\bar{r}^G$ are the projections of the group centroids on the Fisher direction $\boldsymbol{w}=(w_1, w_2, ..., w_p)$ and s_r^2 is the pooled variance of the groups "G" and "B" in the projection on the same direction.

Step 4. For sake of convenience, the values of the FDF (3) are rescaled to make the centroid of "B" class move to 0, and the "G" – to 10. Using a linear transformation along the Fisher direction, as follows, does this. The EWGI for the vector of parameters $\boldsymbol{x(t)}=(x_1(t), ..., x_p(t))$ is defined as

$$EWGI(\mathbf{x}(t)) = 10 * \frac{\sum_i \frac{w_i(x_i(t)-\bar{r}_i^B)}{s_i}}{\sum_i \frac{w_i(\bar{r}_i^G-\bar{r}_i^B)}{s_i}} = C * \sum_i \frac{w_i x_i(t)}{s_i} - B, \tag{5}$$

where $\bar{r}_i^G$ and $\bar{r}_i^B$ are the coordinates of the centroids of the "Good" and "Bad" groups (before rescaling), respectively, and s_i are the standard deviation of the *i-th* parameter, also before rescaling. In formula 5

$$C = 10 * \frac{1}{\sum_i \frac{w_i(\bar{r}_i^G-\bar{r}_i^B)}{s_i}} \quad \text{and} \quad B = 10 * \frac{\sum_i \frac{w_i \bar{r}_i^B}{s_i}}{\sum_i \frac{w_i(\bar{r}_i^G-\bar{r}_i^B)}{s_i}}. \tag{6}$$

3. APPLICATION OF DCA TO ECONOMIC PARAMETERS OF EU COUNTRIES IN 1995-2004

3.1. Initial Data

Consider as initial data the values of six parameters, which characterize economical welfare of European countries:

- **GDP_PER** – GDP in current prices per population, *in $,*
- **INFL** – Inflation level (Annual average rate of change in Harmonized Indices of Consumer Prices),
- **BEZR** – Unemployment level, unemployment expressed in a rate of the total active population;
- **CPI** – Corruption Perceptions Index (relates to perceptions of the degree of corruption as seen by business people, risk analysts and the general public, and ranges between 10 (highly clean) and 0 (highly corrupt));
- **LABOUR** – Labour productivity per person employed (GDP in Purchasing Power Standards per person employed relative to EU-25, where EU-25=100), in %;
- **LIFE** – Life expectancy at birth by gender (total average), in years.

The values of indices were found for 25 EU countries for period 1995-2004 from Eurostat site [4]. Each index satisfies the following natural demands: it has a transparent economic meaning; it is accepted by economist community; it changes in **a monotone way from poor to rich countries**, according to our intuitive understanding what is poor ("bad ") and rich ("good"), and/or what is the meaning of economic welfare.

3.2. Cluster Analysis

Take as the basis t_0 the "middle" of the period of study – the average of year 1999 and 2000 for each index x_i and then standardizes the data. Apply Ward's, Complete Linkage and k-means methods to find out three clusters among the EU countries. The results of the first and the second method are presented on Fig.1.

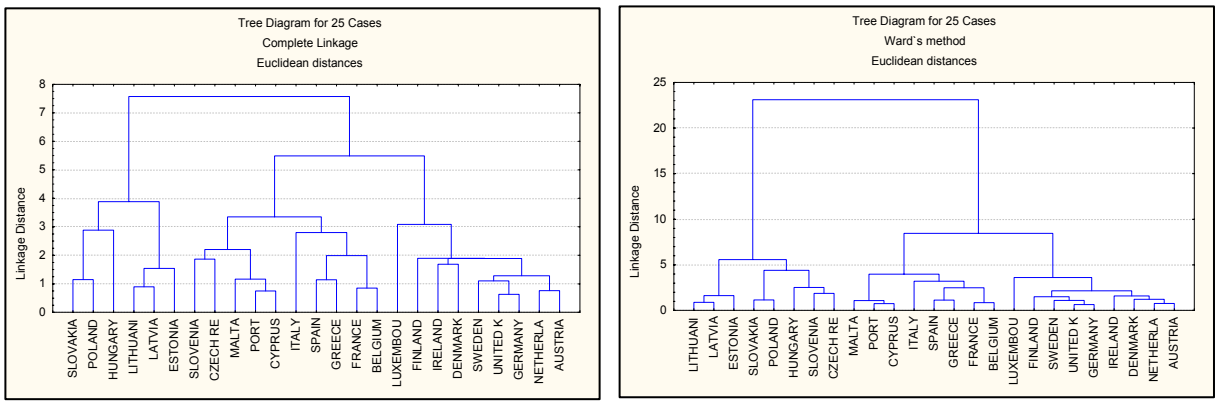


Figure 1. *The results of classification by Complete Linkage (left) and Ward (right) (Euclidian distance)*

Table 1 presents the results of K-means Method - the countries in each cluster and the distances from of their members from the corresponding centroids. The classification results have some small deviations from method to method. That's why we will use a "robust" decision, i.e. the clusters will be are defined as follows. "*Rich*" and "*Poor*" consist of those objects, which were assigned to these clusters by all three methods; cluster "*Middle*" consists of those objects, that do not belong to "Rich" and "Poor". We also homogenize the data for *"Rich*" cluster excepting one country – *Luxembourg* – that looks like an outlier, see Table 1. Finally, two "extreme" clusters are as follows:
1 - (*"Poor", 6 countries*) – Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia;

3 - (*"Rich", 10 countries*) – Austria, Belgium, Denmark, Germany, Finland, France, Ireland, Netherlands, Sweden, UK.
The cluster "*Middle*" contains the remaining 9 countries.

Table 1. Members of Clusters and Distance from Respective Cluster Center

Cluster 1 "Poor"	***Estonia***	***Hungary***	***Latvia***	***Lithuania***	***Poland***	***Slovakia***					
Distance	0.496	0.888	0.596	0.787	0.442	0.879					
Cluster 2 "Middle"	***Cyprus***	***Cz Rep***	***GREECE***	***Italy***	***Malta***	***Port***	***Slovenia***	***Spain***			
Distance	0.380	0.527	0.441	0.908	0.358	0.479	0.677	0.602			
Cluster 3 "Rich"	***Austria***	***Belgium***	***Denmark***	***Germany***	***Finland***	***France***	***Ireland***	***Luxem burg***	***Sweden***	***Nether lands***	**UK**
Distance	0.282	0.591	0.511	0.289	0.551	0.570	0.413	0.922	0.374	0.362	0.215

The descriptive statistics of the three clusters are presented in Table 2 and Fig.2.

Table 2. Descriptive Statistics of Clusters

	Cluster 1 (6 cases)		**Cluster 2 (8 cases)**		**Cluster 3 (11 cases)**	
	Mean	***Std.Dev.***	***Mean***	***Std.Dev.***	***Mean***	***Std.Dev.***
GDP_PER	-1.150	0.061	-0.447	0.366	0.953	0.594
INFL	1.005	1. 513	-0.049	0.628	-0.512	0.289
BEZR	1.168	0.903	-0.018	0.683	-0.624	0.648
CPI	-1.094	0.461	-0.382	0.488	0.874	0.672
LABOUR	-1.334	0.314	-0.135	0.622	0.826	0.497
LIFE	-1.456	0.393	0.162	0.792	0.676	0.297

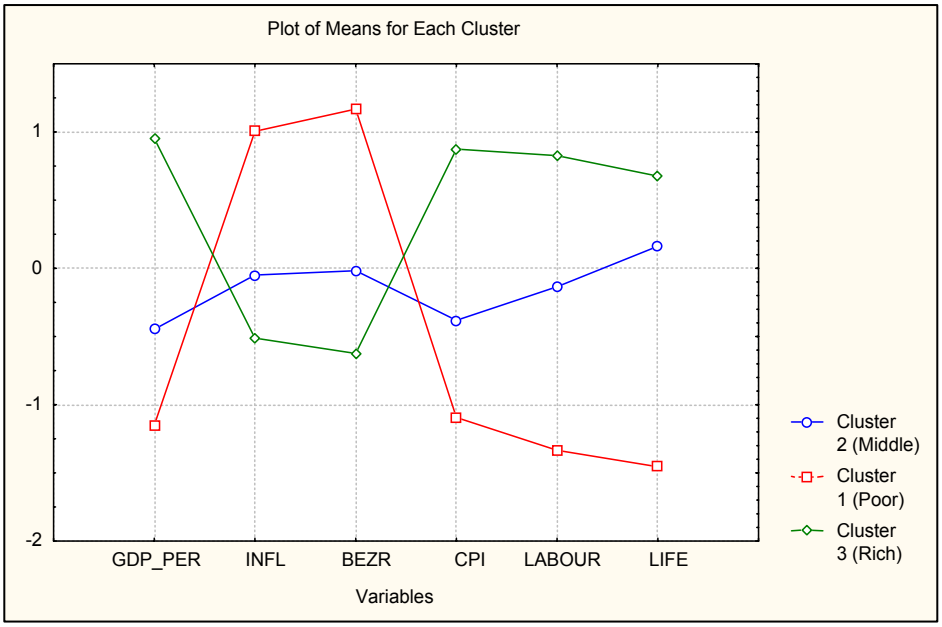


Figure 2. *Plot of Means for Clusters obtained by k-means method*
- *Poor (P) (max: Infl, Bezr; min: GDP, Labour, Life, CPI)*
- *Rich (R) (min: Infl, Bezr; max: GDP, Labour, Life, CPI)*

The cluster, which we call "Rich", consists of objects with the highest values of indices *GDP_PER*, *CPI, LABOUR*, *LIFE_EXP* and with the lowest values of indices *INFL*, *BEZR*. The cluster called "Poor" consists of objects with the lowest values of indices *GDP_PER*, *CPI, LABOUR*, *LIFE_EXP* and with the highest values of indices *INFL*, *BEZR*. The remaining countries constitute the "Middle" cluster.

3.3. Discriminant Analysis

With two clusters left, the training sample is as follows:

Table 3. Training Sample

Country	GDP_PER	INFL	BEZR	CPI	LABOUR	LIFE	GROUP
Austria	0.736	-0.722	-1.098	0.573	0.556	0.702	r
Belgium	0.619	-0.495	-0.159	-0.407	1.170	0.594	r
Denmark	1.320	-0.320	-1.359	1.704	0.490	0.666	r
Estonia	-1.149	0.064	0.827	-0.407	-1.444	-1.711	p
Germany	0.689	-0.809	-0.207	0.648	0.474	0.666	r
Finland	0.668	-0.408	0.375	1.704	0.661	0.540	r
France	0.605	-0.739	0.328	0.070	1.129	1.045	r
Hungary	-1.063	2.333	-0.432	-0.658	-0.885	-1.675	p
Ireland	0.767	0.203	-0.825	0.472	1.033	0.072	r
Latvia	-1.227	-0.338	1.290	-1.563	-1.638	-1.945	p
Lithuania	-1.207	-0.879	1.575	-1.286	-1.690	-1.405	p
Poland	-1.109	1.861	1.540	-1.186	-1.236	-0.991	p
Slovakia	-1.148	2.786	2.205	-1.462	-1.110	-1.009	p
Sweden	1.006	-0.827	-0.539	1.452	0.582	1.261	r
Netherlands	0.695	-0.408	-1.276	1.226	0.428	0.666	r
United Kingdom	0.741	-0.792	-0.658	1.075	0.488	0.558	r

Using the Backward Stepwise Discriminant Analysis (package STATISTICA/WIN), we obtain the following coefficients of the FDF (Table 4).

Table 4. Discriminant function coefficients

Variables	*Coeff.*
GDP_PER	4.9123
LABOUR	3.7311
INFL	-1.0615
LIFE	0.9131

Analysing the DF coefficients we can see that all signs of coefficients are "correct". So, with increasing inflation (**INFL**) the value of FDF, will decrease, but with increasing of **GDP_PER** or **LIFE** or **LABOUR** – it will increase. The table shows that only four parameters are present in the FDF. Apparently, there is redundancy of discriminating variables, probably due significant correlation between them.

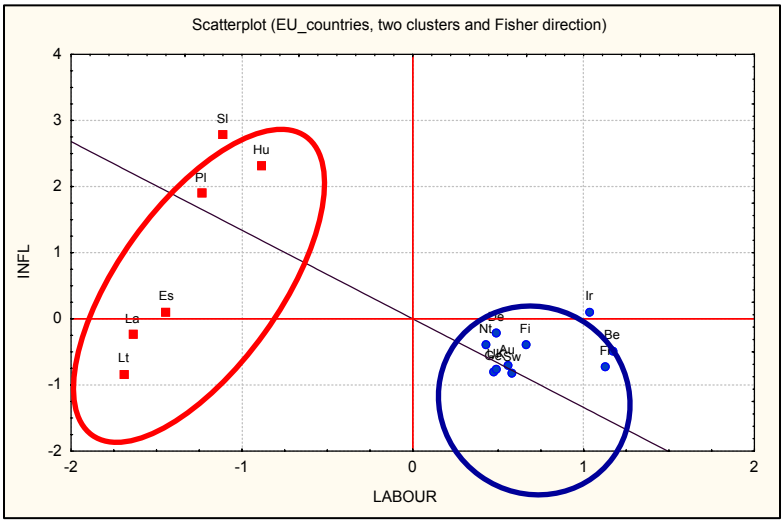


Figure 3. *2D Scatterplots: on the base of standardized values of* ***LABOUR*** *and* ***LIFE***

For visualization of the Fisher approach we illustrate the FDF for the case of two variables – **LABOUR** and **LIFE (**Figure 3). The line which goes thru points A (-2,2.7) and B (1.5,-2) guarantees the maximal Mahalanobis distance between the points representing the objects of two classes, when they are and projected on the line AB. Here the separation is quite good the Mahalanobis distance equals 91.01.

3.4. Obtaining the Formula for the EWGI

The next step in the algorithm is obtaining the formula (5) for EWGI. The coordinates of for both clusters in training sample (non-standardized) are presented in first two columns of Table 5. The standard deviations of variables in training sample are presented in last column of this Table.

Table 5. The coordinates of centroids for both Clusters and standard deviations of variables

Variables	$\bar{r}_i^B$	$\bar{r}_i^G$	s_i
GDP_PER	3747.58	25250.75	11112.33
INFL	6.1	1.795	2.86
LABOUR	46.9	111.47	31.73
LIFE	72.06	77.98	2.78

The constants in this formula are equal to C=0.484 and B=13.863. That's why the final version of formula 5 will be the following:

$$EWGI = C*(\frac{4.91}{11112.33}*GDP_PER+\frac{-1.06}{2.86}*INFL+\frac{3.73}{31.73}LABOUR+\frac{0.91}{2.78}LIFE)-B= \quad (7)$$
$$=0.00021*GDP_PER-0.18*INFL+0.057*LABOUR+0.16LIFE-13.863$$

So, we can take the value of variables for Denmark ***GDP_PER*** = 31202.5, ***INFL*** = 2.4, ***LABOUR***=104.75, ***LIFE***=77.95 and the value of *EWGI* equal by (7) to 10.78.

Using formula (7) we can find out the changes of the Index resulting from the changes of each variable. For instance, if the inflation increases by 1% (***INFL*** increases by 1), the index goes down by 0.18. If GDP increases by 2000$ then the index goes up by 0.42. If the LABOUR increases by 10 units, the EWGI increases by 0.57. Note also that in practice, due correlation between indices, the increase in one of them; let's say the GDP will necessary cause an increase in LABOUR, etc.

3.5. Time Series for the EWGI

Take any particular country *j* and consider the sets of its economic parameters $x_1(t),x_2(t),\ldots, x_6(t)$ for t = 1995, …, 2005. For each fixed value of t we obtain, using formula (7), the corresponding value of EWGI for this country for a fixed year t, EWGI (j, t). Changing t = 1995, ..., 2004, we obtain the desired time series for the EWGI for the whole period of study.

On Figure 4 we can see the dynamics of EWGI for six countries of the first cluster. These graphs, for instance, allow comparing the rate of economic progress of these countries. For instance, Slovakia had the best initial position at the beginning of the period, but did not keep it till the end of the period. Contrary to that, Lithuania had the lowest EWGI at the beginning of the period, but close to the best in 2004.

On Figure 5 we can see the comparison of EWGI for five countries from different clusters, among them Germany and Ireland from the "Rich" and Greece from the "Middle". Special interest deserves Ireland, which had a tremendous increase of EWGI during the last decade and moved from "Middle" to the top of "Rich".

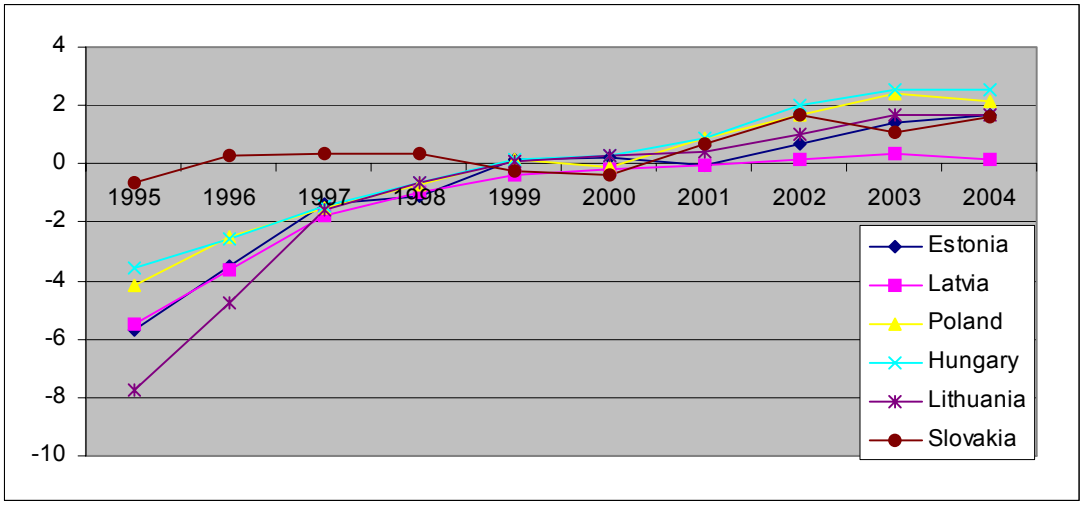


Figure 4. *Time series of EWGI values for countries from "Poor" class*

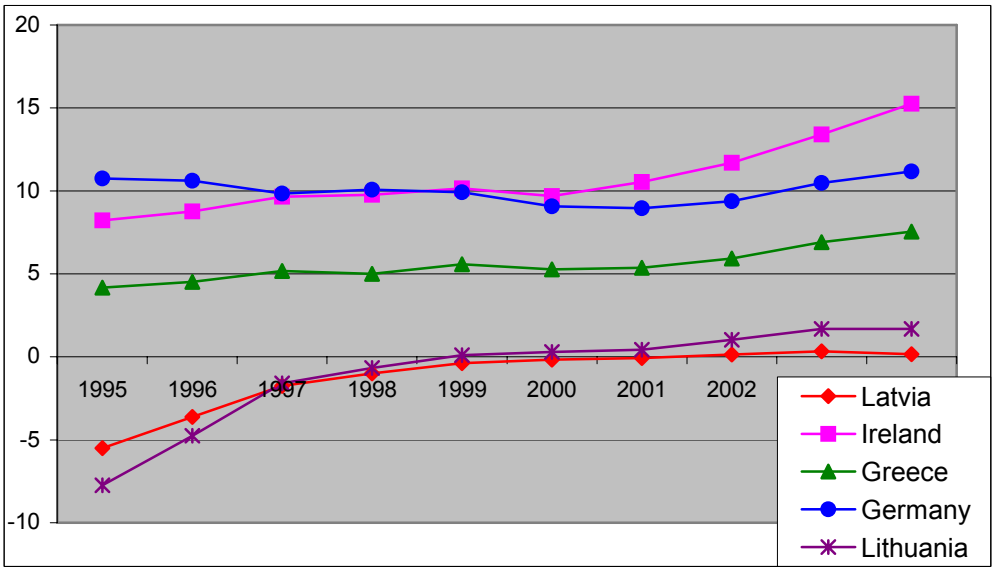


Figure 5. *Examples of time series of EWGI for 5 countries from different classes*

4. CONCLUSIONS

We demonstrated how to obtain an Economic Welfare Growth Index (EWGI) using the suggested Dynamic Classification Algorithm (DCA). The DCA is a combination of cluster analysis and Fisher discrimination technique applied to a training sample based on one-year data and extended to data samples for other years. The EWGI provides a very good separation between "poor", "middle" and "rich" countries, allows analysing and comparing their economic welfare progress and making various forecasts resulting from the changes in their basic economic indices.

References

[1] Gertsbakh I. *Models of Preventive Maintenance.* North-Holland, Amsterdam-New York-Oxford, 1977.
[2] Gordon A. *Classification, 2nd ed.* New York: Chapman & Hall, 1999.
[3] Jonson Richard A. & Wichern Dean W. *Applied Multivariate Statistical Analysis, 4th ed.* New York: Prentice Hall, 1999.
[4] http://epp.eurostat.cec.eu.int/portal/page?_pageid=0,1136184,0_45572595&_dad=portal&_schema=PORTAL

MULTI-PRODUCT INVENTORY CONTROL MODEL WITH CONSTRAINTS

Eugene Kopytov[1], Fedor Tissen[1], Leonid Greenglaz[2]

[1] Transport and Telecommunication Institute
Lomonosov Str. 1, Riga, LV-1019, Latvia
Ph: +371 7100590. Fax: +371 7100660. E-mail: kopitov@tsi.lv, fedortissen@tsi.lv

[2] Riga International School of Economics and Business Administration
Meza Str. 1, k. 2, Riga, LV-1048, Latvia
E-mail: gringlaz@riceba.lv

Purpose of the offered work is the construction of a multi-product inventory control model with random demand for goods, random lead-time and random deviation of prices and structural constraints on the resources (stock capacity, capital and others). It is proposed, that distributions of these random variables are known. Considered task has been solved as the problem of stochastic programming in E-statement.

Keywords: *inventory control, multi-product order, demand, lead-time, optimisation, constraints on resources*

1. INTRODUCTION

A big interest to inventory control problems, arising in last decades, is explained by significant financial effect, which the decisions of these problems have made in various areas of economy. The model considered in the given paper has arisen during studying a problem of storekeeping on the railway [1].

The railway as a part of the transport industry has a number specific features; among them we should note the following:

- large distances between related objects (trains, stations etc.);
- high dynamics of transportation processes;
- dependence on random factors (weather conditions, demands for transportation etc.);
- high requirements for reliability and safety of passenger and cargo transportation;
- large financial, material and labour resources.

Therefore even small errors in management and planning the transportation processes result in a considerable decrease of the efficiency of the railway company performance and of the quality of the clients' service.

It is a quite complicate mathematical task to find an optimal solution for the necessary stock, if you are working in the railways industry. The search of the effective solutions of stock control in transport company should be based on a number of economic, social and technical characteristics. Some of them are random, and some have large dynamic. In practice we have to investigate the stochastic models for different situations characterizing inventory control systems. As the result a number of stochastic models are available to solve the inventory control problem [1, 2].

In previous authors' works some stochastic inventory control models have been created [3, 4]. In the given research we consider a multi-product inventory control model with random demand for goods, random lead-time and random deviation of prices. It is proposed, that distributions of all random variables are known. We assume, that deliveries of different products are independent.

Principal aim of the examined task is to define the amount of the orders and ordering moments of each product to achieve the minimum expenses for products storage, ordering and losses from deficit per a time unit. The model can be made more realistic if we add some restrictions on the used resources. In the suggested model we suppose that there are limits to the stock capacity and used capital. So, the proposed model has two structural constraints: warehouse constraint and financial constraint.

2. DESCRIPTION OF THE MODEL

We consider a multi-product inventory control model under the following conditions.

There are *n* different types of products. For product with number *i* demand, lead time and price are random with known distributions:

- demand for product D_i has Poisson distribution with intensity λ_i ;
- lead time L_i (time between placing an order and receiving it) has normal distribution with parameters μ_i и σ_i ;
- a price p_i for product has normal distributions with parameters $E(p_i)$ and $\sigma(p_i)$.

In the moment of time when the stock level of product with number *i* falls till certain level r_i a new order q_i is placed. The quantity r_i is called *a reorder point,* q_i – the order quantity. We suppose that quantities r_i and q_i for product with number *i* are constant and $q_i \geq r_i$. An order is placed from customer to producer directly.

We underline that r_i and q_i are operating parameters of the considered model.

Let us introduce needed notations for product with number *i:*

- ordering cost C_i^O is function of the order quantity q_i , i.e. $C_i^O = C_i^O(q_i)$;
- holding cost is proportional to quantity of goods in stock and holding time with coefficient of proportionality C_{H_i} ;
- losses from deficit of one unit of *i*-th product are proportional to quantity of deficit with coefficient of proportionality C_{SH_i} ; in case of deficit, the last cannot be covered by expected order.

Suppose that a customer has *restrictions on the resources:* there are limits to the warehouse capacity *V* and used capital (sum of money) *K*. And there exists the probability of simultaneous receiving the orders by all kinds of products, and even in case when the orders for different products are placed at various moments of time places in a warehouse allocated under each product are permanent. Beside that the maximal size of money k_i allocated for purchase of product with number *i* is known and we have $\sum_{i=1}^{n} k_i \leq K$.

3. CREATION OF THE MODEL

Taking in account that demand D_i for product with number *i* has Poisson distribution with intensity λ_i we can write the distribution for demand for fixed period of time τ

$$P\{D_{\tau_i} = j\} = \frac{(\lambda_i \tau)^i}{i!} e^{-\lambda_i \tau}, \quad j = 1, 2, ... \tag{1}$$

Distribution for demand within time L_i can be calculated by formula

$$P\{D_{L_i} = j\} = \int_0^\infty P\{D_{\tau_i} = j\} f_{L_i}(\tau) d\tau \, . \tag{2}$$

Using formula (1) we obtain:

$$P\{D_{L_i} = j\} = \int_0^\infty \frac{(\lambda_i \tau)^j}{j!} e^{-\lambda_i \tau} \frac{1}{\sigma_{L_i}\sqrt{2\pi}} e^{-\frac{(\tau - \mu_{L_i})^2}{2\sigma_{L_i}^2}} d\tau = \frac{\lambda_i^j}{j! \sigma_{L_i}\sqrt{2\pi}} \int_0^\infty \tau^j e^{-\lambda_i \tau} e^{-\frac{(\tau - \mu_{L_i})^2}{2\sigma_{L_i}^2}} d\tau \tag{3}$$

Dynamics of inventory level of product with number *i* during one cycle (time interval between two neighbouring order deliveries) is shown in Fig.1.

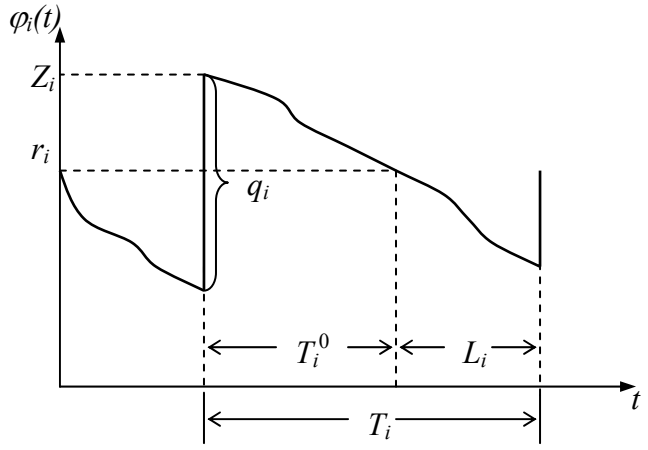


Figure 1. *Dynamics of inventory level of product with number i during one cycle*

In the given figure Z_i is the quantity of product with number i in stock at the time moment immediately after order receiving; T_i^0 – time between receiving the order for product with number i and placing a new order.

Using the definitions given above we get the formula for length of cycle:

$$T_i = T_i^0 + L_i . \tag{4}$$

Thus we can determine the quantity of goods Z_i in stock at the time moment immediately after order receiving as function of demand D_{L_i} during lead-time L_i (see Fig. 1):

$$Z_i = \begin{cases} r_i + q_i - D_{L_i}, & D_{L_i} < r ; \\ q_i, & D_{L_i} \geq r_i . \end{cases} \tag{5}$$

At last, using formulas (3) and (5) we can determine distribution for quantity of goods Z_i in stock at the time moment immediately after order receiving:

$$P\{Z_i = j\} = P\{D_{Li} = r_i + q_i - j\} = \frac{\lambda_i^{r_i+q_i-j}}{(r_i+q_i-j)!\sigma_{L_i}\sqrt{2\pi}} \int_0^\infty \tau^{r_i+q_i-j} e^{-\lambda_i \tau} e^{-\frac{(\tau-\mu_{Li})^2}{2\sigma_{Li}^2}} d\tau, \quad q_i < j \leq q_i + r_i ; \tag{6}$$

$$P\{Z_i = q_i\} = 1 - \sum_{j=q_i+1}^{q_i+r_i} P\{Z_i = j\} .$$

According to formula (4) the average cycle length $E(T_i)$ is the sum of two parts:

$$E(T_i) = E(T_i^0) + E(L_i) . \tag{7}$$

Let us consider them in detail. Since demand for product has Poisson distribution with intensity λ_i, time interval between two neighbouring requests is exponentially distributed with parameter λ_i.

If $Z_i = j$, then time T_i^0 is the sum of $j–r_i$ such independent time intervals. Hence, for $Z = j$ time T_i^0 has Erlang distribution with parameters λ_i and $j - r_i$. The mean of such distribution $E(T_i^0 / Z = j)$ is calculated as follows:

$$E(T_i^0 / Z = j) = \frac{j - r_i}{\lambda_i}.$$

Thus, the average time $E(T_i^0)$ is calculated by formula

$$E(T_i^0) = \sum_{j=r_i+1}^{q_i+r_i} P\{Z_i = j\} \cdot E(T_i^0 / Z_i = j) = \sum_{j=r_i+1}^{q_i+r_i} P\{Z_i = j\} \frac{j - r_i}{\lambda_i}, \quad (8)$$

where $P\{Z_i = j\}$ is defined by (6).

According to conditions of the model second addendum in formula (7) is $E(L_i) = \mu_i$; so average cycle time $E(T_i)$ is the following:

$$E(T_i) = \sum_{j=r_i+1}^{q_i+r_i} P\{Z_i = j\} \frac{j - r_i}{\lambda_i} + \mu_i. \quad (9)$$

Average holding cost $E(TC_{H_i})$ within one cycle:

$$E(TC_{Hi}) = C_{H_i} \sum_{j=q_i}^{r_i+q_i} P\{Z_i = j\} \int_0^\infty \sum_{k=0}^{j-r_i} P\{D_\tau = k\} \cdot (j - k) d\tau + C_{H_i} \int_0^\infty \left[\sum_{k=0}^{r_i} P\{D_\tau = k)(r_i - k) \right] P\{L_i > \tau\} d\tau. \quad (10)$$

Using the similar considerations we obtain average shortage cost during lead-time $E(TC_{SH_i})$:

$$E(TC_{SH_i}) = C_{SH\,i} \sum_{k=r_i+1}^{\infty} \frac{\lambda_i^k (k - r_i)}{k! \sigma_{Li} \sqrt{2\pi}} \int_0^\infty \tau^k e^{-\lambda_i \tau} e^{-\frac{(\tau - \mu_{L_i})^2}{2\sigma_{L_i}^2}} d\tau. \quad (11)$$

The transformations considered in [4] give us

$$E(TC_{SH_i}) = C_{SH_i} \sum_{k=r_i+1}^{\infty} \frac{\lambda_i^{\,k} (k - r_i)}{k!} e^{-b_i} M_k(a_i, \sigma_{L_i}), \quad (12)$$

where $M_k(a_i, \sigma_{L_i}) = \frac{1}{\sigma_{Li} \sqrt{2\pi}} \int_0^\infty \tau^k e^{-\frac{(\tau - a_i)^2}{2\sigma_{L_i}^2}} d\tau$;

$$a_i = \mu_i - \lambda_i \cdot \sigma_{L_i}^2; \quad b_i = \frac{\mu_i^2}{2\sigma_{L_i}^2} - a_i^2.$$

Criteria of optimisation are average total costs (expenses) for all products holding, ordering and losses from deficit per a time unit. Let's denote this average total cost by $E(AC)$. This average cost $E(AC)$ can be found as average total cost during one cycle divided by average cycle time [6]:

$$E(AC) = \sum_{i=1}^{n} \frac{E(TC_i)}{E(T_i)}, \quad (13)$$

where $E(TC_i) = C_i^O(q_i) + E(TC_{H_i}) + E(TC_{SH_i})$;

$E(TC_{H_i})$, $E(TC_{SH_i})$ and $E(T_i)$ are defined accordingly by formulas (10), (12) and (9).

Let's denote:

v_i – volume/square for holding of item of i-th product;

p_i – price of one unit of i-th product;

V – warehouse capacity;

K – maximum capital for one complex order.

Constraints on the resources:

$$\sum_{i=1}^{n} v_i q_i \le V; \quad (14)$$

$$p_i q_i + C_i^O(q_i) \le k_i, \; i = 1,2,\ldots, n. \quad (15)$$

For products' random prices we can write constraint (15) in the form

$$P\{p_i q_i + C_i^O(q_i) \le k_i\} \ge \alpha, \quad (16)$$

where α – given probability.

Using E-formulation of stochastic programming we have deterministic form of constraint (16):

$$\left[E(p_i) + \Phi^{-1}(\alpha) \cdot \sigma(p_i)\right] \cdot q_i + C_i^O(q_i) \le k_i. \quad (17)$$

Using (13), (14) and (17) we can create the mathematical model with operating parameters $q_i, r_i, i = 1,2,...,n$ for the considered situation:

$$E(AC) = \sum_{i=1}^{n} \frac{E(TC_i)}{E(T_i)} \to \min$$

where $E(TC_i) = C_i^O(q_i) + E(TC_{H_i}) + E(TC_{SH_i})$

with constraints

$$\begin{cases} \sum_{i=1}^{n} v_i q_i \le V; \\ \left[E(p_i) + \Phi^{-1}(\alpha) \cdot \sigma(p_i)\right] \cdot q_i + C_i^O(q_i) \le k_i, \quad i = 1,2,...,n. \end{cases}$$

4. CONCLUSIONS

Further guidelines of the current research are the following: to take into account in the model the possible restriction on the volume of delivery; to consider the cases with different distributions of random characteristics of inventory system (demand for goods, lead time and prices of products). Next stages should be computer realization of the task to search the optimal values of operating parameters and solving practical examples.

References

[1] Kopytov E., Tissen F., Greenglaz L. Inventory Control Model for the Typical Railways Company. In: *Proceedings of the International Conference "RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION" (RelStat'03), October 16-17, 2003, Riga, Latvia*. Riga: Transport and Telecommunication, 2004, Vol. 5 (1), pp. 39-45.

[2] Chopra S., Meindl P. *Supply Chain Management*. London: Prentice Hall, 2001.

[3] Prabhu N.U. *Queues and Inventories*. New York: John Willey & Sons, 1967.

[4] Kopytov E., Greenglaz L. On a Task of Optimal Inventory Control. In: *Transactions of XXIV International Seminar on Stability Problems for Stochastic Models. September 10-17, 2004, Jurmala, Latvia.* Riga: Transport and Telecommunication Institute, 2004, pp. 247-252.

[5] Kopytov E., Greenglaz L. On an Inventory Control Model with Random Lead Time and Random Demand. In: *Proceedings of 12th International Conference on Analytical and Stochastic Modelling Techniques and Applications (ASMTA 2005). June 1-4, 2005, Riga, Latvia*. EC IST COST 290 Affiliated Conference, pp. 151-154.

[6] Ross Sh. M. *Applied Probability Models with Optimization Applications*. New York: Dover Publications, INC., 1992.

BAYESIAN APPROACH TO FORECASTING DAMAGE TO BUILDINGS FROM ACCIDENTAL EXPLOSIONS ON RAILWAY

Egidijus R. Vaidogas

Vilnius Gediminas Technical University
Saulėtekio al. 11, LT-10223, Vilnius, Lithuania
Ph: (+370)-5 2745225. Fax: (+370)-5 2745224. E-mail: erv@st.vtu.lt

A procedure for estimating potential damage to buildings induced by accidental explosions on railway is developed. By the damage are meant failures of nearby structures due to actions generated by the accidental explosions. This damage is measured in terms of probabilities of potential failures caused by the explosions. The estimation of the damage probabilities is based on a stochastic simulation of railway accident involving an explosion. The proposed simulation-based procedure quantifies epistemic (state-of-knowledge) uncertainties in the damage probabilities. These uncertainties are expressed in terms of Bayesian prior and posterior distributions. A foundation of the procedure is a computer intensive method known as a Bayesian bootstrap. It is used for approximating the posterior distributions of damage probabilities. An application of the Bayesian bootstrap makes the proposed procedure highly automatic and convenient for assessing structures subjected to the hazard of the accidental actions. In addition, it can be used for specifying safe distances between the railway and nearby buildings. Structures of these buildings can be designed for tolerable probabilities of failures induced by the accidental explosions.

Keywords: *railway, accident, damage, explosion, Monte Carlo simulation, Bayesian bootstrap*

1. INTRODUCTION

Accidental explosions (AEs) on railway are dangerous, generally large-scale phenomena. Accidents involving such phenomena include severe damage to buildings and non-structural property. A selection of such accidents on railway is described in the books [1, 2]. Industrial activities require a rail transportation of explosives and such combustible materials as liquefied gases. They constitute an inevitable potentiality of AEs. Typical AEs are bursting of explosives and physical phenomena called the unconfined vapour cloud explosions (UVCEs) and boiling liquid expanding vapour explosions (BLEVEs). On the other hand, AEs on railway is generally rare, unexpected, and difficult-to-predict phenomena. Actions induced by AEs are uncertain and so is the potential mechanical damage form AEs. Predicting this damage requires a proper dealing with uncertainties related to both blast loading from AEs and response of structures to the AEs. In addition, general knowledge and statistical data on AEs are usually limited. The presence of considerable uncertainties generates a need to apply probabilistic methods to assessing the damage from AEs.

This paper develops a procedure for estimating potential damage to buildings induced by accidental explosions on railway. By the damage are meant failures of nearby structures caused by actions generated by the AEs. This damage is measured in terms of probabilities of potential failures caused by AEs. The estimation of the damage probabilities is based on a stochastic simulation of railway accident involving an explosion. The proposed simulation-based procedure quantifies epistemic (state-of-knowledge) uncertainties in the damage probabilities. These uncertainties are expressed in terms of Bayesian prior and posterior distributions. A foundation of the procedure is a computer intensive method known as a Bayesian bootstrap. It is used for approximating the posterior distributions of damage probabilities. An application of the Bayesian bootstrap makes the proposed procedure highly automatic and convenient for assessing structures subjected to the hazard of the accidental actions. In addition, it can be used for specifying safe distances between the railway and nearby buildings. Structures of these buildings can be designed for tolerable probabilities of failures induced by AEs.

2. METHODOLOGICAL BACKGROUND

The prediction of potential damage to structures from rare AEs on railway can be formulated as a problem of statistical inference. As long as the damage probability serves as a damage measure, its estimation amounts to a statistical estimation of a mean value. However, this estimation is far from trivial. Limited knowledge and uncertainties related to AEs render an application of classical statistics of impossible. A natural approach is applying methods of Bayesian statistical theory. They do not break down in the situation of the limited knowledge about AEs. The damage probabilities can be estimated by combining Bayesian inference with methods of structural reliability analysis (SRA). Such a combination is well known in the field of SRA. Nevertheless, the author's experience suggests that standard techniques of Bayesian updating are not fully suited to the estimation of damage probabilities. These techniques are too general to take account of specificity of predicting AEs and damage from them.

Standard Bayesian updating can be enhanced by a computer intensive method of applied statistics known as "bootstrap" [3]. There is a Bayesian form of the bootstrap or the Bayesian bootstrap. Rubin introduced the latter term in 1981 [4], and he was the first, who found the connection of the bootstrap with Bayesian inference. Bayesian bootstrap is a specialized application of the bootstrap intended for simulating the posterior distribution of a parameter [3]. The Bayesian form of the bootstrap offers the scope for its application to a quantitative risk assessment (QRA), as methods of QRA are substantially based on the Bayesian statistical theory.

QRAs often deal with large-scale accidents that may include AEs. Mechanical actions imposed on structures by AEs are called in terms of structural engineering the explosive actions (e.g., [5]). Estimating probabilities of foreseeable damage events can assess a potential damage to structures due to AEs. Formally, these probabilities can be handled by means of the bootstrap within the pure frequenters framework [6]. However, QRA provides consistent means for dealing with considerable uncertainties related to AEs and, sometimes, response of structures to AEs. The QRA means allow quantifying epistemic uncertainties in probabilities of the events in question in the form of prior and posterior distributions (e.g., [7]). The Bayesian bootstrap is suitable to utilizing attractive features of data resampling techniques. It allows applying these techniques to effective Bayesian updating within a QRA that considers AEs and potential damage from them. In particular, the Bayesian bootstrap can be applied to approximating posterior distributions of damage probabilities.

The present paper considers a practical application of the Bayesian bootstrap to a QRA focused on assessing damage to structures. It is used for Bayesian inference based on two sources of information:

- prior knowledge existing mainly in the form of mathematical models and historical data suitable to an approximate prediction of AE characteristics and
- new information consisting of a small-size sample of measurements of AE characteristics which are highly relevant to an exposure situation (a situation in vicinity of railway where the structure under investigation stands and a potential AE can occur).

The application of the Bayesian approach falls within the general approach to QRA known as classical Bayesian approach [7]. It is shown how to utilize the prior knowledge to specifying a prior distribution of a damage probability. Then it is demonstrated how to approximate its posterior distribution by means of the Bayesian bootstrap when the new sample of AE characteristics becomes available.

3. PROBABILITY OF EXPLOSIVE DAMAGE

Damage to a structure from an AE can be represented by a finite set of n_d random events D_i ($i = 1, 2, \ldots, n_d$), each standing for a foreseeable and specific mechanical damage phenomenon. If the damage is assessed in the context of QRA, probabilities of D_is can be grouped together to establish a risk profile related to a particular AE and a specific exposure situation.

The probability of the damage D_i due to an AE can be expressed in the form

$$P(D_i \mid AE) = \int_{\text{all } \boldsymbol{y}} P(D_i \mid \boldsymbol{y})\, \mathrm{d}F_{\boldsymbol{Y}}(\boldsymbol{y}) = E(P(D_i \mid \boldsymbol{Y}))\,, \tag{1}$$

where D_i is the random event of damage; EA is the random event of imposition of AE with any characteristics; $\boldsymbol{Y}$ is the random vector of AE characteristics; $\boldsymbol{y}$ and $F_{\boldsymbol{Y}}(\boldsymbol{y})$ are the value of $\boldsymbol{Y}$ and its distribution function (d.f.), respectively.

The definition (1) is based of the fragility function $P(D_i \mid \boldsymbol{y})$ relating particular value of AE characteristics, $\boldsymbol{y}$, to probability of the damage event D_i. Fragility function is an often-used tool for describing response of structures to extreme actions (e.g., [8]).

The fragility function can be expressed as some function $p_i(\cdot)$ which relates probability of D_i to $\boldsymbol{y}$ and thus takes on probability values, namely, $p_i(\boldsymbol{y}) = P(D_i \mid \boldsymbol{y})$. This function allows introducing a random variable $\widetilde{P}$ defined as a function of the random vector $\boldsymbol{Y}$, namely, $\widetilde{P} = p_i(\boldsymbol{Y}) = P(D_i \mid \boldsymbol{Y})$. A mean value of $\widetilde{P}$ can be denoted by μ and expressed as $\mu = E(\widetilde{P}) = E(P(D_i \mid \boldsymbol{Y}))$

The problem is that the d.f. $F_{\boldsymbol{Y}}(\boldsymbol{y})$ is not known due to scarcity or irrelevance of information on characteristics of many types of AEs. However, distribution of values of $\boldsymbol{Y}$ can be approximately predicted by existing models and, in addition, data related to $\boldsymbol{Y}$ can be collected by carrying out experiments which are highly relevant to the exposure situation under investigation.

4. KNOWLEDGE AVAILABLE FOR ESTIMATING DAMAGE PROBABILITY

The expression $\mu = E(\widetilde{P})$ implies that the damage probability can be expressed as uncertain distribution parameter μ amenable to Bayesian inference. The learning process involved in Bayesian inference is one of modifying the analyst's initial probability statements about distribution parameters prior to observing data to posterior knowledge incorporating both prior knowledge and the data at hand. In a pure Bayesian analysis, the prior distribution of μ should be specified subjectively. However, the purely subjective specification does not utilize prior knowledge about many types of AEs. Such knowledge, more or less relevant to the exposure situation under investigation, is usually available for the analyst. Therefore one can make a compromise between the frequenters and Bayesian statistical analysis and specify priors for damage probabilities from the prior knowledge.

Formal means for specifying priors based on data are provided by empirical Bayes methods [9]. This paper proposes a simple heuristic approach to specifying priors from existing knowledge. The approach is based on knowledge which is highly specific to a particular AE and is expressed in the form of a mathematical model $\varphi(\cdot)$ relating characteristics of exposure situation to characteristics of AE, namely, $\boldsymbol{y} = \varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ where $\boldsymbol{x}$ is the vector describing characteristics of exposure situation in which an AE can occur; $\boldsymbol{\psi}$ is the vector used to express epistemic uncertainties in those parameters of $\varphi(\cdot)$ which are uncertain in epistemic sense. The exposure situation represented by $\boldsymbol{x}$ may be uncertain in the stochastic sense and a random vector X with an aleatory d.f can model this. $F_{\boldsymbol{X}}(\boldsymbol{x})$. A part of prior knowledge should be represented by the fragility function $p_i(\boldsymbol{y})$ which can be established for an exposed structure by methods of the structural reliability analysis (e.g., [10]). Thus the fragility function $p_i(\cdot)$ together with the model $\varphi(\cdot)$ form the main part of the prior knowledge.

The need to apply Bayesian inference to estimating the damage probability $P(D_i \mid AE)$ may stem mainly from a partial irrelevance of the prior knowledge to a particular exposure situation. The configuration of a structure exposed to an AE as well as the accident capable of inducing the AE may be unique by a large margin and so may not fit in the prior knowledge. The source of the partial irrelevance may lie in (i) the structure of the model $\varphi(\cdot)$ and/or (ii) data used to fit the d.f. $F_{\boldsymbol{X}}(\boldsymbol{x})$ and estimate parameters of $\varphi(\cdot)$, that is, components of $\boldsymbol{\psi}$.

The partial irrelevance may require a correction of AE prediction by experimental data that can be considered highly relevant to an exposure situation under investigation. Clearly, these experiments can be used for improving the model $\varphi(\cdot)$ by, say, increasing its relevance to the exposure situation. However, the highly relevant (case-specific) data on AE characteristics $\boldsymbol{y}$ and, possibly, interaction of AE with the exposed structure can be used directly to estimating $P(D_i \mid AE)$.

In theory, an amount of the case-specific data may be such that the model $\varphi(\cdot)$ will no longer be needed. In practice, however, the amount of the data may be limited because experiments on AEs, especially full-scale ones, are often expensive. This may require combining the new, case-specific data with the prior knowledge behind $\varphi(\cdot)$.

The case-specific data necessary for estimating $P(D_i \mid AE)$ should be gathered and represented in the form of a sample $\mathbf{y}' = (\boldsymbol{y}'_1, \boldsymbol{y}'_2, \dots, \boldsymbol{y}'_n)^T$ containing experimental observations of the AE characteristics. Clearly, each experiment in a series yielding the sample $\mathbf{y}'$ should imitate a potential accident and the sample $\mathbf{y}'$ itself should posses the property called by statisticians the "representativeness" (e.g., [11]). Although this property of $\mathbf{y}'$ is very important, a detailed discussion about how to ensure the representativeness is out of the scope of this paper. In subsequent discussion, it is assumed that the sample $\mathbf{y}'$ possesses this property.

Given the sample $\mathbf{y}'$ and a fragility function of interest, $p_i(\boldsymbol{y})$, one can simplify estimating $P(D_i \mid AE)$ by introducing a fictitious sample $\boldsymbol{p} = (p_1, p_2, \dots, p_n)^T$, each component of which is calculated by $p_j = p_i(\boldsymbol{y}'_j) = P(D_i \mid \boldsymbol{y}'_j)$ $(j = 1, 2, \dots, n)$. In this way the problem of estimating $P(D_i \mid AE)$ is made less complicated by switching from a multi-dimensional analysis to a one-dimensional case. Then the components p_j of $\boldsymbol{p}$ can be treated as realizations of the random variable $\widetilde{P}$.

Expensiveness of experiments on AEs may cause that the size n of the sample $\mathbf{y}'$ will be too small to apply methods of classical statistics for estimating $P(D_i \mid AE)$. In addition, experiments on an AE may be unique and a series of them resulting in $\mathbf{y}'$ may be carried only once. This implies that the procedure of Bayesian updating using $\mathbf{y}'$ will be a single act, rather than a more or less constant process.

5. USE OF BAYESIAN BOOTSTRAP

Epistemic uncertainties related to parameters $\boldsymbol{\psi}$ of the model $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ can be expressed by introducing a random vector $\boldsymbol{\Psi}$ with a d.f. $F_{\boldsymbol{\Psi}}(\boldsymbol{\psi})$. Then $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ by a random function $\varphi(\boldsymbol{X} \mid \boldsymbol{\Psi})$ will yield another random variable

$$\widetilde{M} = m(\boldsymbol{\Psi}) = E_{\boldsymbol{X}}\left(p_i(\varphi(\boldsymbol{X} \mid \boldsymbol{\Psi})) \right) = \int_{\text{all } \boldsymbol{x}} P(D_i \mid \varphi(\boldsymbol{x} \mid \boldsymbol{\Psi}))\, \mathrm{d}F_{\boldsymbol{X}}(\boldsymbol{x}), \tag{2}$$

where $m(\cdot)$ denotes some function relating $\widetilde{M}$ to $\boldsymbol{\Psi}$. A value μ of $\widetilde{M}$ is the damage probability at given $\boldsymbol{\psi}$, namely, $E_{\boldsymbol{X}}\left(P(D_i \mid \varphi(\boldsymbol{X} \mid \boldsymbol{\psi}))\right)$. A density of $\widetilde{M}$ denoted, say, by $\pi(\mu)$ can be used as prior quantifying epistemic uncertainty in damage probability $P(D_i \mid AE)$ (Fig. 1).

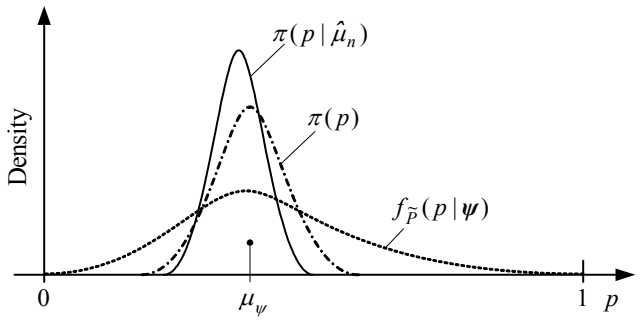


Figure 1. *Schematic representation of densities related to probabilistic damage assessment in Bayesian context:* $f_{\widetilde{P}}(p \mid \boldsymbol{\psi})$ *= density of the random variable* $\widetilde{P} = p_i(\varphi(\boldsymbol{x} \mid \boldsymbol{\psi}))$ *with the mean* μ_{ψ}*;* $\pi(\mathrm{p})$ *= prior distribution of* μ*;* $\pi(p \mid \hat{\mu}_n)$ *= posterior distribution of* μ

The source of the epistemic uncertainty do not necessarily may be only on the side of the model $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ used to predicting AE characteristics. Epistemic uncertainty can also be related to values of the fragility function $p_i(\boldsymbol{y})$ at given $\boldsymbol{y}$. However, this part of epistemic uncertainty can be handled in the framework of (2) and is leaved out for brevity.

The usual Bayesian posterior has the form $\pi(\mu \mid \text{data}) \propto \pi(\mu)\, L(\text{data} \mid \mu)$ where "data" is represented eventually by the samples $\boldsymbol{p}$ or $\mathbf{y}'$. The main idea followed in paper is to replace the usual Bayesian posterior $\pi(\mu \mid \text{data})$ by an estimated posterior $\hat{\pi}(\mu \mid \text{data}) \propto \pi(\mu)\, \hat{L}_B(\text{data} \mid \mu)$ where $\hat{L}_B(\text{data} \mid \mu)$ is an estimate of the likelihood function based on bootstrap estimation of the density of the pivotal quantity $\hat{\mu}_n - \tilde{M}$ with $\hat{\mu}_n = n^{-1} \sum_{j=1}^{n} p_j$. Boos and Monahan [12] suggested a possibility of such a replacement.

The first step is to estimate the distribution function of the data $\boldsymbol{p}$ using the empirical d.f. $\hat{F}_n$ of the p_j's. In the second step, a set of B random samples of size n from $\hat{F}_n$ is generated and a mean $\hat{\mu}'_{nb}$ is calculated for each sample b (b = 1, 2, … , B). From the B simulated estimates $\hat{\mu}'_{n1}$, $\hat{\mu}'_{n2}$, … , $\hat{\mu}'_{nB}$, one can compute a kernel density estimate.

$$\hat{k}_B(u) = \frac{1}{B\,w} \sum_{b=1}^{B} \kappa\left(\frac{u - (\hat{\mu}'_{nb} - \hat{\mu}_n)}{w} \right),$$

where w is a bandwidth (window width, smoothing parameter) and $\kappa(\cdot)$ is a kernel function. Since the function $\hat{k}_B(u - \mu)$ is an estimate of the sampling density of $\hat{\mu}_n$ given μ, the likelihood function of $\hat{\mu}_n$ can be estimated by

$$\hat{L}_B(\hat{\mu}_n \mid \mu) = \hat{k}_B(\hat{\mu}_n - \mu) = \frac{1}{B\,w} \sum_{b=1}^{B} \kappa\left(\frac{2\hat{\mu}_n - \mu - \hat{\mu}'_{nb})}{w} \right).$$

The resulting estimate of posterior of the damage probability is

$$\hat{\pi}(\mu \mid \hat{\mu}_n) = C(\hat{\mu}_n) \pi(\mu)\, \hat{L}_B(\hat{\mu}_n \mid \mu),$$

where the normalizing constant $C(\hat{\mu}_n)$ can be found by numerical integration.

Practical implementation of the bootstrap-based updating procedure is relatively simple, as the estimates $\hat{L}_B(\hat{\mu}_n \mid \mu)$ and $\hat{\pi}(\mu \mid \hat{\mu}_n)$ can be computed almost automatically. The estimate $\hat{L}_B(\hat{\mu}_n \mid \mu)$ is relatively insensitive to the choice of the kernel function $\kappa(\cdot)$ [3]. The only implementation problem is associated with the choice of the bandwidth w that can have considerable influence on $\hat{L}_B(\hat{\mu}_n \mid \mu)$. Shao and Tu [3] provide a review of approaches to choosing w.

6. EXAMPLE: ASSESSING EXPLOSIVE DAMAGE TO INDUSTRIAL BUILDING

6.1. Exposure Situation

Consider an industrial building to be constructed in vicinity of a 500 m section of railway (Fig. 2). This transportation facility is used to carry commercial explosives that can detonate in consequence of a railway accident. The accidental explosion will generate a shock front resulting in an impulsive loading imposed on the building. Characteristics of this loading can be described by the vector $\boldsymbol{y} = (y_1, y_2)^T$, where y_1 (MPa) and y_2 (MPa s/m^2) are the peak positive overpressure and positive impulse of the incident shock front, respectively.

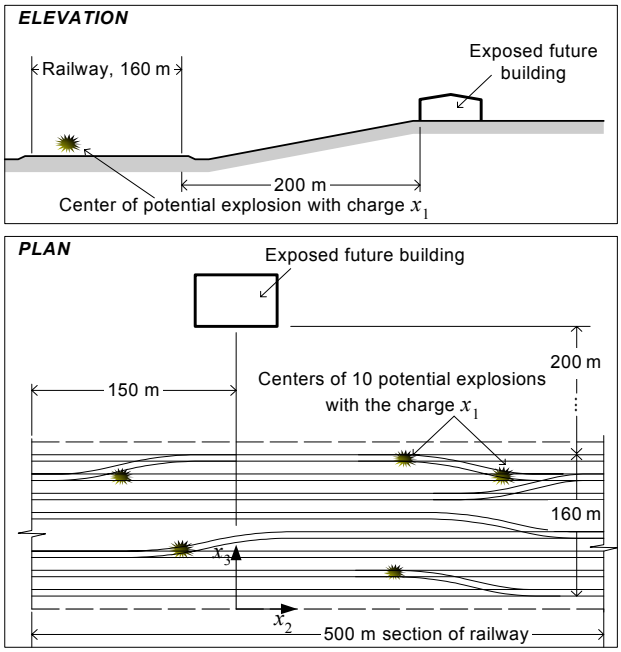


Figure 2. *Exposure situation involving accident with accidental explosion on railway*

The damage to building is represented by the random event D_i consisting in a flexural failure or a shear failure of reinforced concrete panels to be used for external envelope of the building. These panels should resist not only wind pressure but also the pressure arising from a reflection of the shock front by the façade of the future building.

The exposure situation is represented by the vector $\boldsymbol{x} = (x_1, x_2, x_3)^T$, where is x_1 (kg) is the weight of transported explosives (charge weight); x_2 (m) and x_3 (m) are the coordinates of the centre of accidental explosion in the coordinate system shown in Fig. 2. Thus the expression $r = (x_2^2 + (360 - x_3)^2)^{1/2}$ is the standoff of the explosion to the façade and the expression $s = x_1^{1/3} r^{-1}$ is the so-called inverse scaled distance (kg$^{1/3}$/m) (inverse normalized standoff, e.g. [1]).

6.2. Prior knowledge

The model $\boldsymbol{y} = \varphi(\boldsymbol{x} \mid \boldsymbol{\psi}) = \left(\varphi_1(\boldsymbol{x} \mid \boldsymbol{\psi}), \varphi_2(\boldsymbol{x} \mid \boldsymbol{\psi})\right)$ represents the prior knowledge with the model components

$$y_1 = \varphi_1(\boldsymbol{x} \mid \boldsymbol{\psi}) = \psi_1 (\psi'_1 s + + \psi'_2 s^2 + \psi'_3 s^3), \tag{3}$$

$$y_2 = \varphi_2(\boldsymbol{x} \mid \boldsymbol{\psi}) = \psi_2 \psi'_4 x_1^{2/3} r^{-1} \tag{4}$$

and the vector of regression parameters

$$(\psi'_1, \psi'_2, \psi'_3, \psi'_4)^T = (0{,}1\,\text{MPa} \times \text{m/kg}^{1/3}; 0{,}43\,\text{MPa} \times \text{m}^2/\text{kg}^{2/3};\ 1{,}4\,\text{MPa} \times \text{m}^3/\text{kg};\ 6{,}3\,\text{MPa} \times \text{s}/(\text{m}\,\text{kg}^{2/3}))^T$$

Components of the vector $\boldsymbol{\psi} = (\psi_1, \psi_2)^T$ are dimensionless adjustment factors (relative overpressure and relative impulse of the commercial explosive, which can detonate in consequence of the railway accident, compared to an equivalent weight of TNT explosive).

Stochastic uncertainty related to the exposure situation and so arguments of the model $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ are expressed by a random vector $\boldsymbol{X} = (X_1, X_2, X_3)^T$ with components distributed as follows $X_1 \sim$ N(500 kg, 30 kg), $X_2 \sim$ U(0 m, 160 m), $X_3 \sim$ U(0 m, 500 m), where L and U denote the normal distribution and the uniform distribution, respectively. The uniform distribution of X_2 and X_3 implies

that the accidental explosion can occur with the same probability within the 500 m ×160 m area of the railway. The uniform distribution of the explosion point coordinates X_2 and X_3 is considered only the first approximation to forecasting the position of explosion centre.

Epistemic uncertainty can be introduced into the model $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ by assuming components ψ_1 and ψ_2 of $\boldsymbol{\psi}$ to be random variables. The adjustment factors ψ_1 and ψ_2 are conventionally expressed as fixed values or deterministic function of the so-called scaled distance [1]. However, the nature of explosive actions is highly random and adjustment factors may be expressed in the form of random variables Ψ_1 and Ψ_2 having epistemic distributions. In this example, a lognormal distribution is assumed for the random adjustment factors: Ψ_1 ~L(0,15842; 0,09975) with the mode of 1,16; Ψ_2 ~L(0,17551; 0,09975) with the mode of 1.18.

Further part of prior knowledge is represented by the fragility function $p_i(\cdot)$ which relates the peak positive overpressure y_1 and the positive impulse y_2 to failure probability $P(D_i \mid \boldsymbol{y})$. The form of $p_i(\boldsymbol{y})$ can be established using results obtained by Low & Hao [13], who investigated the reliability of RC slabs under impulsive loads. The function $p_i(\boldsymbol{y})$ is represented in the form $p_i(\boldsymbol{y}) = P(D_i \mid \varphi'(x_1, x_2, y_1), \varphi''(y_1, y_2))$ where $\varphi'(.)$ and $\varphi''(.)$ are two deterministic functions which relate the peak overpressure and impulse of reflected shock front to the respective characteristics of the incident shock front. The function $\varphi'(.)$ is called the "reflected pressure factor versus angle of incidence" and is usually represented in the graphical form [14]. The angle of incidence of the shock front can be simply determined from the explosion point coordinates x_2 and x_3. The function $\varphi''(.)$ is a simple formula allowing estimating reflected impulse from the incident impulse y_2 [1].

In this example, the fragility function $p_i(\boldsymbol{y})$ is approximated by a d.f. $F(z_1, z_2 \mid \mu_{P1}, \mu_{P2}, \sigma_{P1}, \sigma_{P2}, \rho)$ of a bivariate normal distribution, namely,

$$p_i(z_1, z_2) = F(z_1, z_2 \mid \mu_{P1}, \mu_{P2}, \sigma_{P1}, \sigma_{P2}, \rho), \tag{5}$$

where the arguments z_1 and z_2 are defined as $z_1 = \varphi'(x_1, x_2, y_1)$ and $z_2 = \varphi''(y_1, y_2)$ and the parameters μ_{P1} =3,2×10^{-3} MPa, μ_{P2} =1,45 MPa×s/m^2, σ_{P1} =0,64×10^{-3} MPa, σ_{P2} = 0,29 MPa×s/m^2, ρ = 0,2.

Clearly, the analyst may have uncertainties in epistemic sense related to elements of the model $p_i(\boldsymbol{y})$ as well as further elements of the model $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$, first and foremost, the vector of the regression parameters, $(\psi_1', \psi_2', \psi_3', \psi_4')^T$; however, these uncertainties are ignored in the present example for simplicity.

The formulas (3) and (4) are standard relations obtained by experiments on TNT. They are, strictly speaking, valid only for a distant explosion of a charge positioned on the ground that forms a horizontal plane. In addition, the model represented by (3) and (4) assumes that the shock front generated by a TNT explosion does not encounter any obstacles. A gentle slope of the ground between the railway and the exposed future building makes the model $\varphi(\boldsymbol{x} \mid \boldsymbol{\psi})$ only partially relevant to the exposure situation shown in Fig. 2. In addition, the assumption of the uniform distribution of the explosion point coordinates X_2 and X_3 may be considered sound; however, a detailed analysis of railway traffic by means of QRA may introduce corrections in this assumption.

Despite the irrelevance of the model represented by (3) and (4), it can be used for specifying a prior distribution of $P(D_i \mid AA)$.

6.3. Specifying Prior from Existing Knowledge

Propagating epistemic uncertainty related to the parameters ψ_1 and ψ_2 can specify the prior distribution of the damage probability $P(D_i \mid AE)$. Thus uncertainty can be transformed into uncertainty in $P(D_i \mid AE)$ by (2). The density $\pi(\mu)$ of the random variable $\tilde{M}$ defined by (2) will serve as the prior distribution.

The density $\pi(\mu)$ can be specified by fitting it to the sample μ_k (k = 1, 2, … , n_k), the elements of which are estimates of the mean values $E_{\boldsymbol{X}}(p_i(\varphi(\boldsymbol{X} \mid \psi_k)))$ for given ψ_k. The values ψ_k is generated

from the epistemic d.f. $F_{\Psi}(\psi)$ by means of stochastic (Monte Carlo) simulation. The mean values $E_X(\cdot)$ can also be estimated by simulation, namely, by $\mu_k = n_e^{-1} \sum_{l=1}^{n_e} p_i(\varphi(\boldsymbol{x}_l \mid \psi_k))$ where $\boldsymbol{x}_l$ is the value of $\boldsymbol{X}$ generated from the aleatory d.f. $F_X(\boldsymbol{x})$. Fig. 3 shows a density of normal distribution fitted to the generated sample μ_k (k = 1, 2, … , 1000) obtained using $n_e = 1\times10^5$. Consequently, the prior density $\pi(\mu)$ is specified as a density of a normal distribution N(0,353; 0,09196) with a 90 % confidence interval]0,202; 0,504[.

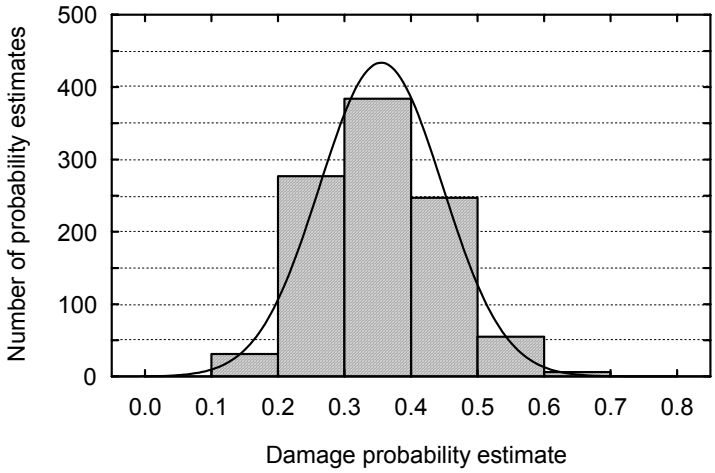


Figure 3. *Histogram of the sample μ_k (k = 1, 2, … , 1000) and a transformed density of a normal distribution N(0.353, 0.09196) fitted to the sample*

6.4. New Data on Possible Railway Accident

The new data may be obtained by an experiment that imitates potential accidents on the railway section. A detailed analysis of traffic in the railway section can yield, say, ten potential centres of accidental explosion (Fig. 2). Then a series of ten explosions can be carried out by detonating charges x_1 of the explosive under investigation in a blast measuring facility that imitates the ground surface of the exposure situation. The weight of charges, x_1, can be chosen by chance from the distribution of X_1.

The series of experiments will yield a sample $\mathbf{y}' = (\boldsymbol{y}'_1, \boldsymbol{y}'_2, \ldots, \boldsymbol{y}'_{10})^T$. Let us say that ten pairs of measured overpressures and impulses given in Table 1 represent results of the experiment.

Table 1. Observed elements $\boldsymbol{y}'_i$ of the sample $\mathbf{y}'$ and computed elements p_j of the sample $\boldsymbol{p}$

j	1	2	3	4	5
$\boldsymbol{y}'_i$ (MPa, MPa×s/m^2)	(2,06; 0,960)	(2,99; 1,38)	(2,68; 1,26)	(2,73; 1,27)	(3,41; 1,59)
p_j	0,001674	0,1484	0,05482	0,06283	0,4286
j	6	7	8	9	10
$\boldsymbol{y}'_i$ (MPa, MPa×s/m^2)	(2,66; 1,23)	(2,74; 1,24)	(3,29; 1,46)	(2,92; 1,30)	(3,82; 1,74)
p_j	0,04543	0,0545	0,2861	0,09814	0,7022

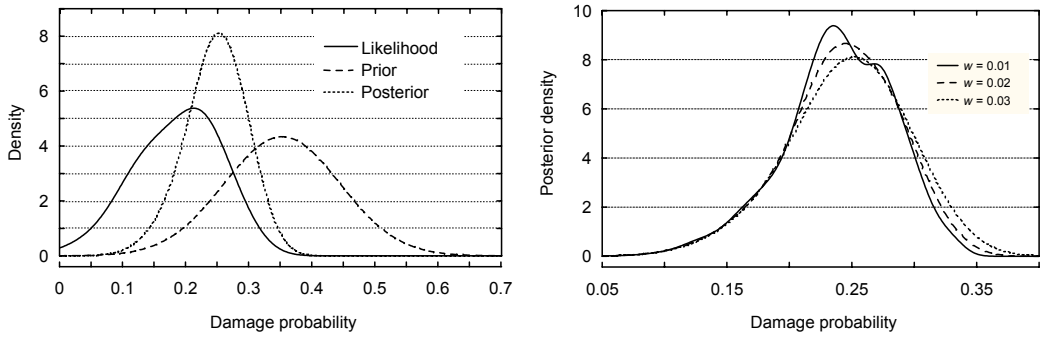
A small size of the sample $\mathbf{y}'$ is likely, as the experiment imitating the accident may be expected to be expensive and time consuming. Clearly, the ten-element sample $\mathbf{y}'$ is too small to estimate the damage probability $P(D_i \mid AE)$ using $\mathbf{y}'$ alone, that is, without prior knowledge. However, this sample may be used to update the prior distribution N(0,353; 0,09196) of $P(D_i \mid AE)$ specified on the basis of prior knowledge. To do this, the fragility function (5) should be applied to transform $\mathbf{y}'$ into the fictitious sample $\boldsymbol{p}$ given in Table 1.

The mean $\hat{\mu}_{10}$ of the sample ***p*** is equal to 0,1882. The sample ***p*** can be applied to estimating the likelihood function $L(\hat{\mu}_{10} \mid \mu)$ and approximating posterior distribution of $P(D_i \mid AE)$.

6.5. Posterior Distribution as an Epistemic Estimate of Damage Probability

The estimate of the likelihood function, $\hat{L}_B(\hat{\mu}_{10} \mid \mu)$, was obtained using the Gaussian kernel function $\kappa(\cdot)$. The number of bootstrap replications, *B*, necessary to generate the sample ($\hat{\mu}'_{n1}$, $\hat{\mu}'_{n2}$, … , $\hat{\mu}'_{nB}$) was taken to be equal to 1000. The choice of *B* was based on the rules of thumb suggested in [3].

The choice of the bandwidth *w* was not investigated in detail. Three values 0,01, 0,02, and 0,03 of *w* were chosen manually to assess the influence of *w* on the posterior density $\hat{\pi}(\mu \mid \hat{\mu}_n)$. As expected, the largest value of *w* produced the smoothest estimate of the likelihood function. Fig. 4a shows a graph of $\hat{L}_B(\hat{\mu}_{10} \mid \mu)$ at *w* = 0.03.



(a) (b)

Figure 4. *Graphs of the functions related to updating via Bayesian bootstrap: (a) graph of the likelihood function estimate* $\hat{L}_B(\hat{\mu}_{10} \mid \mu)$ *, the prior density* $\pi(\mu)$ *and estimate of posterior density* $\hat{\pi}(\mu \mid \hat{\mu}_{10})$ *obtained with the bandwidth w = 0,03; (b) Posterior density of the damage probability at three values of the bandwidth w*

Three approximations of the posterior density $\hat{\pi}(\mu \mid \hat{\mu}_{10})$ computed at the three values of *w* are show in Fig. 4b. These approximations were obtained by a numerical calculation. The approximations $\hat{\pi}(\mu \mid \hat{\mu}_{10})$ express the epistemic uncertainty related to $P(D_i \mid AE)$. The three approximations $\hat{\pi}(\mu \mid \hat{\mu}_{10})$ can be compared and so the influence of the bandwidth *w* on the posterior density assessed by calculating approximate confidence intervals for each of the three $\hat{\pi}(\mu \mid \hat{\mu}_{10})$. Table 2 shows three 90 % confidence intervals at the three values of *w*. These intervals can be easily computed during the to numerical evaluation of $\hat{\pi}(\mu \mid \hat{\mu}_{10})$. The confidence intervals given in Table 2 can be compared with a 90 % bootstrap confidence interval computed using the ten-element sample ***p***. The limits of the latter interval can be taken as the 5th and 95th percentiles of an ordered sample obtained from the bootstrap sample ($\hat{\mu}'_{10,1}$, $\hat{\mu}'_{10,2}$, … , $\hat{\mu}'_{10,1000}$) [6]. The bootstrap confidence interval is]0.0902, 0.304[. This interval is based on the new data only (ignores the prior knowledge). It is apparent that the width of the intervals given in Table 2 is considerably smaller than the one of the bootstrap confidence interval.

Table 2. Approximate 90 % confidence intervals calculated for the damage probability $P(D_i \mid AE)$ from posterior densities

Bandwidth *w*	Constant $C(\hat{\mu}_{10})$	Confidence interval
0,01	1,2311	] 0,158; 0,308 [
0,02	1,2470	] 0,159; 0,315 [
0,03	1,2713	] 0,160; 0,326 [

The approximate confidence intervals given in Table 2 may be used for making a decision concerning whether the resistance of the wall panels is sufficient to resist the damage D_i or, alternatively, to design the panels for a tolerable value of the damage probability $P(D_i \mid AE)$.

7. CONCLUSION

The paper presented an approach to assessing damage to buildings due to accidental explosions (AEs) on railway. The damage can be caused to nearby structures by the blast loading generated by an AE. The attention was focussed on quantifying uncertainties related to both characteristics of AEs and damage from them. The damage was understood as structural failures caused by blast loading. Probabilities of these failures (damage probabilities) were taken as damage measures. The prediction of damage was realised as estimating the damage probabilities. A procedure for estimating the damage probabilities has been proposed. The basis of the procedure is an application of a computer intensive method of applied statistics that is called the Bayesian bootstrap. This method is used for expressing estimates of the damage probabilities in terms of Bayesian posterior distributions. These distributions were treated as measures of epistemic uncertainty in the damage probabilities.

Formally, the Bayesian bootstrap was applied to Bayesian inference using prior knowledge. It consists of mathematical models and historical data suitable to an approximate prediction of loading from an AE. Another part of this knowledge is new information. It is represented by a small-size sample of highly case-specific measurements of the AE. The procedure is to a large measure automatic. It does not require any statistical derivations. Therefore, it can be applied to a practical assessment of existing structures build in vicinity of railway and exposed to the hazard of AEs. The procedure can also be applied to specifying safe distances between railway and nearby future buildings.

References

[1] Baker W.E., Cox P.A., Westine P.S. et al. *Explosion Hazards and Evaluation*. Amsterdam etc.: Elsevier, 1983.

[2] Marshall V.C. *Major Chemical Hazards*. Chichester: Ellis Horwood Ltd., 1987.

[3] Shao J. and Tu D. *The Jackknife and Bootstrap*. New York etc.: Springer, 1995.

[4] Rubin D.B. The Bayesian Bootstrap, *Annals of Statistics*, 9(1), 1981, pp.130-134.

[5] ENV 1991-2-7: Eurocode 1: *Basis of Design and Actions on Structures*. Part 2-7: *Accidental Actions Due to Impact and Explosions*. Brussels: CEN, 1998.

[6] Vaidogas E.R. Statistical Resampling in Assessing External Threats to Structures. In: *Probabilistic Safety Assessment and Management: Proc. PSAM 7-ESREL'04, Vol 5.* / C. Spitzer, U. Schmocker & V.N. Dang (eds). London etc.: Springer, 2004, pp.2921-2925.

[7] Aven T., Pörn K. Expressing and Interpreting the Results of Quantitative Risk Analyses. Review and Discussion, *Reliability Engineering & System Safety*, 61(1), 1998, pp.3-10.

[8] Twisdale L.A. and Vickery P.J. Extreme Wind Risk Assessment. In: *Probabilistic Structural Mechanics Handbook* / C. (Raj) Sundararajan (ed.). New York etc.: Chapman&Hall, 1995, pp.465-509.

[9] Bernardo J.M. and Smith A.F.M. *Bayesian Theory.* Chichester etc.: Wiley, 1994.

[10] Melchers R.E. *Structural Reliability Analysis and Prediction*, 2nd ed. Chichester etc.: Wiley, 1999.

[11] Barnett V. *Sample Survey. Principles and Methods*. London etc.: Edward Arnold, 1991.

[12] Boos D.D. and Monahan J.F. Bootstrap Methods Using Prior Information, *Biometrica*, 73(1), pp.77-83.

[13] Low H.Y. and Hao H. Reliability Analysis of Direct Shear and Flexural Failure Modes of RC Slabs under Explosive Loading, *Engineering Structures*, 24(2), 2002, pp.189-198.

[14] Tedesko J.W., McDougal W.G., Ross C.A. *Structural Dynamics. Theory and Applications*. Melno Parc, California: Addison Wesley, 1999.

PREDICTION LIMITS FOR FUTURE SAMPLES FROM A WEIBULL DISTRIBUTION

Konstantin N. Nechval[1], Nicholas A. Nechval[2]

[1]Transport and Telecommunication Institute
Applied Mathematics Department
Lomonosov Str. 1, LV-1019, Riga, Latvia
E-mail: konstan@tsi.lv

[2]Mathematical Statistics Department, University of Latvia
Raina Blvd. 19, LV-1050, Riga, Latvia
E-mail: nechval@junik.lv

Based on a random sample from the Weibull distribution with unknown shape and scale parameters, lower and upper prediction limits on a set of *m* future observations from the same distribution are constructed. The procedures, which arise from considering the distribution of future observations given the observed value of an ancillary statistic, do not require the construction of any tables, and are applicable whether the data are complete or Type II censored. The results have direct application in reliability theory, where the time until the first failure in a group of *m* items in service provides a measure regarding the operation of the items, as well as in service of fatigue-sensitive structures to construct strategies of inspection of these structures.

Keywords: *likelihood, conditioning, Weibull distribution*

1. INTRODUCTION

The Weibull distribution is a powerful modeling tool used in reliability analyses to predict failure rates and to provide a description of the failure of parts and equipment. The Weibull distribution has been widely used in the empirical modelling of economic models. Applications include the modelling of unemployment spells, strike durations, income distributions, the length of a firm's innovation period, and the size of research and development budgets. Depending on the particular problem, the variable under consideration may not be fully observed, requiring censoring procedures for estimation.

Based on engineering and macroscopic viewpoints, the mechanical properties of metallic materials are often considered homogeneous. However, a considerable amount of scatter has been observed in fatigue data even under the same loading condition. It may be attributed to the inhomogeneous material properties. As a result, probabilistic approaches for the fatigue crack growth have received great attention in recent years. Along with the development of fracture mechanics for the past three decades and the need of reliability or risk assessment for some important structures or components such as

(i) Transportation Systems and Vehicles – aircraft, space vehicles, trains, ships;
(ii) Civil Structures – bridges, dams, tunnel;
(iii) Power Generation – nuclear, fossil fuel and hydroelectric plants;
(iv) High-Value Manufactured Products – launch systems, satellites, semiconductor and electronic equipment;
(v) Industrial Equipment – oil and gas exploration, production and processing equipment, chemical process facilities, pulp and paper,

the so-called 'probabilistic fracture mechanics' has thus arisen [1]. One of the important issues in the probabilistic fracture mechanics analysis lies in the probabilistic modelling of fatigue crack growth phenomenon. Many probabilistic models have been proposed to capture the scatter of the fatigue crack growth data. Some of these models are based on the two-parameter Weibull distribution. It exhibits a wide range of shapes for the density and hazard functions that makes this distribution suitable for modelling complex failure data sets.

In this paper our focus is on prediction limits for future samples of observations from the two-parameter Weibull distribution. The probability density function for the random variable X of the two-parameter Weibull distribution is given by

$$f(x;\sigma,\delta)=\frac{\delta}{\beta}\left(\frac{x}{\beta}\right)^{\delta-1}\exp\left[-\left(\frac{x}{\beta}\right)^{\delta}\right]\ (x>0), \tag{1}$$

where δ>0 and β>0 are the shape and scale parameters, respectively. Writing

$$S=\mu+\sigma Z, \tag{2}$$

where Z is a random variable with standardized extreme value density,

$$f(z)=\exp(z-e^{z}),\ \ -\infty<z<\infty, \tag{3}$$

then the density of S can be obtained as

$$f(u;\mu,\sigma)=\frac{1}{\sigma}\exp\left(\frac{s-\mu}{\sigma}-\exp\left(\frac{s-\mu}{\sigma}\right)\right),\ \ -\infty<s<\infty. \tag{4}$$

The distribution of S is known as the smallest extreme value distribution (SEV). If S=ln$X$, so that, X=e^S, then

$$f(x;\mu,\sigma)=\frac{1}{x}\frac{1}{\sigma}(xe^{-\mu})^{1/\sigma}\exp[-(xe^{-\mu})^{1/\sigma}]. \tag{5}$$

With σ=1/δ and μ=lnβ, X is distributed as Weibull with shape parameter δ and scale parameter β. Given this, for analytical and computational convenience, this paper works in the S=ln$X$ scale, the results, however, is reported directly for the Weibull observations.

2. LOWER CONDITIONAL PREDICTION LIMIT ON THE MINIMUM OF A SET OF *M* FUTURE OBSERVATIONS

Theorem 1. Let $X_1<\ldots<X_r$ be the first r ordered past observations from a sample of size n from the distribution (1). Then a lower conditional $(1-\alpha)$ prediction limit y_l on the minimum Y_1 of a set of m future ordered observations $Y_1<\ldots<Y_m$ is given by

$$\Pr\{Y_1>y_l;\mathbf{z}\}=\Pr\left\{\hat{\delta}\ln\left(\frac{Y_1}{\hat{\beta}}\right)>\hat{\delta}\ln\left(\frac{y_l}{\hat{\beta}}\right);\mathbf{z}\right\}=\Pr\{W_1>w_l;\mathbf{z}\}$$

$$=\frac{\int_0^{\infty}v^{r-2}e^{v\hat{\delta}\sum_{i=1}^{r}\ln(x_i/\hat{\beta})}\left(me^{vw_l}+\sum_{i=1}^{r}e^{v\hat{\delta}\ln(x_i/\hat{\beta})}+(n-r)e^{v\hat{\delta}\ln(x_r/\hat{\beta})}\right)^{-r}dv}{\int_0^{\infty}v^{r-2}e^{v\hat{\delta}\sum_{i=1}^{r}\ln(x_i/\hat{\beta})}\left(\sum_{i=1}^{r}e^{v\hat{\delta}\ln(x_i/\hat{\beta})}+(n-r)e^{v\hat{\delta}\ln(x_r/\hat{\beta})}\right)^{-r}dv}=1-\alpha, \tag{6}$$

where $\hat{\beta}$ and $\hat{\delta}$ are the maximum likelihood estimators of σ and δ based on the first r ordered past observations (X_1, …, X_r) from a sample of size n from the Weibull, which can be found from solution of

$$\hat{\beta} = \left(\frac{\sum_{i=1}^{r} x_i^{\hat{\delta}} + (n-r)x_r^{\hat{\delta}}}{r} \right)^{1/\hat{\delta}}, \quad \hat{\delta} = \left[\begin{array}{l} \left(\sum_{i=1}^{r} x_i^{\hat{\delta}} \ln x_i + (n-r)x_r^{\hat{\delta}} \ln x_r \right) \\ \times \left(\sum_{i=1}^{r} x_i^{\hat{\delta}} + (n-r)x_r^{\hat{\delta}} \right)^{-1} - \frac{1}{r}\sum_{i=1}^{r} \ln x_i \end{array} \right]^{-1}, \tag{7}$$

$$\mathbf{z} = (z_1, z_2, ..., z_{r-2}), \tag{8}$$

$$Z_i = \hat{\delta} \ln\left(\frac{X_i}{\hat{\beta}} \right), \quad i = 1, ..., r-1, \tag{9}$$

$$W_1 = \hat{\delta} \ln\left(\frac{Y_1}{\hat{\beta}} \right), \quad w_l = \hat{\delta} \ln\left(\frac{y_l}{\hat{\beta}} \right). \tag{10}$$

Proof. The joint density of $S_1=\ln(X_1)$, …, $S_r=\ln(X_r)$ is given by

$$f(s_1, ..., s_r; \mu, \sigma) = \frac{n!}{(n-r)!} \prod_{i=1}^{r} \frac{1}{\sigma} \exp\left(\frac{s_i - \mu}{\sigma} - \exp\left(\frac{s_i - \mu}{\sigma} \right) \right) \exp\left(-(n-r)\exp\left(\frac{s_r - \mu}{\sigma} \right) \right). \tag{11}$$

Let $\hat{\mu}$, $\hat{\sigma}$ be the maximum likelihood estimators (estimates) of μ, σ based on S_1, …, S_r and let

$$V_1 = \frac{\hat{\mu} - \mu}{\hat{\sigma}}, \tag{12}$$

$$V = \frac{\hat{\sigma}}{\sigma}, \tag{13}$$

and

$$Z_i = \frac{S_i - \hat{\mu}}{\hat{\sigma}}, \quad i = 1(1)r. \tag{14}$$

Parameters μ and σ in (11) are location and scale parameters, respectively, and it is well known that if $\hat{\mu}$ and $\hat{\sigma}$ are estimates of μ and σ, possessing certain invariance properties, then the quantities V_1 and V are parameter-free. Most, if not all, proposed estimates of μ and σ possess the necessary properties; these include the maximum likelihood estimates and various linear estimates. Z_i, i=1(1)r, are ancillary statistics, any r-2 of which form a functionally independent set. We then find in a straightforward manner that the joint density of V_1, V_2, conditional on fixed $\mathbf{z}$= $(z_1, z_2, ..., z_{r-2})$, is

$$f(v_1, v; \mathbf{z}) = \vartheta(\mathbf{z}) v^{r-1} \exp\left(\sum_{i=1}^{r} (z_i + v_1)v - \sum_{i=1}^{r} \exp[(z_i + v_1)v] - (n-r)\exp[(z_r + v_1)v] \right),$$

$$v_1 \in (-\infty, \infty), \quad v \in (0, \infty). \tag{15}$$

where

$$\vartheta(\mathbf{z}) = \left(\int_0^{\infty} \int_{-\infty}^{\infty} v^{r-1} \exp\left(\sum_{i=1}^{r} (z_i + v_1)v - \sum_{i=1}^{r} \exp[(z_i + v_1)v] - (n-r)\exp[(z_r + v_1)v] \right) dv_1 dv \right)^{-1} \tag{16}$$

is the normalizing constant. For notational convenience we include all of $z_1, \ldots, z_r$ in (11); z_{r-1} and z_r can be expressed as function of $z_1, \ldots, z_r$ only.

Writing

$$W = \frac{\ln Y_1 - \mu}{\sigma}, \tag{17}$$

where Y_1 is the smallest observation from independent second sample of m observations also from the distribution (1), and noting that $\exp(W)$ is the smallest observations in a sample of m from the standard exponential distribution, we have the density of W as

$$f(w) = me^w \exp(-me^w), \quad w \in (-\infty, \infty). \tag{18}$$

Since W is distributed independently of v_1, v we find the joint density of w, v_1, v, conditional on $\mathbf{z}$, as the product of (15) and (18),

$$f(w, v_1, v; \mathbf{z}) = f(w) f(v_1, v; \mathbf{z}). \tag{19}$$

Note that

$$W_1 = \frac{\ln Y_1 - \hat{\mu}}{\hat{\sigma}} = \frac{W - V_1 V}{V}; \tag{20}$$

making the transformation $w_1=(w-v_1v)/v$, $v_1=v_1$, $v=v$ we find the joint density of w_1, v_1, v, conditional on $\mathbf{z}$, as

$$f(w_1, v_1, v; \mathbf{z}) = m\mathcal{G}(\mathbf{z}) v^r \exp\left((r+1)v_1 v + \left(w_1 + \sum_{i=1}^{r} z_i \right) v \right) \exp\left(-m \exp[(w_1 + v_1)v] \right)$$

$$\times \exp\left(-\exp[v_1 v] \left(\sum_{i=1}^{r} \exp[z_i v] + (n-r)\exp[z_r v] \right) \right), \quad w_1 \in (-\infty, \infty), \quad v_1 \in (-\infty, \infty), \quad v \in (0, \infty). \tag{21}$$

Now v_1 can be integrated out of (21) in a straightforward way to give

$$f(w_1, v; \mathbf{z}) = \frac{\Gamma(r+1)\mathcal{G}(\mathbf{z}) v^{r-2} \exp\left(v \sum_{i=1}^{r} z_i \right) mv \exp[w_1 v]}{\left(m \exp[w_1 v] + \sum_{i=1}^{r} \exp[z_i v] + (n-r)\exp[z_r v] \right)^{r+1}}$$

$$= \frac{\dfrac{r v^{r-2} \exp\left(v \sum_{i=1}^{r} z_i \right) mv \exp[w_1 v]}{\left(m \exp[w_1 v] + \sum_{i=1}^{r} \exp[z_i v] + (n-r)\exp[z_r v] \right)^{r+1}}}{\displaystyle\int_0^{\infty} v^{r-2} \exp\left(v \sum_{i=1}^{r} z_i \right) \left(\sum_{i=1}^{r} \exp[z_i v] + (n-r)\exp[z_r v] \right)^{-r} dv}, \quad w_1 \in (-\infty, \infty), \quad v \in (0, \infty). \tag{22}$$

Thus, for fixed w_l ($-\infty < w_l < \infty$),

$$\Pr\{W_1 > w_l; \mathbf{z}\} = \int_0^{\infty}\int_{-\infty}^{\infty} f(w_1, v; \mathbf{z}) dw_1 dv$$

$$= \frac{\int_0^{\infty} v^{r-2} \exp\left(v\sum_{i=1}^{r} z_i \right)\left(m\exp[w_l v] + \sum_{i=1}^{r}\exp[z_i v] + (n-r)\exp[z_r v] \right)^{-r} dv}{\int_0^{\infty} v^{r-2} \exp\left(v\sum_{i=1}^{r} z_i \right)\left(\sum_{i=1}^{r}\exp[z_i v] + (n-r)\exp[z_r v] \right)^{-r} dv}$$

$$= \frac{\int_0^{\infty} v^{r-2} e^{v\hat{\delta}\sum_{i=1}^{r}\ln(x_i/\hat{\beta})}\left(me^{vw_l} + \sum_{i=1}^{r} e^{v\hat{\delta}\ln(x_i/\hat{\beta})} + (n-r)e^{v\hat{\delta}\ln(x_r/\hat{\beta})} \right)^{-r} dv}{\int_0^{\infty} v^{r-2} e^{v\hat{\delta}\sum_{i=1}^{r}\ln(x_i/\hat{\beta})}\left(\sum_{i=1}^{r} e^{v\hat{\delta}\ln(x_i/\hat{\beta})} + (n-r)e^{v\hat{\delta}\ln(x_r/\hat{\beta})} \right)^{-r} dv}. \quad (23)$$

This completes the proof. ¸

Corollary 1.1. If $r=n$ and n is large, (23) should be more or less independent of **Z**. Also, $Z_1, \ldots, Z_n$ will be nearly independent and approximately distributed as standard extreme values, with pdf

$$f_{\circ}(w) = e^{w}\exp(-e^{w}), \quad w \in (-\infty, \infty). \quad (24)$$

Our first step is to replace $z_1, \ldots, z_n$ in the numerator of (19) by $n\mathrm{E}\{W\} = -n\gamma$, where $\gamma = 0.577215\ldots$ is the Euler constant. We now suppose that $(1/n)\sum_{i=1}^{n}\exp[z_i v]$ will be approximately equal to the moment generating function for (24), with dummy variable v. Since $\mathrm{E}\{\exp[w\eta]\} = \Gamma(1+\eta)$, we approximate the above sum in the denominator of (23) by $n\Gamma(1+v)$. We thus arrive at the following approximation to (6)

$$\Pr\{Y_1 > y_l\} = \Pr\left\{ \ln\left(\frac{Y_1}{\hat{\sigma}}\right)^{\hat{\delta}} > \ln\left(\frac{y_l}{\hat{\sigma}}\right)^{\hat{\delta}} \right\} = \Pr\{W_1 > w_l\}$$

$$= \frac{\int_0^{\infty} v^{r-2} e^{-r\gamma v}\left[(m/n)e^{vw_l} + \Gamma(1+v) \right]^{-r} dv}{\int_0^{\infty} v^{r-2} e^{-r\gamma v}\left[\Gamma(1+v) \right]^{-r} dv} = 1-\alpha. \quad (25)$$

3. UPPER CONDITIONAL PREDICTION LIMIT ON THE MAXIMUM OF A SET OF *M* FUTURE OBSERVATIONS

Theorem 2. Let $X_1 < \ldots < X_r$ be the first r ordered past observations from a sample of size n from the distribution (1). Then an upper conditional $(1-\alpha)$ prediction limit y_u on the maximum Y_m of a set of m future ordered observations $Y_1 < \ldots < Y_m$ is given by

$$\Pr\{Y_m < y_u; \mathbf{z}\} = \Pr\left\{\hat{\delta}\ln\left(\frac{Y_m}{\hat{\beta}}\right) < \hat{\delta}\ln\left(\frac{y_u}{\hat{\beta}}\right); \mathbf{z}\right\} = \Pr\{W_m < w_u; \mathbf{z}\}$$

$$= 1 - \frac{\sum_{j=0}^{m-1}\binom{m-1}{j}(-1)^j \int_0^\infty v^{r-2} e^{v\hat{\delta}\sum_{i=1}^{r}\ln(x_i/\hat{\beta})} (j+1)^{-1}\left((j+1)e^{vw_u} + \sum_{i=1}^{r} e^{v\hat{\delta}\ln(x_i/\hat{\beta})} + (n-r)e^{v\hat{\delta}\ln(x_r/\hat{\beta})}\right)^{-r} dv}{\sum_{j=0}^{m-1}\binom{m-1}{j}(-1)^j \int_0^\infty v^{r-2} e^{v\hat{\delta}\sum_{i=1}^{r}\ln(x_i/\hat{\beta})} (j+1)^{-1}\left(\sum_{i=1}^{r} e^{v\hat{\delta}\ln(x_i/\hat{\beta})} + (n-r)e^{v\hat{\delta}\ln(x_r/\hat{\beta})}\right)^{-r} dv}$$

$$= 1-\alpha. \qquad (26)$$

Proof. The proof is similar to that of Theorem 1. ∎

Corollary 2.1. If $r=n$ and n is large, in the same manner as in Theorem 1 we arrive at the following approximation to (26)

$$\Pr\{Y_m < y_u\} = \Pr\left\{\ln\left(\frac{Y_m}{\hat{\sigma}}\right)^{\hat{\delta}} < \ln\left(\frac{y_u}{\hat{\sigma}}\right)^{\hat{\delta}}\right\} = \Pr\{W_m < w_u\}$$

$$= 1 - \frac{\sum_{j=0}^{m-1}\binom{m-1}{j}(-1)^j \int_0^\infty v^{r-2} e^{-r\gamma v}(j+1)^{-1}\left[(j+1)(m/n)e^{vw_u} + \Gamma(1+v)\right]^{-r} dv}{\sum_{j=0}^{m-1}\binom{m-1}{j}(-1)^j \int_0^\infty v^{r-2} e^{-r\gamma v}(j+1)^{-1}\left[\Gamma(1+v)\right]^{-r} dv} = 1-\alpha. \qquad (27)$$

4. CONCLUSION

The method of constructing prediction limits for future samples from a Weibull distribution introduced in this paper utilizes all the information in a sample, but since it involves the use of numerical integration, many may prefer to use this technique only in situations not readily handled by other of the methods described earlier. With modern computing, however, the conditional prediction limits are not difficult to calculate and should be recommended when the ability to do computations is available.

ACKNOWLEDGMENTS

This research was supported in part by Grant No. 02.0918 and Grant No. 01.0031 from the Latvian Council of Science and the National Institute of Mathematics and Informatics of Latvia.

References

[1] Blischke W.R., Murthy D.N.P. *Reliability*. New York: Wiley, 2000.

NORMAL, LOGNORMAL, WEIBULL OR P-SEV DISTRIBUTION OF ULTIMATE STRENGTH OF STRANDS AND COMPOSITE SPECIMENS

A. Paramonova[1], M. Kleinhof[2], Yu. Paramonov[3]*

[1] *Transport and Telecommunication Institute*
Lomonosov Str. 1, Riga, LV-1019, Latvia

[2,3] *Aviation Institute of Riga Technical University*
Lomonosov Str. 1, Riga, LV-1019, Latvia

**Corresponding author. Ph: +371 7255394. Fax: +371 7089990. E-mail: rauprm@junik.lv*

Analysis of ultimate strength of strands (bundles) and specimens of composite material is considered with the use of simple goodness-of-fit test for cumulative distribution function (cdf) with location and scale parameters. The test, offered for preliminary analysis, is based on comparison of ordered statistics with their standard distribution expected values (when location parameter is equal to zero and scale parameter is equal to one). For specific W-L dilemma testing (**W**eibull against **L**ognormal distribution) some approximation of uniformly most powerful invariant test (UMPIT) is offered. The critical boundary of the region of rejection of null-hypothesis and power of the tests can be calculated using modern PC. Numerical examples (processing of ultimate strength dataset) are given. As a subject of further research new p-sev family distribution is offered for ultimate strength distribution description. The weakest link model can be combined in this family with lognormal or some other distribution law.

Keywords: *distribution function, composite, static strength*

1. INTRODUCTION. INVESTIGATION OF DISTRIBUTION FUNCTION OF STATIC STRENGTH OF COMPOSITE ITEMS

The significant dependence of static strength of composite on scatter of static strength of its items can be seen in the following example. Let us consider three parallel items, which have the following strengths: 10 N, 15 N, and 30 N. It is a surprise in some way that the total loads 30 N will destroy them, as if the strength of every item is equal to 10 N. Why?

The reason is that by the total load 30 N at first will be destroyed the weakest item because its strength is equal to 10 N and, at the uniform distribution of total loads, its load is equal to 10 N also. Now uniform load of every "survived" item is equal to 15 N. So the second item, the strength of which is equal to the same value 15 N, will be destroyed. Now the load for the last strongest item will be equal to 30 N. It will be destroyed also because its strength is just equal to this load. This process is shown in Fig.1. The same "domino phenomenon" for n items take place if there strengths are proportional to the items of harmonic series: 1, ½, 1/3,…, 1/n. So it is obvious, that it is necessary to study distribution of strength of components of composite. Usually Weibull distribution and its modification are used for processing of tensile ultimate strength [1]. But sometimes-lognormal distributions are considered appropriate also [2]. It is not easy to differentiate one from another [3]. In logarithm scale both these distributions are distributions of location-scale families and for corresponding distribution identification a graphical technique is used usually. "It allows check visually how closely the data follow the hypothetical distribution function. Furthermore, it provides a quick estimation of distribution parameters" [4]. We offer to make some change of this technique so at first we'll give it's short description. Let $x_{(1)}, x_{(2),} \ldots x_{(n)}$ be the ordered observations from population with cdf of the type $F(x) = F_0((x-\theta_0)/\theta_1)$. The main idea of this graphical technique is:

the values $x_{(i)}$ are plotted against $F_0^{-1}((i-C_1)/(n+C_2))$, where $F^{-1}(.)$ is the inverse function of $F(.)$, C_1, C_2 are some constants. The using of these constants allows to avoid the following problem: if i/n is close to zero then $F^{-1}(.)$ is close to $-\infty$ and when i/n is close to 1 then $F^{-1}(.)$ is close to $+\infty$ but real $x_{(i)}$ are finite and for i=1 and i =n.

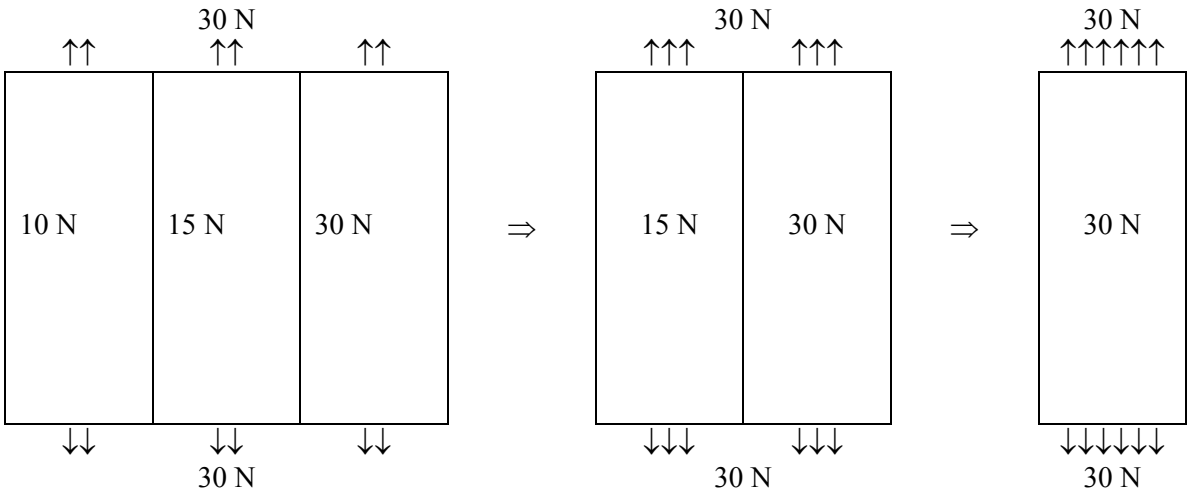


Figure 1. *The ultimate strength of "composite" of three items is defined by strength of the weakest item*

But choice of C_1, C_2 is very obscure and really it should depend on *n* and $F(.)$. The values C_1=0.5, C_2=0 are recommended, for example in [4], the values C_1=0.3, C_2=0.4 are used in [1].

The other disadvantage of this graphical technique is that it is used only for ***visual*** testing hypotheses. We offer to avoid both disadvantages. Much more precise preliminary analysis of the considered problem is the use of the offered here OSPPTest (**T**est based on **P**robability **P**lot of **O**rdered **S**tatistics, $x_{(i)}$, against expected values of standard order statistics, $E(\overset{o}{X}_{(i)})$, corresponding to θ_0=0, θ_1=1). It is discussed in section 2. In section 3 for specific W-L dilemma testing (**W**eibull against **L**ognormal distribution) some approximation of uniformly most powerful invariant test (UMPIT) is offered. Numerical examples are provided for both tests. In section 4 analysis of "classical model of bundle of n parallel fibres are stretched between two clamps", which is considered as a model of unidirectional composite. It is shown that Daniels prediction of normal distribution should be used only with great caution because uniform distribution of stresses between fibres probably does not take place. In section 5 as a subject of further research a new family of ultimate strength is offered in which the weakest link model can be combined with lognormal or some other distribution law.

2. OSPPTEST FOR PRELIMINARY ANALYSIS

So it is offered to plot $x_{(1)}, x_{(2),}...x_{(n)}$, the ordered observations from population with cdf of the type $F(x)=F_0((x-\theta_0)/\theta_1)$ against $E(\overset{o}{X}_{(i)})$, expected values of standard order statistics, corresponding to θ_0=0, θ_1=1.

Corresponding plot again can be used for visual analysis. But the critical region for the test of the hypothesis in question is offered to define by inequality

$$OSPPt = \overline{R}_{LR} = (1-R^2)^{1/2} = \Big(\sum_{i=1}^{n} (\hat{x}_{(i)} - x_{(i)})^2 / ns^2 \Big)^{1/2} > C_{alfa},$$

where *OSPPt* is statistic of OSPPTest, $\overline{R}_{LR}$ is specific notation of $OSPPt$, if linear regression analysis is used for θ_0 and θ_1 estimation (another index must be used if another method of estimation is used), R^2 is the standard statistic of linear regression analysis (it is so called coefficient of determination), $\hat{x}_{(i)} = \hat{\theta}_0 + \hat{\theta}_1 E(\overset{o}{X}_{(i)})$, $\hat{\theta}_0$, $\hat{\theta}_1$ are estimates of θ_0, θ_1, $\overline{x} = \sum_{i=1}^{n} x_i / n$, $s^2 = \sum_{i=1}^{n} (x_i - \overline{x})^2 / n$.

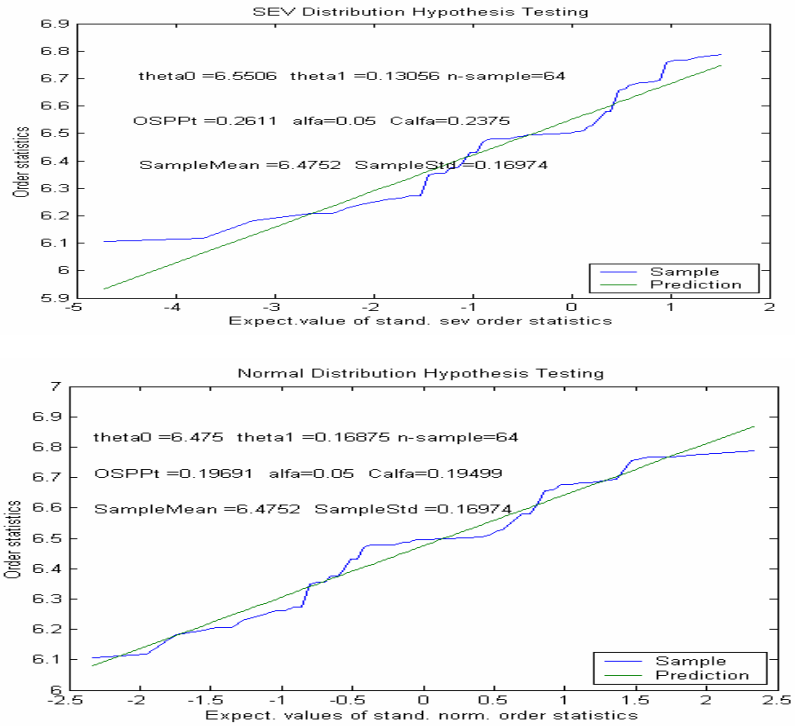


Figure 2. *OSPPT plots for the 1-strand-specimen ultimate strengths. Null hypotheses: sev (Weibull) in upper part and normal(lognormal) distributions in lower part*

Results of processing of sample, $(y_1,...,y_{64})$, of ultimate strengths of 64 carbon-fibre strands for testing of Weibull and lognormal hypotheses are shown in Fig.2 $x_{(i)}$, against $E(\overset{o}{X}_{(i)})$. It should be mentioned that in considered problem $X = \log(Y)$ has smallest extreme values (sev) or normal distribution with cdf

$$F_X(x) = 1 - \exp(-\exp((x-\theta_0)/\theta_1)) \quad \text{or} \quad F_X(x) = \Phi((x-\theta_0)/\theta_1)$$

if random variable *Y* has Weibull or lognormal distribution correspondingly.

We see that in accordance with Monte Carlo estimate of the (1-α)-quintile (where α is significance level) of *OSPPt*- statistic, Calfa, for α=.05 (see Fig.2) both hypotheses should be rejected. But really this decision is very doubtful because the power of this test for considered specific W-L dilemma is equal to 0.55 (see Fig.3).

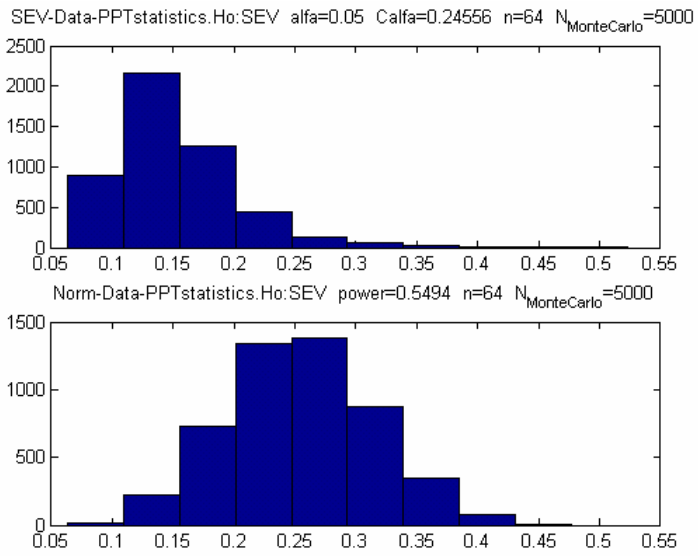


Figure 3. *Histogram of OSPPt statistics; hypothesis H_0 is sev distribution alternative H_1 is normal distribution*

Probably it can be increased if the best linear unbiased estimates will be used instead of estimates of linear regression analysis. In this case estimates of parameters θ_0 and θ_1 are defined by formula

$$(\hat{\theta}_0, \hat{\theta}_1)^T = (A^T V^{-1} A)^{-1} A^T V^{-1} X ,$$

where $X = (X_{(1)}, ..., X_{(n)})^T$,

$$A = \begin{bmatrix} 1 & E(\overset{o}{X}_{(1)}) \\ 1 & E(\overset{o}{X}_{(2)}) \\ ..... & \\ 1 & E(\overset{o}{X}_{(n)}) \end{bmatrix},$$

$V = \| Cov[\overset{o}{X}_{(i)}, \overset{o}{X}_{(j)}] \|$, $i, j = 1,2,...,n$ is variance-covariance matrix of standard order statistics, symbol $(.)^T$ is transposition sign.

Corresponding *OSPPt* can be denoted by $\overline{R}_{BU}$ ("best unbiased"). Similarly *OSPPt* based on using the method of moments, $\overline{R}_{MM}$, or maximum likelihood, $\overline{R}_{ML}$, and any others (but with "true" structure: $\hat{\theta}_0(a + bx_1, ..., a + bx_n) = a + b\hat{\theta}_0(x_1, ..., x_n)$, $\hat{\theta}_1(a + bx_1, ..., a + bx_n) = b\hat{\theta}_1(x_1, ..., x_n)$) can be considered. Investigation of power of corresponding tests is subject of special paper. Here we limit ourselves by standard regression analysis just because of its simplicity. But for solution of specific W-L dilemma testing (**W**eibull against **L**ognormal distribution) some approximation of uniformly most powerful invariant test (UMPIT) is discussed in section 3.

3. APPROXIMATION OF UNIFORMLY MOST POWERFUL INVARIANT TEST

In [4,5] can be found uniformly most powerful invariant test for testing hypothesis $f(x) = (1/\theta_1) g((x - \theta_0)/\theta_1)$ when the alternative $f(x) = (1/\theta_1) h((x - \theta_0)/\theta_1)$. But the calculation of distribution of corresponding statistics is very labour consuming.

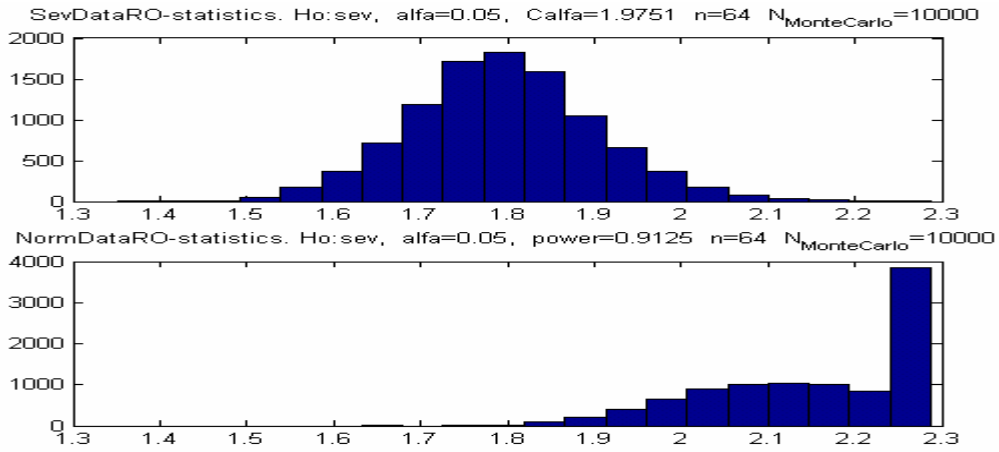


Figure 4. *The histograms of ρ -statistics for samples from sev and normal distributions*

For the case, when g(.) is sev probability mass function (pmf) but h(.) is normal pmf the approximation of UMPIT with the critical region

$$\rho = \sum_{i=1}^{n} \exp(\pi(x_i - \bar{x})^2 / s\sqrt{6}) > C_{alfa}$$

can been used [3,6]. It was shown that it has nearly the same power as the power of UMPIT. Now the rejection of Weibull distribution for α=0.05 (for processed dataset ρ=2.03> C_{alfa}=1.98) is much more convincing: the power of the ρ-test in this case appears to be equal to 0.91 (see Fig.4). Although really we never know the "truth" in this "random world" it seems that the lognormal distribution is more appropriate. This means that the model of the weakest item in *this case* does not work properly. The process of accumulation should be taken into account also. And it is the reason why the lognormal distribution appears more adequate for considered dataset.

4. RELATIONSHIP BETWEEN THE DISTRIBUTIONS OF ULTIMATE STRENGTH OF UNIDIRECTIONAL FIBRE COMPOSITE AND ITS COMPONENTS

At every step of development of complex composite material (from fibre to strands, from strands to film and then to multi layer composite) we see the change of ultimate strength probability distribution function and its parameters.

Solution of the problem to get more precise relationship between static strength of unidirectional fibre composite material and static strength of its rigid items (parallel rigid components (strands or fibres) is an important input to design-for-reliability process. A great number of articles are devoted to the problem. It seems that Daniels [7] made the most significant steps in this direction, studying in details a model, which is now called the "classical model of bundle of n parallel fibres stretched between two clamps". Phoenix and Tailor [8] extended the model to cover certain types of inhomogeneity among the fibres, such as random slack, but still within the basic framework of equal load sharing. Paramonov and Kleinhof [2] developed similar approach. Daniels himself [9] made, which have used this time the theory of Brownian Bridge. Local load sharing and the chain-of-bundles model were studied by Pitt and Phoenix [10] and by Smith [11] and earlier references therein]. Wolf and Linka [12] considered some new approach to the calculations of "the strength of rope composed from several strands". They have used the methods and relevant theory of counting processes to get solution of some mathematical aspect of this problem. Experimental data show that mean strength decreases, standard deviation decreases also when complexity of structure increases: ultimate strength of fibres lesser than ultimate strength of strand (bundle) and ultimate strength of strand lesser than ultimate strength of specimens.

The main idea of Daniels's model is uniform distribution of tension loads between parallel-unbroken items (strands or fibres). The main result of Daniels is formulated in following way: " If all the fibres have the same load-tension curve and $b(s)$ is probability of failure of one fibres under load s and $(1-b(s))$ converges to 0 faster than $1/s$, then the strength s of strand of enough larger number $\boldsymbol{n}$ of fibres has normal distribution with expectation value

$$S_r = n \cdot s_r \cdot [1 - b(s_r)],$$

standard deviation

$$\sigma = s_r \cdot \sqrt{n \cdot b(s_r) \cdot [1 - b(s_r)]},$$

where s_r corresponds to maximum of $s \cdot [1 - b(s)]$".
So the mean strength is defined by formula

$$\bar{S}_r = s_r \cdot [1 - b(s_r)],$$

and its standard deviation by formula

$$\bar{\sigma} = s_r \cdot \sqrt{b(s_r) \cdot [1 - b(s_r)]} / \sqrt{n}\ .$$

In previous section we have chosen the lognormal distribution as the most appropriate for the static strength distribution of composite components. In this case we are interested in studying the function

$$y(x) = x(1 - \Phi_0((\log(x) - \theta_0)/\theta_1)),$$

where $\Phi_0(\cdot)$ – is normal standard distribution function.

Results of calculations of this function for several values of θ_0 = 6,0; 6,5; 7 and θ_1 = 0,15; 0,2; 0,25; 0,3; 0,35 are given in Fig.5.

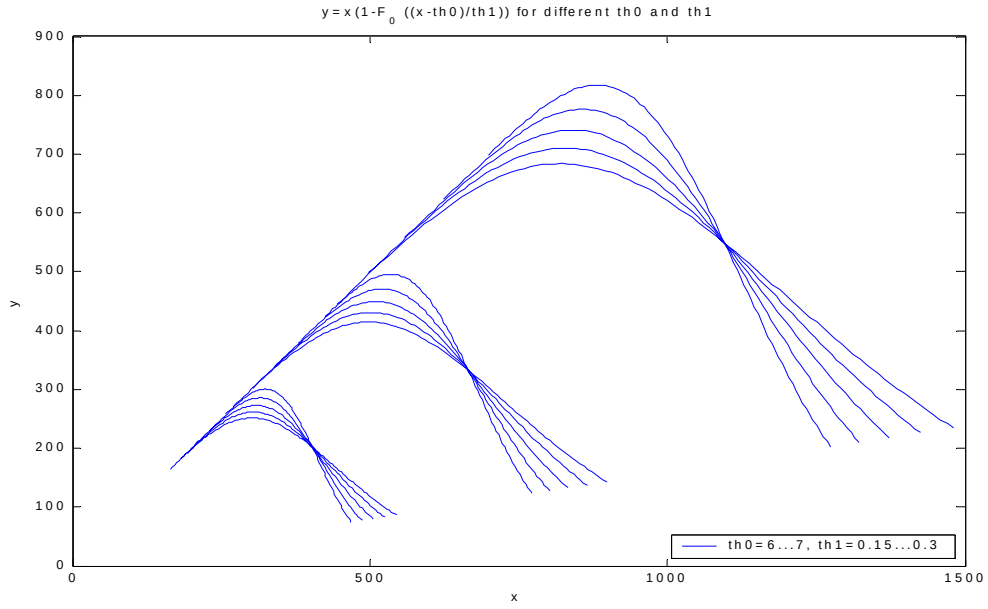


Figure 5. *Results of calculations of function* $y(x) = x(1 - \Phi_0((\log(x) - \theta_0)/\theta_1))$ *for* θ_0 *= 6,0; 6,5; 7 and* θ_1 *=0,15; 0,2; 0,25; 0,3; 0,35.*

Maximal values of these functions correspond to strengths of bundle of items with corresponding initial parameters of static strength distribution if the number of items is large enough. But as it will be showed later really we should consider the destruction of relatively small number of items. And we need to consider this case more attentively.

Just after destruction of r items the total load, which is applied to the still survived items, is equal to

$$S_{(r)} \cdot (n - r),$$

where $S_i, i = 1,...,n$ is random strength of ith item, $S_{(r)} - rth$ order statistic

$$S_{(1)} \le S_{(2)} \le ... \le S_{(r-1)} \le S_{(r)} \le ... \le S_{(n)},$$

of item strengths. So average strength of one item in bundle is defined by formula

$$\overline{S} = \max_r S_{(r)} \cdot \left(1 - \frac{r}{n}\right). \qquad (1)$$

Ultimate strength tests of 64 one-strand specimens (bundle) and of 64 10-strands specimens (every specimen comprised 10 strands) were made in order to study the connection of corresponding parameters of ultimate strength distribution functions. The following lognormal distribution parameter and mean value of strength ($\hat{\theta}_0$, $\hat{\theta}_1$, $\hat{\mu}$) was obtained: (6.476, 0.169, 658 MPa) for one-strand and (6.156, 0.195, 481 MPa) for 10-strands specimens.

Monte Carlo modelling of ultimate strength of 5 - and 10-strands specimens was made with and without taking into account the scatter of the Young's modulus. Standard deviation of logarithm of Young's modulus (for one-strand specimen) is equal to 0.332. So total standard deviation was taken equal to 0.3723.

The best prediction of mean strength we get under assumption that if in10-strands specimens there are really only 5 strands and if we take into account the scatter of Young's modulus. In this case the predicted mean strength is equal to 482.39 MPa but real mean strength of 10-strands specimen is equal to 481 MPa. Predicted standard deviation of logarithm of strength is equal to 0.1904 but real standard deviation of logarithm of strength is equal to 0.1945. We see that prediction of strength by the use of Daniels model (really, formula (1)) is not too bad, but to get it we need to decrease the number of strands in Monte Carlo calculation.

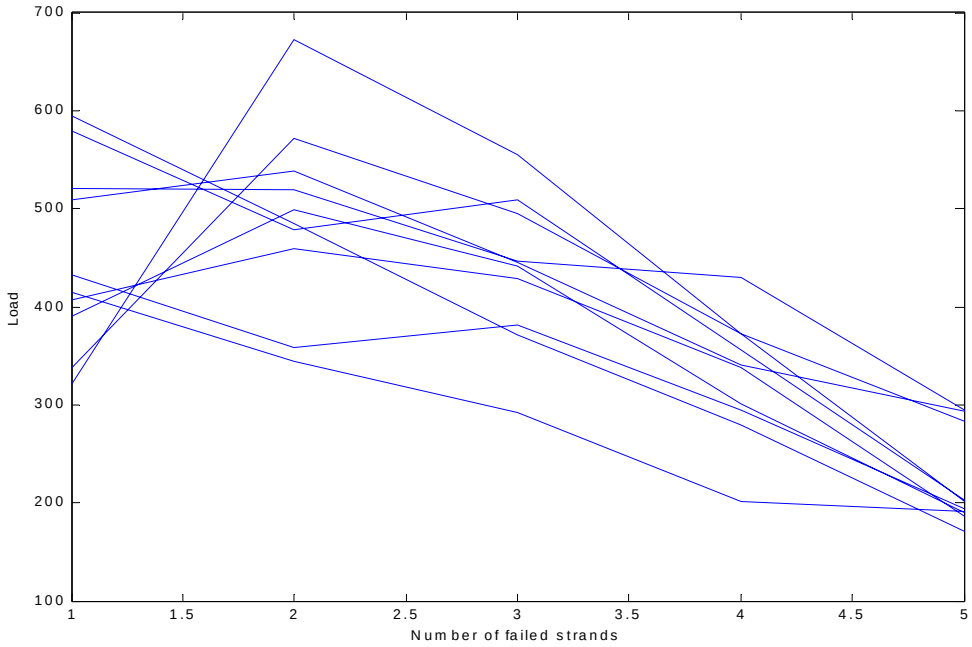


Figure 6. *Results of 10 Monte Carlo trials of strength of 5-strands specimens*

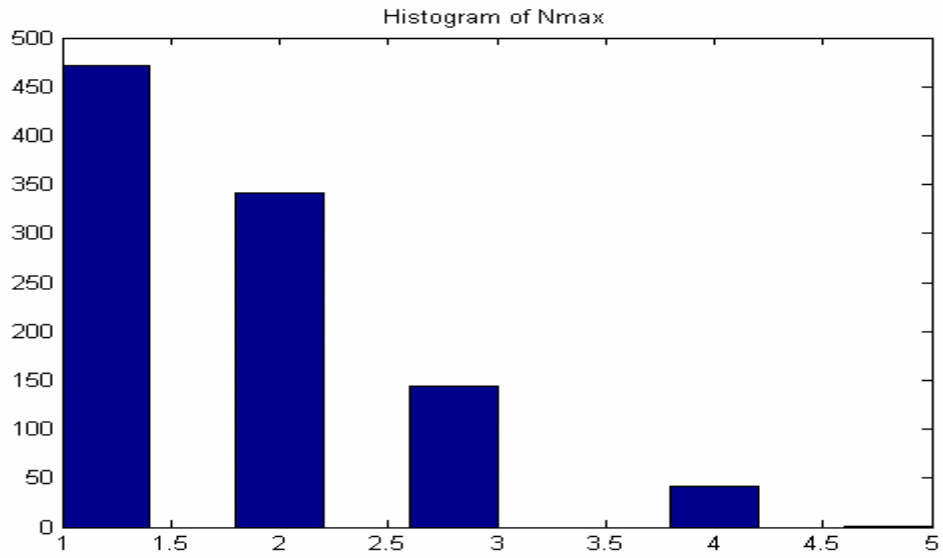


Figure 7. *Histogram of order numbers of fibre (Nmax) after failure of which the failure of specimen take place*

In Fig. 6 we see the samples of the random process of destruction of 5-strands specimens. We see that some times at the beginning of this process we can increase the load despite the failure of the weakest items but then we see that the load, which can be carried by survived specimens, decreases. The order number of the failure corresponding to the maximum of load is shown in Fig. 8. We see that in nearly 50% of trials the catastrophic failure take place just after failure of only one strand ("domino phenomenon'). This is the reason that during Monte Carlo modelling we should decrease the real number of strands in order to minimize the discrepancy between the result of calculation and test data.

10 realizations (10 Monte Carlo trials) of this type process for 5-fibers specimens are shown in Fig. 6, but total 1000 trials were made. For every realization of this process we can find maximum. It is the strength of specimen.

The histograms of strengths (maximums in Fig. 6) in natural and in logarithm scale and corresponding OSPPT plots are shown in Fig. 8.

Analysis of Fig. 8 shows that lognormal distribution much better fit these data than normal distribution. Daniels's theorem predicts normal distribution only if we have uniform distribution between n items and n is large enough. But really we have not uniform distribution. It can be true for bundle of disconnected threads but in composite new damage appears near previous damage. This process begins, as a rule, in the surface, then grows along cross-section of specimens and finishes by catastrophic failure of specimens. This means that even approximate uniform distribution of stress can be expected only in very limited volume with drifting location. For example, as it was mentioned already) the result of calculation of standard deviation of strength of 10-strands specimens (by Monte Carlo method) is very near to the previously mentioned experimental data if we assume (for Monte Carlo modelling) that in this specimens there are only 5 strands.

5. AREAS FOR FURTHER RESEARCH. P-SEV DISTRIBUTION FAMILY

The main result of presented investigation is the great doubt that the widely used Weibull distribution is the only one, which should be used for processing of ultimate strength data of fibre and strands. At least sometimes lognormal distribution is more appropriate. Should be mention however some indisputable advantage of Weibull distribution: it offers very natural explanation of decreasing of mean ultimate strength if the fibre length increases [1]. But similar model can be offered and with the use of lognormal distribution. Let us considered a fibre as a chain of n elementary items with length l_1.

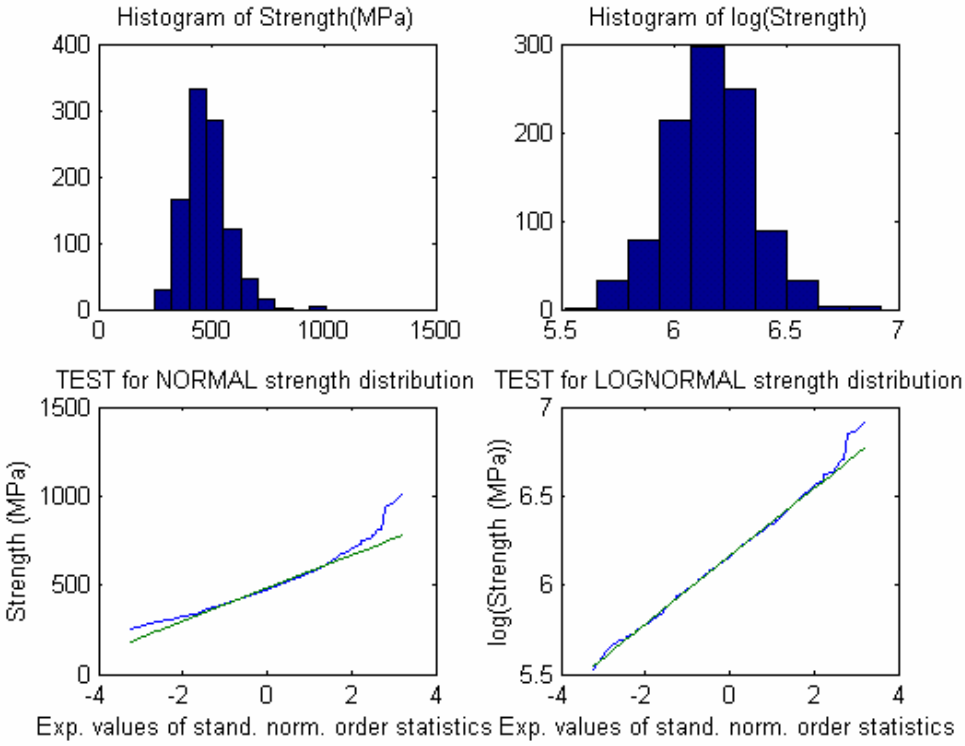


Figure 8. *Histograms (1000 Monte Carlo trials) of strength of 5-fibers specimens and OSPPT plots in natural and logarithm scale*

Let us suppose that fibre destruction process has two stages. First, in K items, $K \le n$, some flaws appear. Then in the weakest item the destruction process develops up to fibre specimen failure. Stress is uniformly distributed along the fibre so binomial distribution of random variable K is expected. Corresponding probability mass function

$$p_k = b(k;n,p) = (n!/(k!(n-k)!))p^k(1-p)^{n-k},$$

where $n = [l/l_1]+1$, $[x]$ rounds the x to the nearest integers towards minus infinity,

$p = F_0(s)$, s is stress , $F_0(x)$ is some cumulative distribution function (cdf).

Then cdf of specimen strength

$$F(x) = \sum_{k=0}^{n} p_k (1-(1-F_1(x))^k),$$

where $F_1(x)$ is cdf of strength of elementary item (with length l_1).

If n is large enough then instead of Binomial the Poisson distribution can be used with parameter $\lambda = (l/l_1)\,F_0(x)$. The number of elementary items should be more or equal to 1, so equation

$$F(x) = \sum_{k=0}^{\infty} \exp(-\lambda)(\lambda^k/k!)(1-(1-F_1(x))^{k+1}) \qquad (2)$$

is more appropriate.

For different $F_0(x)$ and $F_1(x)$ we have the whole family of models. The lognormal distribution (and Weibull also!) can be used here for describing cdf $F_0(x)$ and $F_1(x)$. The calculation of $F(x)$ is not too difficult if we use Monte Carlo (MC) method. Let N is the number or random variables (rv) with Poisson distribution and $\{K_1, K_2, ..., K_N\}$ is the set of rv from corresponding population. If N is large enough then approximately

$$F(x) = (1/N)\sum_{i=0}^{N}(1-(1-F_1(x))^{K_i+1}).$$

This family of distributions may be called ***p-sev family***, because it is connected with Poisson and sev (smallest extreme value) distributions. In the simplest case we can assume that cdf $F_1(x) = F_0(x) = \overset{0}{F}((x-\theta_0)/\theta_1)$, where $\overset{0}{F}(\cdot)$ is some known (standard) cdf, then for ***fixed*** $\theta_2 = (l/l_1)$ the cdf $F(x)$ again has location and scale parameters: θ_0 and θ_1. So all the methods of mathematical statistics appropriate to the location-scale cdf family can be used and for offered $F(x)$ (but only for fixed θ_2!). For example, for fixed θ_2 using method of moment we have following estimates of θ_0 and θ_1:

$$\hat{\theta}_1 = (s^2)^{1/2} / \overset{0}{\sigma},\ \hat{\theta}_0 = \bar{x} - \hat{\theta}_1 \overset{0}{\mu},$$

where $\overset{0}{\mu}$, $\overset{0}{\sigma}$ are mean and standard deviation of X for $\theta_0 = 0$ and $\theta_1 = 1$, as functions of θ_2 these values can be found using (for example) Monte Carlo method.

Parameter θ_2 defines the dependence of mean ultimate strength on the length of fibre. Preliminary investigations of the dataset described in [1] show that this dependence is nearly the same as the one provided by the cdf

$$F(x) = 1 - \exp(-(l/l_0)^{\gamma}(x/\beta)^{\alpha}), \qquad (3)$$

which was offered [13,14, 15] especially for better fit of experimental data with different length. It seems that model (2) has more natural ground and allow much more general approach than the model (3) and models described in [16-19]. At least it has right to exist and deserves more checking. But this is area for further research.

References

[1] Andersons J., Joffe R., Hojo M., Ochiai S. Fiber Fragment Distribution in a Single-Fiber Composite Tension Test, *Composites B*, Vol. 32, No. 4, 2001, pp. 323-332.

[2] Kleinhof M.A. *Investigation of Static and Fatigue Composite Material in Airframe Structure:* Dr. Sc. thesis. Riga, 1983. (In Russian)

[3] Paramonov Yu.M., Bormotin R.A. Effectiveness of Preliminary Distribution Type Test in the Problem of Specified Life Nomination. In: *AVIATION, #5*. Vilnius: Technika, 2000, pp. 105-108.

[4] Gertsbakh I. *Reliability Theory. With Application to Preventive Maintenance*. Berlin Heidelberg New York: Springer-Verlag, 2000. 220 p.

[5] Cox D.R., Hinkly D.V. *Theoretical Statistics*. Imperial College. London: Chapmen &Hall, 1974. 560 p.

[6] Paramonov Yu. M. *Mathematical Statistics Methods for Estimation and Ensuring of Aircraft Structures Reliability*. Riga: Institute of Civil Aviation, 1992. 248 p.

[7] Daniels H.E. The Statistical Theory of the Strength of Bundles of Threads, *Mathematical and Physical Sciences, Series A,* Vol. 183, #995, 1945, pp.405-435.

[8] Phoenix S.L. and Taylor H.M. The Asymptotic Strength of a General Fiber Bundle*, Adv. Appl. Prob.,* Vol. 22, 1973, pp. 200-216.

[9] Daniels H.E. The Distribution of Bundle Strength under General Assumptions. In: *The First World Congress of the Bernoulli Society.* Tashkent, USSR, September 1986. 3p.

[10] Pitt R.E. and Phoenix S.L. Probability Distributions for the Strength of Composite Materials, III and IV, *Int. J. Fracture*, Vol. 20, 1982, pp.291-311; Vol.22, pp.243-276.

[11] Smith R.L. Statistical Models for Composite Materials. In: *The First World Congress of the Bernoulli Society.* Tashkent, USSR, September 1986. 11 p.

[12] Volf P. and Linka A. On Reliability of System Composed from Parallel Units. In: *The First International Symposium on Industrial Statistics*. Linkoping, Sweden, August 1999. 9 p.

[13] Gutans J.A., Tamuzh V.P. Scale Effect of the Weibull Distribution of Fibre Strength, *Mech. Comp. Mater.,* Vol. 6, pp.1107-1109 (in Russian).

[14] Watson A.S., Smith R.L. An Examination of Statistical Theories for Fibrous Materials in the Light of Experimental Data, *J Mater Sci*, Vol. 20, 1985, pp.3260-3270.

[15] Padgett W.J., Durham S.D., Mason A.M. Weibull Analysis of the Strength of Carbon Fibers Using Linear and Power Law Models for the Length Effect, *J Comp Mater*., Vol.29(14), 1995, pp.1873-1884.

[16] Curtin W.A. Tensile Strength of Ber-Reinforced Composites: III.Beyond the Traditional Weibull Model for Fiber Strengths, *J Comp. Mater*., Vol.34(15), 2000, pp.1301–1332.

[17] Phani K.K. Strength Distribution and Gauge Length Extrapolations in Glass Fibre, *J Mater Sci,* Vol.23, 1988, pp.1189-1194.

[18] Gurvich M.R., DiBenedetto A.T., Ranade S.V. A New Statistical Distribution for Characterizing the Random Strength of Brittle Materials*, J Mater Sci,* Vol.32, 1997, pp.2559-2564.

[19] Knoff. WF. Combined Weakest Link and Random Defect Model for Describing Strength Variability in Fibres, *J Mater Sci*, Vol. 28, 1993, pp.931-941.

MULTIPERIOD PROJECT PORTFOLIO INVESTMENT STRATEGY

Gundars Berzins, Nicholas A. Nechval, Edgars K. Vasermanis

Mathematical Statistics Department, University of Latvia
Raina Blvd. 19, LV-1050, Riga, Latvia
E-mail: nechval@junik.lv

This paper considers an analytical optimal solution to the mean-variance formulation of the problem of optimisation of multiperiod investment strategy for project portfolio. Specifically, analytical optimal multiperiod investment strategy for project portfolio is derived. An efficient algorithm is proposed in order to maximize the expected value of the terminal wealth under constraint that the variance of the terminal wealth is not greater than a pre-assigned risk level or to minimize the variance of the terminal wealth under constraint that the expected terminal wealth is not smaller than a pre-assigned level. A numerical example is given.

Keywords: *project portfolio, multiperiod investment strategy, optimisation*

1. INTRODUCTION

Investment of project portfolio is to seek the best allocation of wealth among a basket of projects. Project portfolio investment is the periodic activity involved in investing a portfolio of projects, that meets an organization's stated objectives without exceeding available resources or violating other constraints. Some of the issues that have to be addressed in this process are the organization's objectives and priorities, financial benefits, intangible benefits, availability of resources, and risk level of the project portfolio. Investment strategy for a set of proposed projects is a crucial decision in many organizations, which must make informed decisions on investment, where the appropriate distribution of investment is complex, due to varying levels of risk, resource requirements, and interaction among the proposed projects. The mean-variance formulation by Markowitz [1-2] provides a fundamental basis for project portfolio investment in a single period. Smith [3], Mossin [4], Merton [5], Samuelson [6], Fama [7], Hakansson [8], Elton and Gruber [9], Winkler and Barry [10], Francis [11], Dumas and Luciano [12], Grauer and Hakansson [13], and Pliska [14] have studied the problem of multiperiod portfolio investment. The literature in multiperiod portfolio investment has been dominated by the results of maximizing expected utility functions of the terminal wealth and/or multiperiod consumption. Specially, investment situations where the utility functions are of power form, logarithm function, exponential function, or quadratic form have been extensively investigated in the literature.

To our knowledge, no analytical or efficient numerical method for finding the optimal strategy for the mean-variance formulation of the problem of multiperiod project portfolio investment has been reported in the literature. In this sense, the concept of the Markowitz's mean-variance formulation has not been fully utilized in multiperiod project portfolio investment. This paper considers an analytical optimal solution to the mean-variance formulation of the problem of multiperiod project portfolio investment. Specifically, analytical optimal multiperiod investment strategy for project portfolio is derived. An efficient algorithm is proposed in order to maximize the expected value of the terminal wealth under constraint that the variance of the terminal wealth is not greater than a pre-assigned risk level or to minimize the variance of the terminal wealth under constraint that the expected terminal wealth is not smaller than a pre-assigned level.

2. PROBLEM STATEMENT

We consider a portfolio with $(m+1)$ risky projects, with random rates of returns. Let w_0 be an initial wealth of an investor at time 0. The investor can allocate his wealth among the $(m+1)$ projects. The wealth can be reallocated among the $(m+1)$ projects at the beginning of each of the following $(T-1)$ consecutive time periods. The rates of return of the risky projects at time period τ within the

planning horizon are denoted by a vector $\mathbf{r}_\tau=[r_{\tau(0)}, r_{\tau(1)}, \ldots, r_{\tau(m)}]'$, where $r_{\tau(j)}$ is the random return for project j at time period τ. It is assumed in this paper that vectors $\mathbf{r}_\tau$, $\tau = 0, 1, ..., T-1$, are statistically independent and return $\mathbf{r}_\tau$ has a known mean $\mathrm{E}\{\mathbf{r}_\tau\}=[\mathrm{E}\{r_{\tau(0)}\}, \mathrm{E}\{r_{\tau(1)}\}, \ldots, \mathrm{E}\{r_{\tau(m)}\}]'$ and a known covariance

$$\mathrm{Cov}\{\mathbf{r}_\tau\} = \begin{bmatrix} \sigma_{\tau(00)} & \cdots & \sigma_{\tau(0m)} \\ \vdots & \ddots & \vdots \\ \sigma_{\tau(om)} & \cdots & \sigma_{\tau(mm)} \end{bmatrix}. \tag{1}$$

Let w_τ be the wealth of the investor at the beginning of the τth period, and let $s_{\tau(j)}, j\in\{1, \ldots, m\}$, be the amount invested in the jth risky project at the beginning of the τth time period. The amount investigated in the 0th risky project at the beginning of the τth time period is equal to

$$w_\tau - \sum_{j=1}^{m} s_{\tau(j)}. \tag{2}$$

An investor is seeking a best multiperiod investment strategy, $\mathbf{s}_\tau=[s_{\tau(0)}, s_{\tau(1)}, \ldots, s_{\tau(m)}]'$ for $\tau = 0, 1, 2, \ldots, T-1$, such that either (i) the expected value of the terminal wealth w_T, $\mathrm{E}\{w_T\}$, is maximized if the variance of the terminal wealth, $\mathrm{Var}\{w_T\}$, is not greater than a pre-assigned risk level $v^\bullet$, or (ii) the variance of the terminal wealth, $\mathrm{Var}\{w_T\}$, is minimized if the expected terminal wealth, $\mathrm{E}\{w_T\}$, is not smaller than a pre-assigned level $e^\bullet$. Mathematically, a mean-variance formulation for multiperiod project portfolio investment can be posed as one of the following two forms:

(i) Maximize

$\mathrm{E}\{w_T\}$

subject to

$\mathrm{Var}\{w_T\}\le v^\bullet$,

$$w_{\tau+1} = \sum_{j=1}^{m} r_{\tau(j)} s_{\tau(j)} + \left(w_\tau - \sum_{j=1}^{m} s_{\tau(j)} \right) r_{\tau(0)} = r_{\tau(0)} w_\tau + \mathbf{R}'_\tau \mathbf{s}_\tau, \quad \tau=0, 1, 2, \ldots, T-1, \tag{3}$$

and

(ii) Minimize

$\mathrm{Var}\{w_T\}$

subject to

$\mathrm{E}\{w_T\}\ge e^\bullet$,

$$w_{\tau+1} = \sum_{j=1}^{m} r_{\tau(j)} s_{\tau(j)} + \left(w_\tau - \sum_{j=1}^{m} s_{\tau(j)} \right) r_{\tau(0)} = r_{\tau(0)} w_\tau + \mathbf{R}'_\tau \mathbf{s}_\tau, \quad \tau=0, 1, 2, \ldots, T-1, \tag{4}$$

where

$$\mathbf{R}_\tau = [r_{\tau(1)} - r_{\tau(0)}, r_{\tau(2)} - r_{\tau(0)}, ..., r_{\tau(m)} - r_{\tau(0)}]'. \tag{5}$$

Notice that

$$\mathrm{E}\{\mathbf{r}_\tau \mathbf{r}_\tau'\} = \mathrm{Cov}\{\mathbf{r}_\tau\} + \mathrm{E}\{\mathbf{r}_\tau\}\mathrm{E}\{\mathbf{r}_\tau'\}. \tag{6}$$

It is assumed in this paper that $\mathrm{E}\{\mathbf{r}_\tau \mathbf{r}_\tau'\}$ is positive definite for all time periods, that is, $\mathrm{E}\{\mathbf{r}_\tau \mathbf{r}_\tau'\}>0$, $\forall \tau=0(1)T-1$.

Formulation (i) or (ii) enables an investor to specify a risk level he can afford when he is seeking to maximize his expected terminal wealth or specify an expected terminal wealth he would like to achieve when he is seeking to minimize the corresponding risk.

A strategy of multiperiod project portfolio investment is an investment sequence,

$$\mathbf{S}_T=[\mathbf{s}_0, \mathbf{s}_1, \mathbf{s}_2, \ldots, \mathbf{s}_{T-1}], \tag{7}$$

where

$$\mathbf{s}_\tau=[s_{\tau(1)}, s_{\tau(2)}, \ldots, s_{\tau(m)}]', \quad \forall \tau=0(1)T-1, \tag{8}$$

More specifically, $\mathbf{S}_T$ is a feedback policy and $\mathbf{s}_\tau$ maps the wealth at the beginning of the τth period, w_τ, into a project portfolio decision in the τth period, i.e., $\mathbf{s}_\tau \equiv \mathbf{s}_\tau(w_\tau)$. A multiperiod project portfolio investment strategy, $\mathbf{S}_T^*$, is said to be efficient if there exists no other multiperiod portfolio policy, $\mathbf{S}_T$, such that $\mathrm{E}\{w_T;\mathbf{S}_T\}\geq\mathrm{E}\{w_T;\mathbf{S}_T^*\}$ and $\mathrm{Var}\{w_T;\mathbf{S}_T\}\leq\mathrm{Var}\{w_T;\mathbf{S}_T^*\}$ with at least one equality strictly. By varying the value of $v^\bullet$ in (i) or the value of $e^\bullet$ in (ii), we can generate the set of efficient multiperiod project portfolio investment strategies.

3. OPTIMAL MULTIPERIOD INVESTMENT STRATEGY

Theorem 1. The optimal strategy for multiperiod project portfolio investment for problems (i) and (ii) is specified by the following analytical expression:

$$\mathbf{s}_\tau^* = -\mathrm{E}^{-1}\{\mathbf{R}_\tau \mathbf{R}_\tau'\}\mathrm{E}\{r_{\tau(0)}\mathbf{R}_\tau\}w_\tau$$

$$+\left(\frac{gw_0+b_1(2ch)^{-1}}{2}\right)\left(\prod_{t=\tau+1}^{T-1}\frac{a_{1t}}{a_{2t}}\right)\mathrm{E}^{-1}\{\mathbf{R}_\tau \mathbf{R}_\tau'\}\mathrm{E}\{\mathbf{R}_\tau\}, \quad \tau=0(1)T-2, \tag{9}$$

$$\mathbf{s}_{T-1}^* = -\mathrm{E}^{-1}\{\mathbf{R}_{T-1} \mathbf{R}_{T-1}'\}\mathrm{E}\{r_{T-1(0)}\mathbf{R}_{T-1}\}w_{T-1}$$

$$+\left(\frac{gw_0+b_1(2ch)^{-1}}{2}\right)\mathrm{E}^{-1}\{\mathbf{R}_{T-1} \mathbf{R}_{T-1}'\}\mathrm{E}\{\mathbf{R}_{T-1}\}, \tag{10}$$

where

$$h=\begin{cases}\dfrac{b_1}{2\sqrt{c(v^\bullet-qw_0^2)}}, & \text{when (i) is solved,}\\[2ex] \dfrac{b_1^2}{2c[e^\bullet-(a_1+gb_1)w_0]}, & \text{when (ii) is solved,}\end{cases} \tag{11}$$

$$a_{1\tau} = \mathrm{E}\{r_{\tau(0)}\}-\mathrm{E}\{\mathbf{R}_\tau'\}\mathrm{E}^{-1}\{\mathbf{R}_\tau \mathbf{R}_\tau'\}\mathrm{E}\{r_{\tau(0)}\mathbf{R}_\tau\}, \tag{12}$$

$$a_{2\tau} = \mathrm{E}\{r_{\tau(0)}^2\}-\mathrm{E}\{r_{\tau(0)}\mathbf{R}_\tau'\}\mathrm{E}^{-1}\{\mathbf{R}_\tau \mathbf{R}_\tau'\}\mathrm{E}\{r_{\tau(0)}\mathbf{R}_\tau\}, \tag{13}$$

$$b_\tau = \mathrm{E}\{\mathbf{R}'_\tau\}\mathrm{E}^{-1}\{\mathbf{R}_\tau\mathbf{R}'_\tau\}\mathrm{E}\{\mathbf{R}_\tau\}, \tag{14}$$

$$b_{1\tau} = b_\tau\left(\prod_{t=\tau+1}^{T-1} a_{1t}\right)\left(2\prod_{t=\tau+1}^{T-1} a_{2t}\right)^{-1}, \tag{15}$$

with

$$\prod_{t=T}^{T-1} a_{1t} = \prod_{t=T}^{T-1} a_{2t} = 1, \tag{16}$$

$$a_1 = \prod_{\tau=0}^{T-1} a_{1\tau}, \tag{17}$$

$$a_2 = \prod_{\tau=0}^{T-1} a_{2\tau}, \tag{18}$$

$$b_1 = \sum_{\tau=0}^{T-1}\left(\prod_{t=\tau+1}^{T-1} a_{1t}\right) b_{1\tau}, \tag{19}$$

$$c = \frac{b_1}{2} - b_1^2, \tag{20}$$

$$g = \frac{a_1 b_1}{c}, \tag{21}$$

$$q = a_2 - a_1^2 - cg^2. \tag{22}$$

In this case, the expected value and the variance of the terminal wealth are given by

$$\mathrm{E}\{w_T\} = (a_1 + gb_1)w_0 + \frac{b_1^2}{2ch}, \tag{23}$$

and

$$\mathrm{Var}\{w_T\} = \frac{b_1^2}{4ch^2} + qw_0^2. \tag{24}$$

Proof. The proof is carried out by means of the method of Lagrange multipliers, optimality principle, and the method of mathematical induction. It is omitted here and will appear elsewhere. ∎

Thus, the optimal multiperiod investment strategy for project portfolio consists of two terms and exhibits a decomposition property between the investor's risk attitude and his current wealth. The second term in $\mathbf{s}_\tau^*$ is dependent on the investor's risk attitude and is independent of his current wealth. It can be calculated off-line before the real investment process starts. The first term in $\mathbf{s}_\tau^*$ is dependent on the current wealth and is independent of the investor's risk attitude. It is calculated on-line at every time period when the current wealth is observed.

4. NUMERICAL EXAMPLE

Consider the case of a stationary multiperiod process with $T = 4$. An investor has one unit of wealth at the very beginning of the planning horizon, i.e., $w_0 = 1$ The investor is trying to find the best allocation of his wealth among three risky projects, 0, 1, and 2 in order to maximize $\mathrm{E}\{w_4\}$ while keeping his risk not exceeding 1; that is, $v^{\bullet} = 1$. The expected returns for risky projects, 0, 1, and 2 are $\mathrm{E}\{r_{\tau(0)}\}$=1.189, $\mathrm{E}\{r_{\tau(1)}\}$=1.314, and $\mathrm{E}\{r_{\tau(2)}\}$=1.335, τ = 0, 1, 2, 3. The covariance of $\mathbf{r}_\tau=[r_{\tau(0)}, r_{\tau(1)}, r_{\tau(2)}]'$ is

$$\mathrm{Cov}\{\mathbf{r}_\tau\} = \begin{bmatrix} 0.0099 & 0.0114 & 0.0120 \\ 0.0114 & 0.0535 & 0.0508 \\ 0.0120 & 0.0508 & 0.0864 \end{bmatrix}, \ \tau = 0, 1, 2, 3. \tag{25}$$

Thus,

$$\mathrm{E}\{\mathbf{R}_\tau\} = \mathrm{E}\{[r_{\tau(1)} - r_{\tau(0)}, r_{\tau(2)} - r_{\tau(0)}]'\} = [0.125, 0.146]', \tag{26}$$

$$\mathrm{E}\{\mathbf{R}_\tau \mathbf{R}_\tau'\} = \mathrm{E}\left\{\begin{bmatrix} r_{\tau(0)}^2 - 2r_{\tau(0)}r_{\tau(1)} + r_{\tau(1)}^2 & r_{\tau(0)}^2 - r_{\tau(0)}r_{\tau(1)} - r_{\tau(0)}r_{\tau(2)} + r_{\tau(1)}r_{\tau(2)} \\ r_{\tau(0)}^2 - r_{\tau(0)}r_{\tau(1)} - r_{\tau(0)}r_{\tau(2)} + r_{\tau(1)}r_{\tau(2)} & r_{\tau(0)}^2 - 2r_{\tau(0)}r_{\tau(2)} + r_{\tau(2)}^2 \end{bmatrix}\right\}$$

$$= \begin{bmatrix} 0.056225 & 0.05555 \\ 0.05555 & 0.093616 \end{bmatrix}, \tag{27}$$

$$\mathrm{E}\{r_{\tau(0)}\mathbf{R}_\tau'\} = [\mathrm{E}\{r_{\tau(0)}r_{\tau(1)}\} - \mathrm{E}\{r_{\tau(0)}^2\}, \mathrm{E}\{r_{\tau(0)}r_{\tau(2)}\} - \mathrm{E}\{r_{\tau(0)}^2\}] = [0.150125, 0.175694], \ \tau = 0,1,2,3. \tag{28}$$

Furthermore, we have

$$b_\tau = 0.290972, \tag{29}$$

$$a_{1\tau} = 0.839340049, \tag{30}$$

$$a_{2\tau} = 1.003433478, \quad \tau = 0, 1, 2, 3, \tag{31}$$

$$a_1 = 0.496308579, \tag{32}$$

$$a_2 = 1.013804806, \tag{33}$$

$$b_1 = 0.36969, \tag{34}$$

$$c = 0.048174261, \tag{35}$$

$$g = 3.808681367, \tag{36}$$

and

$$q = 0.068664187. \tag{37}$$

From (11), the corresponding

$$h = 0.87266436. \tag{38}$$

The associated optimal strategy for multiperiod project portfolio investment is given, using equations (9) and (10), as follows:

$$\mathbf{s}_0^* = -\begin{bmatrix} 1.97189131 \\ 0.706668067 \end{bmatrix} w_0 + \begin{bmatrix} 3.960204 \\ 1.394898 \end{bmatrix}, \tag{39}$$

$$\mathbf{s}_1^* = -\begin{bmatrix} 1.97189131 \\ 0.706668067 \end{bmatrix} w_1 + \begin{bmatrix} 4.734435 \\ 1.667604 \end{bmatrix}, \tag{40}$$

$$\mathbf{s}_2^* = -\begin{bmatrix} 1.97189131 \\ 0.706668067 \end{bmatrix} w_2 + \begin{bmatrix} 5.660031 \\ 1.993626 \end{bmatrix}, \tag{41}$$

$$\mathbf{s}_3^* = -\begin{bmatrix} 1.97189131 \\ 0.706668067 \end{bmatrix} w_3 + \begin{bmatrix} 6.766584 \\ 2.383385 \end{bmatrix}. \tag{42}$$

The investment in the 0th project at period τ is equal to

$$s_{\tau(0)} = w_\tau - \sum_{j=1}^{m} s_{\tau(j)}, \quad \forall \tau = 0(1)3. \tag{43}$$

Since it is known that w_0=1, we obtain from (39) a percent investment (on w_0) in three risky projects, 0, 1, and 2, at period τ=0 as follows: $s_{0(0)}$ = 97.323%, $s_{0(1)}$ = 1.988%, $s_{0(2)}$ = 0.689%.

The corresponding expected terminal wealth and the risk level are given by $E\{x_4\}$ = 3.529827827 and $Var\{x_4\}$ = 1, respectively, using equations (23) and (24).

5. CONCLUSION

The Markowitz mean-variance approach has been extended in this paper to multiperiod project portfolio investment problems. The derived analytical optimal multiperiod project portfolio investment strategy provides investors with the best strategy to follow in a dynamic investment environment.

References

[1] Markowitz H.M. *Portfolio Selection: Efficient Diversification of Investment*. New York: John Wiley & Sons, 1959.

[2] Markowitz H.M. *Mean-Variance Analysis in Portfolio Choice and Capital Markets.*Cambridge, MA: Basil Blackwell, 1989.

[3] Smith K.V. A Transition Model for Portfolio Revision, *Journal of Finance*, 22, 1967, pp.425-439.

[4] Mossin J. Optimal Multiperiod Portfolio Policies, *Journal of Business*, 41, 1968, pp.215-229.

[5] Merton R.C. *Continuous-Time Finance.* Cambridge, MA: Basil Blackwell, 1990.

[6] Samuelson P.A. Lifetime Portfolio Selection by Dynamic Stochastic Programming, *The Review of Economics and Statistics*, 50, 1969, pp.239-246.

[7] Fama E.F. Multiperiod Consumption-Investment Decisions, *American Economic Review*, 60, 1970, pp.163-174.

[8] Hakansson N.H. Multi-Period Mean-Variance Analysis: Toward a General Theory of Portfolio Choice, *Journal of Finance*, 26, 1971, pp.857-884.

[9] Elton E.J. and Gruber M. J. *Finance as a Dynamic Process.* Englewood Cliffs, NJ: Prentice Hall, 1975.

[10] Winkler R.L. and Barry C. B. A Bayesian Model for Portfolio Selection and Revision, *Journal of Finance*, 30, 1975, pp.179-192.

[11] Francis J.C. *Investments: Analysis and Management.* New York: McGraw-Hill, 1976.

[12] Dumas B. and Luciano E. An Exact Solution to a Dynamic Portfolio Choice Problem under Transaction Costs, *Journal of Finance*, XLVI, 1991, pp.577-595.

[13] Grauer R.R. and Hakansson N. H. On the Use of Mean-Variance and Quadratic Approximations in Implementing Dynamic Investment Strategies: a Comparison of Returns and Investment Policies, *Management Science*, 39, 1993, pp.856-871.

[14] Pliska S.R. *Introduction to Mathematical Finance.* Malden, MA: Basil Blackwell, 1997.

NEW INFORMATION CRITERION AND IT'S APPLICATIONS TO MULTIPLE REGRESSION

Jury Krasts, Nicholas A. Nechval, Kristine Rozite, Natalie Zolova

Informatics Department, University of Latvia
Raina Blvd. 19, LV-1050, Riga, Latvia
E-mail: nechval@junik.lv

In this paper, we propose a new information criterion for variable selection in the classical regression model based on F statistic with an added penalty term for penalizing over fitting (or informational complexity). The penalty function denoted by ϑ depends on the number of independently adjusted parameters and the sample size n. It is chosen to ensure the consistency in the selection of true model.

Keywords: *multiple regression, variable selection, change detection, new approach*

1. INTRODUCTION

In recent years, the statistical literature has placed more and more emphasis on model selection criteria. The problem is to choose the best approximating model among a class of competing models by a suitable model selection criterion given a finite data set. That model which optimises the criterion is chosen to be the best model. In many situations where regression analysis is useful, the investigator has strong justification for including certain variables in the equation. The justification may be to produce results comparable to previous studies or to conform to accepted theory. But often the investigator has no preconceived assessment of the importance of some or all of the independent variables. It is in the latter situation that variable selection procedures can be useful. Any variable selection procedure requires a criterion for deciding how many and which variables to select.

In many areas of scientific endeavour, scientists are often faced with the problem of inference for the point in a sequence of time-series data at which regression relationships change. This problem is a special case of a general class of problems concerned with the detection of changes of model structure over time.

In the present paper we consider two-phase or switching multiple regression models which have many applications. For example, in econometrics a variable such as gross domestic product is assumed to have a normal distribution whose mean is a linear function of several explanatory variables, such as labour input and capital input, and it is suspected that the model parameters have changed after an unknown time. Brown, Durbin, and Evans [1] give three examples involving the growth in the number of local telephone calls, the demand for money, and staff requirements of an organization. In economics the problem is met with frequently. A regression model for a market may show a structural shift, for example, when the demand exceeds supply. This point may, of course, have economic significance. Teräsvirta [2] studied the price elasticity in the demand of post and telephone services in Finland from this point of view. His main aim was to detect over what period the regression structure describing the market had been stable, to get as firm a basis for predictions as possible. This is not an unusual problem in economic control and prediction situations. A common feature of the situations we have in mind is that there exists a natural ordering of the data points, either by time, size, age, or some other variable.

The problem was first studied by Quandt [3], who proposed a maximum likelihood method for estimating the parameters in two separate regression lines that switch at an unknown point τ. The first τ observations in a sample size T follow one regression model, and the last T-τ observations follow another. A likelihood ratio test was proposed by Quandt [4] to test for two separate regression lines as opposed to the null hypothesis that the data follow only one. Except in some special cases, the exact null distribution of the likelihood ratio statistic remains intractable. It depends on the values of the independent variables, and, as Hawkins [5] points out, no limiting distribution is known. Beckman and Cook [6] give some Monte Carlo results for a single independent variable.

The purpose of this paper is to suggest a new technique for solving the above problems. To illustrate the proposed technique, numerical examples are given.

2. PRELIMINARIES

Consider the general linear regression model

$$y = Xb + \varepsilon, \tag{1}$$

where y is an $n \times 1$ vector of observable random variables, X is an $n \times (p+1)$ matrix of full rank with first column unities, b is a $(p+1) \times 1$ vector of regression coefficient, and ε is an $n \times 1$ vector of normal random variables, with $\varepsilon \sim N(0,\sigma^2 I)$. For the moment we assume that the elements of X are fixed constants. Let X and b be conformably partitioned so that

$$y = X_1 b_1 + X_2 b_2 + \varepsilon, \tag{2}$$

where X_1 is $n \times (p_1 + 1)$. It is well known that the likelihood ratio test for $b_2 = 0$ is based on the statistic

$$F = \frac{\mathbf{y}'(\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}' - \mathbf{X}_1(\mathbf{X}_1'\mathbf{X}_1)^{=1}\mathbf{X}_1')\mathbf{y}/(p-p_1)}{\mathbf{y}'(\mathbf{I} - \mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}')\mathbf{y}/(n-p-1)} = \frac{n-p-1}{p-p_1}\frac{R_{\mathbf{X}}^2 - R_{\mathbf{X}_1}^2}{1-R_{\mathbf{X}}^2}, \tag{3}$$

where $R_{\mathbf{X}_1}^2$ is the squared sample multiple correlation of y with the set of predictors in X_1, and correspondingly for $R_{\mathbf{X}}^2$. Then F has a no central $F'_{p-p_1,n-p-1}(\lambda_2)$ distribution, where

$$\lambda_2 = \mathbf{b}_2'(\mathbf{X}_2'\mathbf{X}_2 - \mathbf{X}_2'\mathbf{X}_1(\mathbf{X}_1'\mathbf{X}_1)^{=1}\mathbf{X}_1'\mathbf{X}_2)\mathbf{b}_2/\sigma^2, \tag{4}$$

provided that the partition of X is specified. In this case the null hypothesis $b_2 = 0$ may be tested at level α by rejecting if $F > F_{p-p_1,n-p-1;\alpha}$, the upper 100α% point of the central $F_{p-p_1,n-p-1}$ distribution. The subset of predictor variables corresponding to X_1 will be called an R^2-adequate (α) set if

$$F \le F_{p-p_1,n-p-1;\alpha}. \tag{5}$$

Here "adequate" is used in a restricted sense, meaning "providing an R^2 which is not significantly less than the R^2 from the complete set of predictor variables".

3. INFORMATION CRITERION

Now a new informative criterion (NIC) for selecting the best R^2-adequate (α) set of predictor variables is given by

$$\mathrm{NIC} = \frac{n-p-1}{p-p_1}\frac{R_{\mathbf{X}}^2 - R_{\mathbf{X}_1}^2}{1-R_{\mathbf{X}}^2} - F_{p-p_1,n-p-1;\alpha} + \vartheta(p_1,n), \tag{6}$$

where $\vartheta(p_1,n)$ is a penalty term for penalizing over fitting (or informational complexity). It may be taken from penalized information criteria (for model comparison) such as, say, the Akaike information criterion (AIC) or the Schwarz information criterion (SIC). Then the best R^2-adequate (α) set of predictor variables is one, which minimizes NIC. For instance, consider the case when $\vartheta(p_1,n)$ is based on AIC. In this case,

$$\mathrm{NIC} = \frac{n-p-1}{p-p_1}\frac{R^2_{\mathbf{X}} - R^2_{\mathbf{X}_1}}{1-R^2_{\mathbf{X}}} - F_{p-p_1,n-p-1;\alpha} + 2(p_1+1). \quad (7)$$

That model which optimises this criterion is chosen to be the best model.

4. Example of NIC Application to Variable Selection in Multiple Regression

Consider the well-known Hald data discussed by Draper and Smith [7]. The response variable y is the heat evolved in the hardening of a cement mixture, and the predictors x_1, …, x_4 are the percentage constituents of various chemicals in the cement mix. For these data, n = 13, p = 4, $R^2_{\mathbf{X}} = 0.982376$. The $R^2_{\mathbf{X}_1}$ values for all subsets of variables are listed below:

Subset (X_1)	(1)	(2)	(3)	(4)	$(12)^*$	(13)	$(14)^*$
$R^2_{\mathbf{X}_1}$	0.533948	0.666268	0.285873	0.674542	0.978678	0.548167	0.972471
Subset (X_1)	(23)	(24)	(34)	$(123)^*$	$(124)^*$	$(134)^*$	$(234)^*$
$R^2_{\mathbf{X}_1}$	0.847025	0.68006	0.93529	0.982285	0.982335	0.981281	0.97282

If we take α=0.05, the R^2-adequate (α) sets of predictor variables are indicated by asterisks with $\mathrm{NIC}_{(12)^*}$ =2.37931; $\mathrm{NIC}_{(14)^*}$ =3.788071; $\mathrm{NIC}_{(123)^*}$ =2.721307; $\mathrm{NIC}_{(124)^*}$ =2.698611; $\mathrm{NIC}_{(134)^*}$ =3.177049; $\mathrm{NIC}_{(234)^*}$ =7.017721. Thus, the best R^2-adequate (α) set is $(12)^*$.

5. EXAMPLE OF NIC APPLICATION TO CHANGE DETECTION IN MULTIPLE REGRESSION

To illustrate the suggested technique, consider the following table of data taken from Beckman and Cook [6].

Table 1. Yield of hydrogen sulphide from gamma radiolysis as a function of krypton pressure

Krypton Pressure (x_t)	1.00	1.50	1.75	2.10	2.35	2.65	3.00
Yield (y_t)	6.4	7.0	7.4	8.8	9.0	6.4	6.6

It is necessary to test the null hypothesis

$$H_0: y_t = a_1(0) + a_2(0)x_t + w_t, \quad t = 1(1)7, \quad (8)$$

against the alternative

$$H_1: y_t = a_1(0) + a_2(0)x_t + w_t, \quad t = 1(1)\tau;$$

$$y_t = a_1(1) + a_2(1)x_t + w_t, \quad t = \tau + 1(1)7, \quad (9)$$

where w_t, t = 1(1)7, is a sequence of independent random variables each is assumed to be $N(0,\sigma^2)$. The parameters $a_1(0)$, $a_2(0)$, $a_1(1)$, $a_2(1)$, σ^2 and k, the point after which the change occurs, are unknown. In order to detect a possible change in the regression coefficients, we use the technique proposed above. The above null hypothesis is rejected when $\hat{\tau} = 5$. This result is the same as in Beckman and Cook [6], but no simulation method for determining the critical values for testing for a two-phase regression is used.

6. CONCLUSIONS

It has been shown that the technique proposed in this paper provides a sufficient way to make inferences about the change-point of the linear model and variables in the classical regression model.

Many other problems can be studied. For example, one could consider the problem of more than one change, or the detection of outliers, or prediction of future observations of a changing linear model.

References

[1] Brown R.L., Durbin J., and Evans J.M. Techniques for Testing the Constancy of Regression Relationships over Time, *Journal of the Royal Statistical Society*, 37, 1975, pp.149-192 (with discussion).

[2] Teräsvirta T. *On Stepwise Regression and Economic Forecasting*: Economic Studies XXXI. Helsinki: The Finnish Economic Association, 1970.

[3] Quandt R.E. The Estimation of the Parameters of a Linear Regression System, Obeying Two Separate Regimes, *Journal of the American Statistical Association*, 53, 1958, pp.873-880.

[4] Quandt R.E. Test of the Hypothesis that a Linear Regression Obeys Two Separate Regimes, *Journal of the American Statistical Association*, 55, 1960, pp.324-330.

[5] Hawkins D.M. A Note on Continuous and Discontinuous Segmented Regressions, *Technometrics*, 22, 1980, pp.443-444.

[6] Beckman R.J., Cook R.D. Testing for Two-phase Regressions, *Technometrics*, 21, 1979, pp.65-69.

[7] Draper N.R., Smith H. *Applied Regression Analysis*. New York: Wiley, 1966.

RESEARCH OF A STATISTICAL PROCESS CONTROL IN SOFTWARE ENGINEERING PROJECT

Jurijs Senbergs[1], Boriss Misnevs[2]

Transport and Telecommunication Institute
Lomonosov Str.1, Riga, LV-1019, Latvia
Ph: (+371)-7100650. Fax: (+371)-7100660
[1] E-mail: jurijs.senbergs@apollo.lv
[2] E-mail: bfm@tsi.lv

This paper presents some results of the "Research of a Statistical Process Control in Software Engineering Project", which was performed in Transport and Telecommunication Institute.The purpose of the research was evaluation of stability of Software Engineering processes of the Organization.

Keywords: *software measurement, process management and improvement, statistical control*

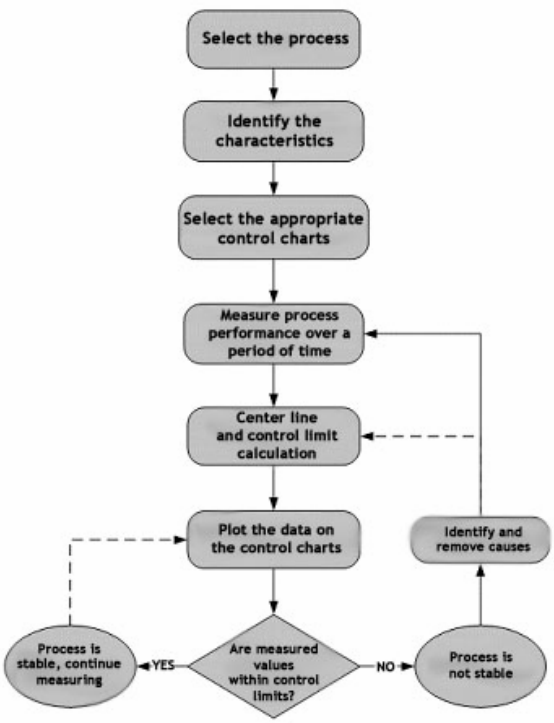
The research was based on the information of an IT related division of a large state company. The subject of the research was internal software product development project started in 1997 and based on DBMS Oracle platform. Data model has a very complex structure and is continuously modified. The objects of research were software engineering process maturity characteristics. The main problem was that the organization was not informed about real software engineering process attributes, which may be used for problem solving. Before the research actuality was started a lot of findings over Internet related to the research topic were investigated. For example, more than 120 conference reports on "Software Measurement" were reviewed. We used the following two main definitions of base process characteristics – stable process and capable process. Stable process — the underlying distributions of its measurable characteristics are consistent over time, and the results are predictable within determined limits. Capable process – it is stable, meeting specifications process. There were the following four research tasks:

1) Developed process stability hypotheses proof / declining;
2) Out-of-control situation detection, cause understanding and prevention;
3) Control limits definition for further process stability investigation;
4) Process capability definition.

Research process was separated into three sub activities. They are as follows: Collect and retain data, Analyze data and Act on results. Data from two last years containing 422 defect reports, 108 change requests with related process information were collected for the analyses. As an analyses tool the Control chart was utilized. During this phase control limits and out-of-control situations were detected. The last phase was related to the process capability definition. Every detected out-of-control situation was checked regarding possible out-of-control situation to refrain from repetition.

Six processes with two main characteristics (number and time) were selected for the stability research. The research was using variable data from continues measurements; the appropriate X-band and R control charts were selected. The Shewhart or 3 sigma deviation control limits were used for limit control management. The centre line and control limits were calculated and placed into charts. Values were grouped into sub groups. For the first three processes weeks, and one group – by months, grouped the data. For all other processes the sub group is a quarter. After that

populated values were compared with calculated limit values. If a populated value is placed upper or lower of the centreline, but within control limits, this means that the process was stable during the period of measurements. If any measuring value is out of the limit it means that the process is not stable. In this case we have to assess the cause of the deviation and fix it to prevent the case repetition. (If the fix is successful we have to introduce this improvement into the process as an integral part of it).



The procedure for X-bar and R chart limit calculation is the following:

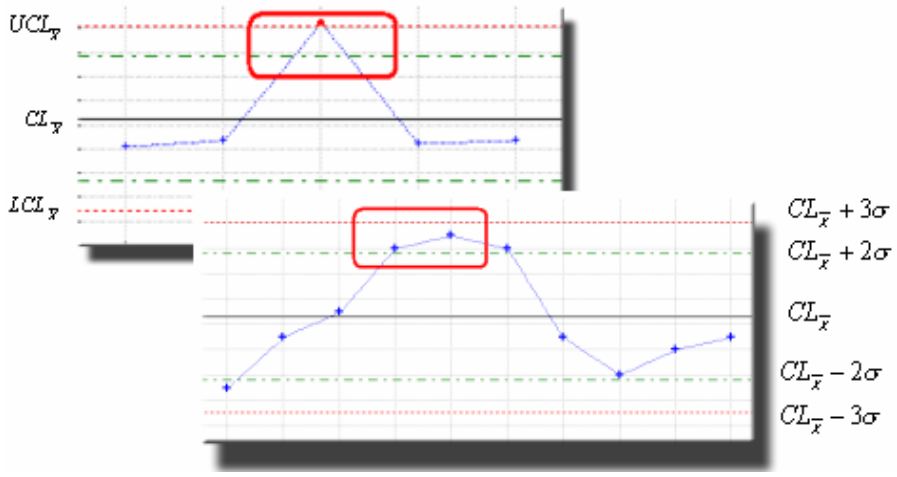
1. Calculate average value $\overline{X}$ and variation *R* for each k sub group;
2. Calculate common average value $\overline{\overline{X}}$, calculating average value $\overline{X}$ from k sub group average value;
3. Calculate common average value $\overline{\overline{X}}$, calculating average value $\overline{X}$ from k sub group average value;
4. Calculate deviation average value $\overline{R}$, calculating each k sub groups deviation *R;*
5. Centre line for the chart is $\overline{\overline{X}}$, centre line for the R chart is $\overline{R}$. Select from the table values of A_2, D_3 and D_4, which are in accordance with the sub group size n;
6. Multiply A_2 to $\overline{R}$ receiving $A_2\overline{R}$. Add common average $\overline{\overline{X}}$ value to $A_2\overline{R}$ to get the upper control limit – UCLx;
7. Subtract from common average $\overline{\overline{X}}$ value $A_2\overline{R}$ to get the lower control limit LCLx;
8. Multiply D_4 and $\overline{R}$ to get the upper control limit to R chart. Multiply D_3 and $\overline{R}$ to get the lower control limit to R chart.

n	A_2	D_3	D_4
2	1.880	—	3.268
3	1.023	—	2.574
4	0.729	—	2.282
5	0.577	—	2.114
6	0.483	—	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

Constants for Computing Control Limits for X-Bar and R Charts from [1]

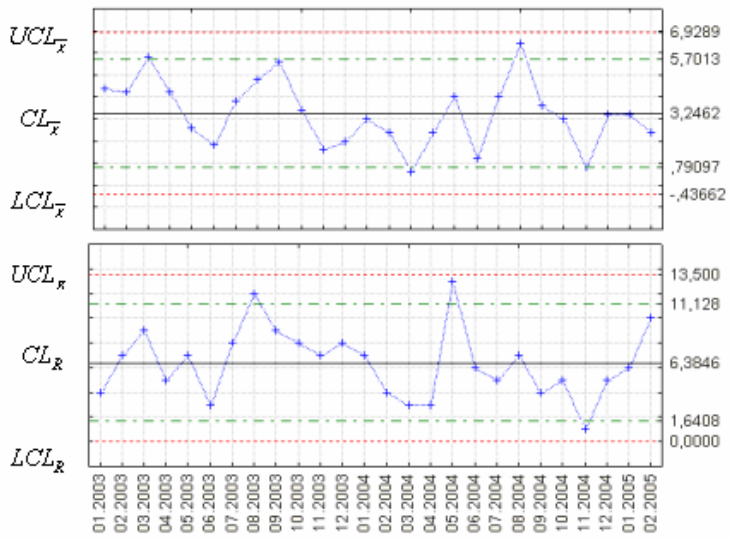
Two of four General Electric described tests were used for the purpose of unstable and out-of-control situations assessing. They were the most effective from the author's point of view. They are the following:

1. One point is out of 3 sigma limits;
2. At least two points from three consecutive points deviate to one and the same side for more that 2-sigma distance from the centreline.

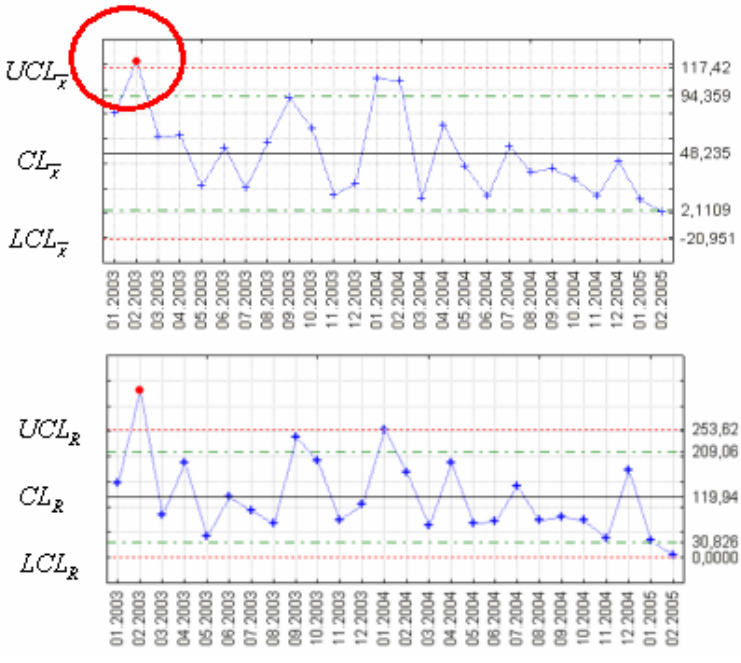


The following processes were selected for the stability research as processes directly connected to the customer and the developer: Defect reports management process: Critical defects detection, Critical defects fixing, Change requests management process: Change request application, Change approval, Change request closing, and Change request implementation.

First example is critical defects detection process. The process was assessed using the approach described earlier. The question was "Is the Process stabile or not?" As the main process characteristic was used number of defects. Analyzed data covers 2003 and 2004 years critical defect management process. Data was grouped on the weekly base. Control chart represents one group as one point per months. Control chart limits were detected using the same approach as was discussed earlier. Out-of-control cases were not discovered. There are no 2 sequential points deviating 2-sigma from the centreline. This means that the critical defect management process is stable and is in accordance with process quality requirements. From the chart we may find that we have 3.2 defects per week as an average value. All R charts are in control limits.



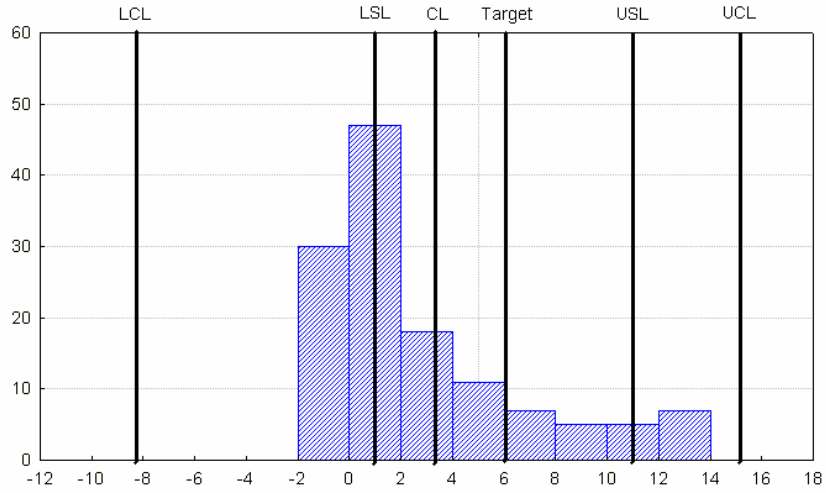
Second example is critical defects fixing process (time for fixing). The process stability assessment using the discussed approach was performed and characteristics defined. The question is "May we consider the process as stable?" The defect fixing statistics for 2003 and 2004 years were used as the data for the analysis. Data were divided into weekly sub groups. But



in control charts one point is one month. Control limit charts were created using the method mentioned earlier. Because one point is out of control limit the process was assessed as out of control.

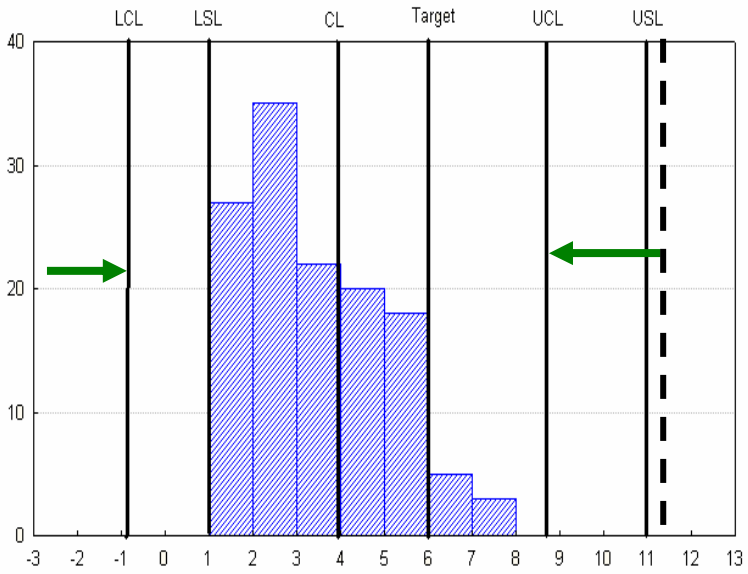
Because of X-bar chart standard deviation $sigma_{\overline{X}}$ is as standard deviation from individual values it is divided to $\sqrt{n}$, where n is sub group size (measurements number). That upper control limit for capability histogram UCLx is equal to $\overline{\overline{X}} + 3sigma_X$. And lower control limit for capability histogram LCLx is equal to $\overline{\overline{X}} - 3sigma_X$. To confirm the process stability need also to put capability histogram into specification limit. Relation between capability histogram and specification limits reflects the process capability. Optimal value or target is calculated as average from upper (USL) and lower (LSL) specification limits $LSL + \frac{USL - LSL}{2}$. Specification tolerance is equal to $\frac{USL - LSL}{sigma_X}$. Distance to the nearest specification is equal to $\frac{USL - \overline{\overline{X}}}{sigma_X}$.

It is clear from capability histogram that the process values distribution is approximately within control limits. Lower specification level (LSL) is equal to 1 and upper specification level (USL) is equal to 11. The distribution must be symmetric and the target (or optimal value) is equal to 6. Then the specification tolerance is equal to 10 fixed defects per week and a specification tolerance sigma item is equal to 2.79. The distance to the nearest specification is equal to 2.11. From the received results we can see that the specification tolerance sigma item critical defects detection process is equal to 2.79 and does not exceeds six sigma items. This means that only 47% of all values are within the specification limits, but the process is stabile. This also means that the process is stabile, but is not enough capable and repeatable out-of-range values often exceed the specification limits. To do the process more capable it is possible to perform the following activities: prevent the process variability, change the process average or decrease the specification requirements.



Capability histogram for the process of critical defects detection

For example, if for the critical defect fixing process deviation is decreased for the level ~3 than upper control limit constricts to ~9. In this case control limit is placed into specification limit and the process capability is increased to 7. This means that the process is in accordance to the specification. In this case distance from upper control limit to lower control limit is the field of refinement. Values, which are outside of the control limits, are the process defects, which can be removed and, if this is done before they overcome upper specification limit, means that client will never see them. In other words the process will be stabilized timely and specification requirements will be always implemented.

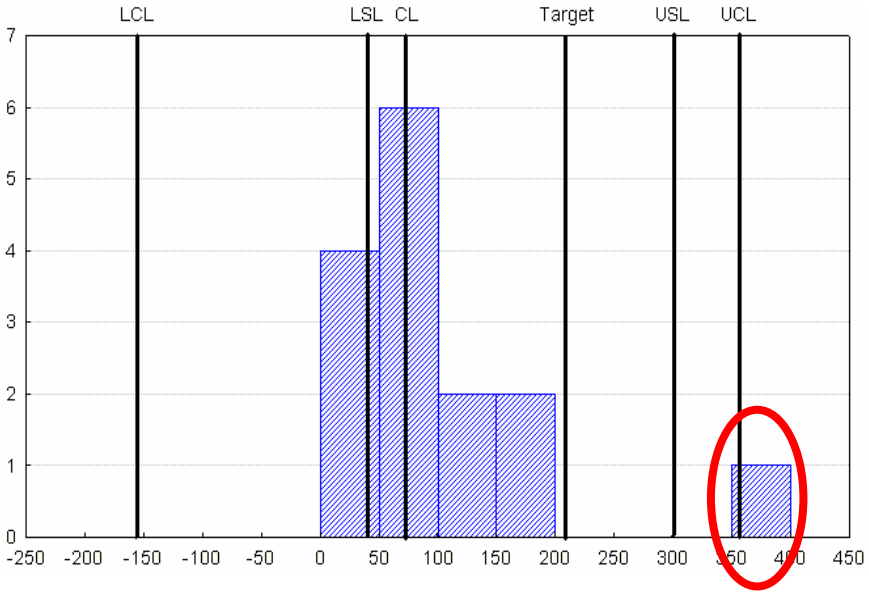


Capability histogram for the defect correction process after its refinement

Although it is possible to refine the process further. From the capability histogram we can state that the process is not centred enough. This means that the DNS index is not high. Through the moving average value to the specification average value will guarantee good DNS index. For example, if critical defects fixing process average value is near to specification average value from 4 to 5 (distance will be reduced from 2 to 1; DNS will be increased from 4.2 to 4.5. Both DNS will overcome 3 sigma items, but the process becomes more centred).

During the research it was concluded that for further analyses we need to investigate individual values, or XmR charts. Because the X-bar charts using average values do not always reflect all out-of-control situations.

For example, for the change request implementation process in X-bar charts populated values were within the control limits, but in the process capability assessment histograms it seems that separate values are out of the upper control limit.



Capability histogram for change request implementation process

During the research the following statements were proved:

1) Two from the six investigated processes are stable and may be used for the future situation forecasting;

2) For four processes out-of-control values are detected, causes are detected un control limits are recalculated;
3) Out-of-control situation in the first process affects other process and causes out-of-control situation for the second process;
4) Defined control limits may me used for further process stability investigation;
5) The Organization Process capability is defined;
6) More deep process analyses may be done only investigating individual values of the process characteristics (e.g. using XmR charts).

References

[1] Florac W., Park R., Carleton A. Practical Software Measurement: Measuring for Process Management and Improvement, *CMU/SEI-97-HB-003*, April 1997, 246 p.
[2] David N. Card "Sorting out Six Sigma and the CMM", *IEEE Software JNL*, May 2000, pp. 11-13.
[3] Caivano D. Continuous Software Process Improvement through Statistical Process Control. In: *Ninth European Conference on Software Maintenance and Reengineering (CSMR'05)*, March 2005, pp. 288-293.
[4] Eickelmann N., Anant A. Statistical Process Control: What You Don't Measure Can Hurt You! *IEEE Software JNL*, March 2003, pp. 49-51.
[5] Florac W., Carleton A, Barnard J. Statistical Process Control: Analyzing a Space Shuttle Onboard Software Process, *IEEE Software JNL*, July 2000, pp. 97-106.
[6] Misnevs B., Daineko D. Developing a New Testing Model, *Transport and Telecommunication,* Vol.3, No 1, 2002, pp. 26-33.

THE INFLUENCE OF FOREIGN DIRECT INVESTMENT ON DOMESTIC INVESTMENT PROCESSES IN LATVIA

Deniss Titarenko

Transport and Telecommunication Institute
Lomonosov Str. 1, Riga, LV-1019, Latvia
Ph: (+371)-7100573. E-mail: den_titar@tsi.lv

The primary aim of the paper is to estimate the extent of FDI influence on domestic investment processes in Latvia. Author analyses the theoretical issues of FDI effect on capital formation process in the host economy. The results of econometric analysis of the total investment model presented in this paper show the evidence of crowding out long-term effect of FDI on investment in Latvia.

Keywords: *foreign direct investment, econometric analysis of the total investment model, crowding in/out effect*

1. INTRODUCTION

Recent theoretical and empirical studies show that foreign investments as a part of international capital movement play a crucial role in sustainable development of host economies. Nowadays-free capital flows across national borders allow capital to seek out the highest rate of return. International flows of capital reduce the risk faced by owners of capital by allowing them to diversify their lending and investment.

In economic literature, international investments usually are identified as long-term international movements, which are divided into portfolio and direct investment.

International investment in the form of portfolio investment is the purchase of a stock or bond issued in a foreign currency. Portfolio investment includes investment whose primary purpose is to get future income, but not to acquire control in a firm. The economic literature stresses that this is the essential distinction between portfolio and direct investment. [5; 303] Capital flows are typically designated as foreign *direct* investment (FDI) when a foreigner owns 25% or more of a firm (in the US – 10% or more), regardless of weather the capital flows are used to purchase new plant and equipment or to buy an ownership position in an existing firm. [9; 462]

FDI may take a number of different forms including:

- the establishment of a new enterprise in an other country – either as a branch or as a subsidiary;
- the expansion of an existing overseas branch or subsidiary;
- the acquisition of an overseas business enterprise or its assets. [2; 110]

The significant role in the supply of foreign capital plays multinational enterprises (MNEs). MNEs as the firms with significant FDI assets are characterized by their ability to derive and transfer capital resources worldwide and to operate facilities of production and penetrate markets in more than one country, usually on a global scale. Significant part of the MNEs assets deployed into the host economies is intangible assets. They include technology, management skills, channels for marketing products internationally, product design, quality characteristics, brand names, etc. The gains to host countries from FDI can take several forms.

First of all FDI provides capital inflows that finance current account deficit and compensate for insufficient capital formation of the local firms. Furthermore FDI allows the transfer of technology – particularly in the form of new varieties of capital inputs – that cannot be achieved through financial investments or trade in goods and services. FDI can also promote competition in the domestic input market, to improvement of knowledge and managerial skills and to other important inputs for the entrepreneurial capacity expansion. Recipients of FDI often gain employee training in the course of operating the new businesses, which contributes to human capital development in the host country. Also profits generated by FDI contribute to corporate tax revenues in the host country. Thus FDI

improve the international competitiveness of the local firms and the overall economic performance and stimulate host economy integration into international markets, distribution and production networks.

In evaluating the impact of FDI on development, however, a key question is whether MNEs crowd in domestic investments (as, for example, when their presence stimulates new downstream or upstream investments that would not have taken place in their absence), or whether they have the opposite effect of displacing domestic producers or pre-empting their investment opportunities.

A comprehensive study by Bosworth and Collins (1999) provides evidence on the effect of capital inflows on domestic investment for 58 developing countries during 1978-95[1]. The authors distinguish among three types of capital inflows: FDI, portfolio investment, and other financial flows (primarily bank loans).

Bosworth and Collins find that an increase of a dollar in capital inflows is associated with an increase in domestic investment of about 50 cents. (Both capital inflows and domestic investment are expressed as percentages of GDP.) The results of this analysis also show the significant differences among types of inflow. FDI appears to bring about a one-for-one increase in domestic investment; there is virtually no discernible relationship between portfolio inflows and investment (little or no impact); and the impact of loans falls between those of the other two. These results hold both for the 58-country sample and for a subset of 18 emerging markets. (See the Chart 1.) [5]

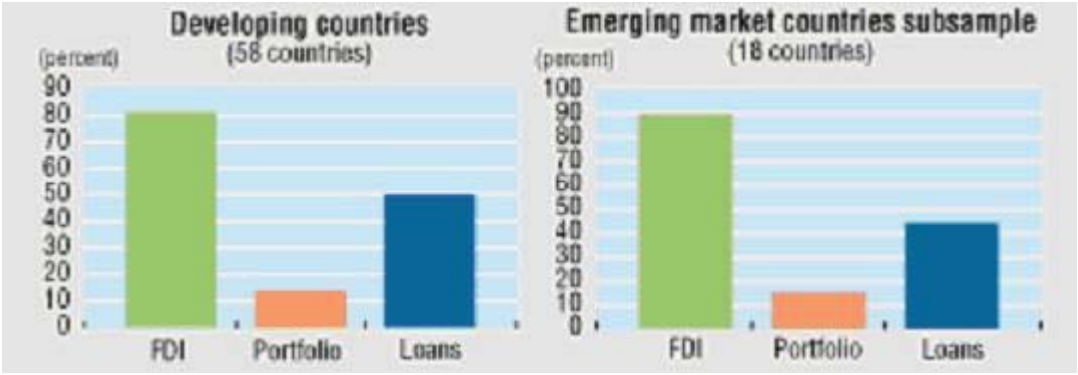


Chart 1. *The Influence of Different Types of Capital Inflows on Domestic Investment [5]*

In consideration of such significance of FDI (as shown above) the estimation of FDI influence on domestic investment processes is a rather important issue. In recent theoretical and empirical work, investment has been identified as a key variable determining economic growth. Thus, if FDI crowds out domestic investment or fails to contribute to capital formation, there would be good reasons to question its benefits for the development of recipient economies. This paper addresses the question of whether FDI causes crowding in (CI) or crowding out (CO) of domestic investment in Latvia.

2. THE THEORETICAL ISSUES OF FDI INFLUENCE ON DOMESTIC INVESTMENT

FDI contributes directly to overall investment, because it is part of it. We can present the total gross investment (I) in the simple form as real domestic investment (I_d) plus real foreign investments (I_f):

$$I \equiv I_d + I_f . \qquad (1)\ [1]$$

Foreign investments I_f can be thought of as being a function of FDI.

A very important question as regards the development influence of FDI is the extent to which it affects investment by domestic firms (I_d). If it has no effect whatsoever, any increase in FDI ought to

[1] The sample covers nearly all countries of Latin America and Asia and many countries in Africa.

be reflected in a lat-for-lat increase in total investment. If FDI *crowds out* (CO effect) investment by domestic firms, the increase in *I* ought to be *smaller* than the increase in FDI. Finally, if there is *crowding in* (CI effect), *I* ought to increase by *more* than the increase in FDI.

The effects of FDI on investment of course may vary from country to country, depending on domestic policy, the kinds of FDI that a country receives, and the strength of domestic enterprises. It is possible, however, to specify conditions for CI or CO effect.

The foreign investments, which introduce goods, and services that are new to the domestic economy are more likely to have favourable effects on capital formation than foreign investments in areas where there already exist domestic producers. In the former case, the effects on capital formation will be positive because domestic producers do not have the knowledge required to undertake these activities and, therefore, foreign investors do not displace domestic investors.

If FDI enters the economy in sectors where there are competing domestic firms, foreign investment may take away investment opportunities that were open to domestic entrepreneurs prior to the foreign investments. The contribution to total capital formation of such FDI is likely to be less than the FDI flow itself.

This leads to a conclusion that the sectoral distribution of FDI can be significant factor that determines the influence of FDI on capital formation process. When the sectoral distribution of FDI is substantially different from the distribution of the existing capital stock or of production, the contribution of FDI to capital formation will be more positive than when the distribution of FDI follows roughly the existing sectoral distribution of the capital stock. In other words, the relationship between FDI and domestic investment is likely to be complementary when investment is in an undeveloped sector of the economy (owing to technological factors or to the lack of knowledge of foreign markets). In developing countries the attempts of domestic entrepreneurship to expand in the new undeveloped sector of economy usually are very costly, especially in high technology sectors where the financial and technological requirements run too far ahead of domestic capabilities.

On the other hand, FDI is more likely to substitute for domestic investment when it takes place in sectors where there exist plenty of domestic firms. The same may occur where domestic firms already have access to the technology that the MNEs bring into the country.

It could be argued that FDI can lead to investments by domestic firms in order to become more competitive. However, given the vast technological superiority of MNEs, their investments are more likely to displace domestic firms, and even cause their bankruptcy, than to induce domestic firms to invest.

Also it should be noted that mergers and acquisitions might not lead to increase in the physical capital of a host country. In some cases, the acquisition of a domestic firm is almost akin to a portfolio investment, with foreign investor doing nothing to improve the operation of the domestic firm.

The main conclusion, which emerges from the short theoretical analysis given above, is that the positive influence of FDI on domestic investment is not assured. The extent of FDI influence on domestic investment of course is an empirical question, and undoubtedly the situation will vary from country to country. In order to test the FDI for CI or CO effect in Latvia the author will analyse the model of total investment presented in the third part of the paper.

3. FOREIGN DIRECT INVESTMENT DYNAMICS IN LATVIA

At the end of 2004 the foreign direct investment stock in Latvia amounted to 2318.3 million LVL or 31.5% of GDP and the volume of the FDI inflow in the last four years equalled on average to 17% of fixed investment. [12; 64] In 2004 the amount of the FDI inflow in Latvia reached 350.2 million LVL, which was twice more than in 2003. [12; 64] The dynamics of intensity[2] of investment processes in Latvia are presented in Chart 2.

[2] Gross capital formation intensity was calculated as gross capital formation and GDP ratio. FDI intensity was calculated as FDI and GDP ratio. All data is in average 2000-year prices.
Calculations based on data from annual statistical database of Central Statistical Bureau of Latvia http://data.csb.lv/EN/dialog/statfile1.asp?xu=&yp=&lang=1

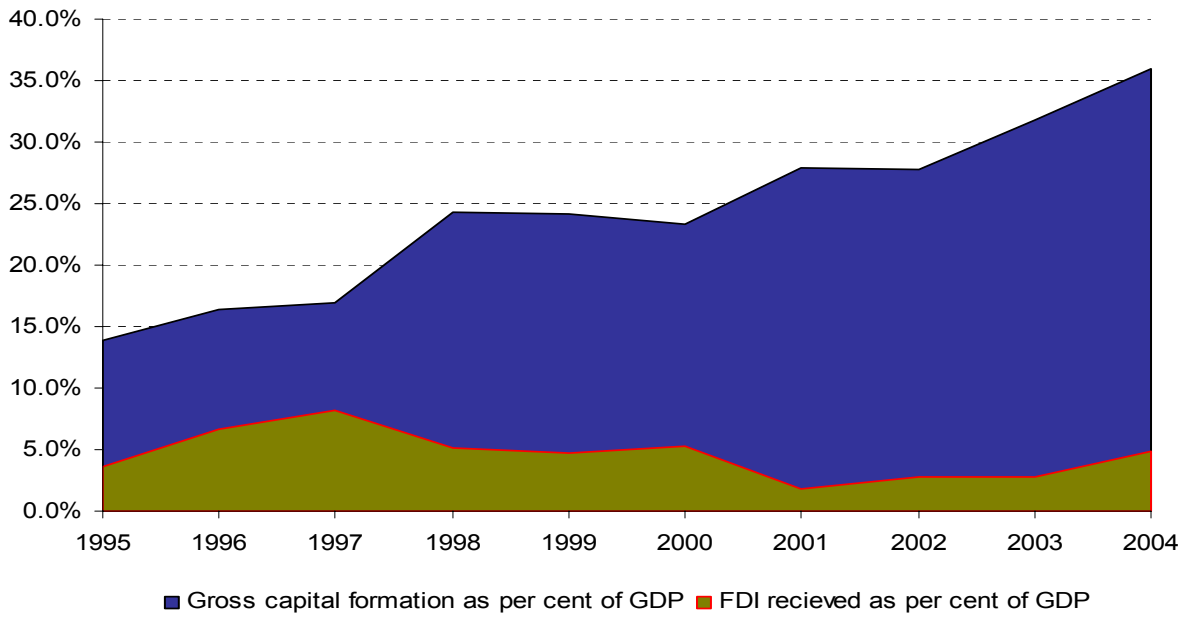


***Chart 2**. The Intensity of Gross Capital Formation and FDI in Latvia 1995-2004 (% of GDP)*

As we see from Chart 2, the highest FDI intensity during the overview period was in 1997 what can be associated with large-scale privatisation process in Latvia. During the next 4 years FDI intensity is falling and only for the last 3 years again shows moderate growing tendency what can be associated with the influence of EU enlargement process. Significant fall of FDI intensity in Latvia in 2001 was caused by "Hansabank group" reorganization, when all "Hansa Capital" owned subsidiaries in Latvia and Lithuania were sold to "Hansabank Group" owned banks in these countries (the approximate value of this arrangement in Latvia was about 100 mln. LVL).

The main conclusion that emerges from the analysis of data presented in chart 1 is that over the last 10 years the intensity of total investment (gross capital formation) shows considerable growing tendency while the intensity of FDI during this period is relatively low and does not show significant growth tendency. In spite of positive FDI dynamics during the last 3 years its should be stressed that at the end of 2004 FDI amounted to 1002 LVL per capita, which is one of the lowest indicators among the new EU member states. [12, 63]

According to data of the Bank of Latvia, the biggest amounts of investment have been received from Germany, Sweden, Denmark, Finland, USA, Norway, Estonia and Russia, contributing to almost 80% of all FDI stock in Latvia. [12, 64] Majority of these countries are also the biggest trade partners of Latvia. The sectoral composition of FDI in Latvia in 2004 is presented in Chart 3.

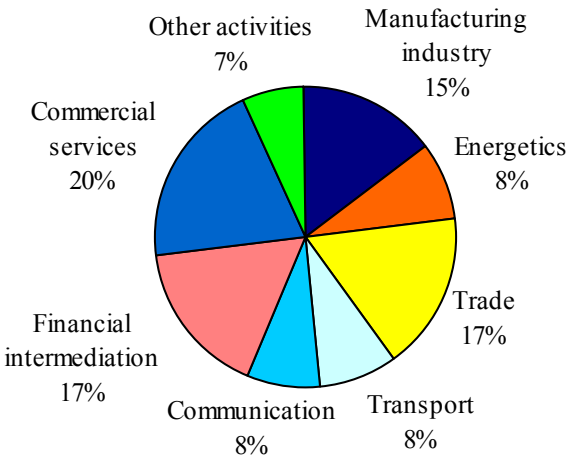


***Chart 3.** FDI Stock by Kind of Activity in Latvia (%, 2004) [12; 65]*

As we see from Chart 3, the highest share in the total structure of FDI stock belongs to the commercial services sector. The main activity of foreign investors is concentrated in 4 economy sectors - commercial services, financial intermediation, transport and communication and trade. The total share of these sectors amounts to 70% of FDI stock in Latvia. Such distribution of FDI pretty precisely corresponds to the sectoral distribution of total investment and sectoral structure of GDP in Latvia.

It should be noted that FDI in production of goods during the last years grew almost twice faster than in services, but only a few the so-called Greenfield projects, involving introduction of new and modern technologies by foreign investors, have been implemented.

4. TESTING OF THE TOTAL INVESTMENT MODEL FOR FDI CROWDING IN OR CROWDING OUT EFFECT

A model of total investment was estimated for a quarterly data for Latvian economy over the period 1995–2004. Following the approach described in Agosin and Mayer (2000) the initial investment equation used for testing for CI or CO effects was of the following form:

$$I_t = \alpha + \beta_1 F_t + \beta_2 F_{t-1} + \beta_3 F_{t-2} + \beta_4 F_{t-3} + \beta_5 F_{t-4} + \beta_6 I_{t-1} + \beta_7 I_{t-2} + \beta_8 I_{t-3} + \beta_9 I_{t-4} +$$

$$+ \beta_{10} G_{t-1} + \beta_{11} G_{t-2} + \beta_{12} G_{t-3} + \beta_{13} G_{t-4} + \varepsilon_t , \qquad (2)$$

where I is investment/GDP ratio; F is FDI/GDP ratio; G is growth of GDP; α is fixed country effect and ε is a serially uncorrelated random error.

The investment equation (2) represents the total investment as the sum of domestic investment and FDI (based on equation (1)).

The resources that cross the exchanges as FDI are often not used at once to finance real investment. There is a lag between FDI and real investment – so the lagged explanatory variables of investment equation were used.

The growth rate (G) was used as the explanatory variable of desired level of capital stock of domestic firms. Equation (2) is a version of total investment model with adaptive expectations with respect to the growth rate[3].

The data of recent research (Stikuts (2003, 2004)) shows, that the difference between actual output and full-capacity output during the last years in Latvia is relatively small. So the output gap as explanatory variable was not used.

The source data for the model is data provided by Bank of Latvia and the Central Statistical Bureau of Latvia. All series are in 2000-year prices. For the estimation of the investment function, the method employed was that of Least Squares (LS).

As it was mentioned above the significant fall of FDI happened in 2001. To eliminate the influence of this shock, the value of "Hansabank group" arrangement (approximately 100 million LVL) was not taken into account in FDI data for investment model (2) estimation.

After the estimation of the model and removing all statistically insignificant variables the final investment model equation can be represented as follows:

$$I_t = \alpha + \beta_1 F_t + \beta_2 F_{t-1} + \beta_3 I_{t-3} + \beta_4 I_{t-4} + \beta_5 G_{t-3} + \beta_6 G_{t-4} + dummy + \varepsilon_t . \qquad (3)$$

Also the dummy variable for the period of first and second quarter of 2004 was introduced to the model to eliminate the shock influence of EU enlargement process on investment in Latvia.

The results of regression equation (3) for Latvia are shown in Table 1.

[3] where the expected growth $G_t^e = \eta_1 G_{t-1} + \eta_2 G_{t-2} + \eta_3 G_{t-3} + \eta_4 G_{t-4}$.

Table 1. Estimates of the total investment model

Dependent Variable: total investment, *I* Method: Least Squares Sample(adjusted): 1996:2 2004:4 Included observations: 35 after adjusting endpoints				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
α	-2.413	0.487	-4.954	0.000
F	-0.315	0.178	-1.771	0.088
F_{t-1}	-0.492	0.168	-2.927	0.007
I_{t-3}	0.183	0.107	1.708	0.099
I_{t-4}	0.425	0.123	3.458	0.002
G_{t-3}	1.302	0.346	3.762	0.001
G_{t-4}	1.225	0.347	3.526	0.002
Dummy variable	0.067	0.018	3.675	0.001
Adjusted R-squared	0.876			
S.E. of regression	0.022			
Durbin-Watson stat	1.902			

As we see from Table 1 presented equation (3) explains a high percentage of the variation in investment and all coefficients are reasonable and statistically significant (at least at 10 per cent level).

The coefficient for long-term CI or CO effect testing is:

$$\hat{\beta}_{LT} = \frac{\sum_{j=1}^{2} \hat{\beta}_j}{1 - \sum_{j=3}^{4} \hat{\beta}_j}. \tag{4}$$

The criteria used to determine the CO/CI effect is the value and significance of coefficient $\hat{\beta}_{LT}$. There are three possibilities:

1. With a Wald test it is not possible to reject the hypothesis that $\hat{\beta}_{LT} = 1$. This means that in the long run an increase in FDI of one lat (or, more precisely, of one percentage point of GDP) becomes one lat of additional total investment (or investment amounting to one percentage point of GDP).
2. Consider now the case in which the null $\hat{\beta}_{LT} = 1$ is rejected and $\hat{\beta}_{LT} > 1$. This is evidence of CI: in the long run, one additional lat of FDI becomes more than one additional lat of total investment.
3. If the null $\hat{\beta}_{LT} = 1$ is rejected and $\hat{\beta}_{LT} < 1$, there is long-run CO: one additional lat of FDI leads to less than a one-lat increase in total investment. In other words, there is displacement of domestic investment by FDI. [1]

How to interpret a result in which $\hat{\beta}_{LT} \neq 1$? If the equality holds, investment by MNEs simply adds one-to-one to investment by domestic firms, and there are no macroeconomic externalities stemming from FDI. If the long-term effect of FDI is to produce CI, long-term macroeconomic externalities are positive. And evidence for CO implies that FDI has negative long-term externalities on investment. [1]

The Wald test results of $\hat{\beta}_{LT}$ coefficient for our regression model are showed in Table 2.

Table 2. Wald test results for $\hat{\beta}_{LT}$ coefficient

Test Statistic	Value	Df	Probability
F-statistic	37.105	(1, 27)	0.000
Chi-square	37.105	1	0.000
Null Hypothesis Summary:			
Normalized Restriction (= 0)		Value	Std. Err.
$-1+(\beta_1+\beta_2)/(1-(\beta_3+\beta_4)$		-3.051	0.501

As we see from Table 2 $\hat{\beta}_{LT}$ coefficient is significantly different from one. The coefficient value is negative (-2.051) what is the evidence of CO long-term effect of FDI on investment in Latvia.

It is very important to note, that the analysis of FDI CI/CO effect using total investment model (1.2) is crucially dependent on FDI being exogenous to the variables determining investment (here, the growth rate of GDP with respective time lags). In order to test for the exogeneity of FDI, the regression with FDI as the dependent variable and the growth rate with one-, two-, three- and four-quarter lags as the explanatory variables was tested. The two equations estimated were as follows:

$$F_t = \delta + \gamma_1 G_{t-1} + \gamma_2 G_{t-2} + \gamma_3 G_{t-3} + \gamma_4 G_{t-4} + u_t, \quad (5)$$

$$F_t = \delta + \gamma_1 G_{t-1} + \gamma_2 G_{t-2} + \gamma_3 G_{t-3} + \gamma_4 G_{t-4} + \gamma_5 F_{t-1} + \gamma_6 F_{t-2} + \gamma_7 F_{t-3} + \gamma_8 F_{t-4} + u_t. \quad (6)$$

These two models were estimated with data for 1995 – 2004 using LS method. The results of estimation are presented in Table 3.

Table 3. Regression estimations with FDI as a dependent variable and lagged growth as explanatory variable

Variable	P-values of coefficients in equation (5)	P-values of coefficients in equation (6)
G_{t-1}	0.548	0.578
G_{t-2}	0.850	0.462
G_{t-3}	0.481	0.205
G_{t-4}	0.445	0.119
Adjusted R^2	-0.066	0.105

As we can see from Table 3, the estimated coefficients of G_{t-1}, G_{t-2}, G_{t-3} and G_{t-4} are not statistically significant. Adjusted *R* squares of estimated equations are low. So it is possible to conclude that the variables explaining domestic investment (past growth) do not explain FDI in Latvia. Therefore including of FDI as an exogenous variable in the equations for total investment is justified.

5. CONCLUSIONS

The econometric analysis of the total investment function for the period 1995 – 2004 conducted in this paper demonstrates the evidence of the crowding out (CO) influence of FDI on domestic investment in Latvia. CO effect means that FDI displace domestic investment in Latvia i.e. one additional lat of FDI inflow in Latvian economy leads to less than a one-lat increase in total investment. However it should be noted that due to the relatively short times series data available the values of total investment function coefficients for Latvia estimated in this paper should be interpreted carefully.

One of the reasons of CO effect can be the relatively low FDI intensity in Latvia over the last 10 years. It should be obvious that low FDI inflows cannot ensure any significant CI effect.

The second reason of CO effect can be the peculiarities of FDI distribution in Latvia, which, as it was mentioned above, pretty precisely corresponds to the sectoral distribution of total investment. The FDI inflows in Latvia are oriented generally to the most dynamic sectors of the national economy. Some of these sectors *de jure* or *de facto* are monopolized or are oligopolies (gas supply, telecommunication, retail sale of fuel, metal industry and others). In other sectors of foreign investor interest operate plenty of domestic firms (banking and insurance sector, real estate, wholesale trade and other services). And in many cases the firms with foreign capital simply displace or take over the domestic firms, which are not enough competitive. This is especially relevant for Latvian economy joining the EU. Thus FDI inflow in Latvia rarely stimulates the domestic firms to invest more to increase their competitiveness. In some cases acquisitions, when foreign investor acquires control in a domestic firm to enter the local market and does nothing to improve its capacity, do not lead to significant increase in physical capital. Foreign investors are not active in less developed sectors of Latvian economy where FDI inflow could be a significant incentive for growth and can ensure the crowding in effect on investment of domestic firms.

The main conclusion from the analysis undertaken in this paper is that the positive influence of FDI on domestic investment processes in Latvia is not assured. The question of maximization of FDI contribution to total investment is a policy question. The national investment policy should focus on improving the investment climate for all kinds of capital, domestic as well as foreign. Today the primary aim is to find the new incentives for FDI inflow in the less developed industrial sectors of Latvian economy where the foreign investors can contribute new technologies introduce new products and stimulate the activity of domestic firms ensuring the CI investment effect.

References

[1] Agosin M.R., Mayer R. Foreign Investment in Developing Countries: does It Crowd in Domestic Investment? In: *United Nations (UN) Conference on Trade and Development (UNCTAD)*, 2000. http://www.unctad.org/en/docs/dp_146.en.pdf

[2] Buckley A. *International Investment: value creation and appraisal, a real options approach*. First edition. Handshojskolens Forlag. Copenhagen, 1998

[3] Bosworth B. P., Collins S.M. *Capital Flows to Developing Economies: Implications for Saving and Investment. Brookings Papers on Economic Activity: 1*. Brookings Institution, 1999, pp. 143-69.

[4] Desai M.A., Foley C.F., Hines Jr. J.R. *Foreign Direct Investment and Domestic Economic Activity*. November 2004. www.ncaer.org/Upload/Event/28/MDesai.pdf

[5] Ethier W. J. *Modern International Economics*. Second edition. New York: WW Norton and Company, 1995.

[6] Hecht Y., Razin A., Shinar N.G. *Interactions between capital inflows and domestic investment: Israel and developing countries.* www.bankisrael.gov.il/deptdata/mehkar/iser/04/iser_1.pdf

[7] Loungani P., Razin A. How Beneficial Is Foreign Direct Investment for Developing Countries? *Finance and Development,* Vol.38, No 2, June 2001. A quarterly magazine of the International Monetary Fund - http://www.imf.org/external/pubs/ft/fandd/2001/06/loungani.htm

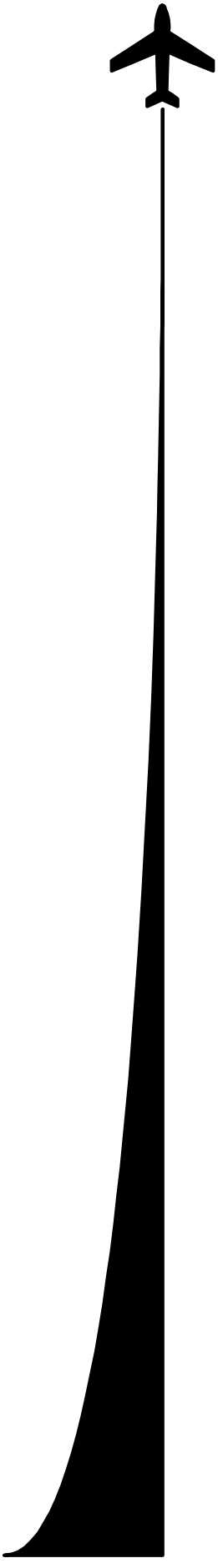
[8] Schaffer R. *International Business Law and Its Environment*. Third edition. Minneapolis:West Publishing company, 1996.

[9] Soberston B. and Reed G. *International Economics.* Third edition. London: Macmillan, 1994.

[10] Stikuts D. Latvia`s Potential Output – Using Production Function and HP-filter. In: *Acta Universitatis Latviensis.. Economics and Management.* Riga: University of Latvia, Vol. 677, 2004, pp. 372-382.

[11] Stikuts D. *Measuring Output GAP in Latvia*. Bank of Latvia. Working Paper 2/2003. http://www.bank.lv/images/img_lb/izdevumi/english/citas/Measuring_Output_Gap_in_Latvia.pdf

[12] Ziņojums par Latvijas tautsaimniecības attīstību. Latvijas Republikas Ekonomikas ministrija. 2005.gada jūnijs.



Session 2

Applications of Mathematical Methods in Logistics and Business

MULTICRITERIA TECHNIQUE FOR PROJECT SELECTION UNDER RISK

Maciej Nowak

The Karol Adamiecki University of Economics
1 Maja Str. 50, 40-287 Katowice, Poland
Ph: (+48)-32-2577470. Fax: (+48)-32-2577471. E-mail: nomac@ae.katowice.pl

Profitable investments lead to the growth and prosperity of each corporation. Various objectives are usually taken into account when an engineering, construction or R&D projects are analysed, including economic desirability, technical issues, and environmental and social factors. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, so a multicriteria decision problem arises. Criteria, according to which projects are compared, are usually of different nature. While some of them are quantitative ones, others are of qualitative type. When faced with the decision of selecting a project, the decision maker has also to face uncertainty.
The paper proposes a comprehensive methodology for project selection problem, that enables handling both quantitative and qualitative criteria, and takes into account risk associated with each objective. Monte Carlo simulation is used for generating alternatives' evaluations with respect to quantitative measures. Experts' assessments are taken into account when projects are appraised in relation to qualitative criteria. A multicriteria procedure presented in the paper is based on two concepts: stochastic dominance and interactive approach. The first is employed for comparing projects with respect to each criterion separately, the latter in used for generating final solution of the problem. A numerical example is presented to illustrate the applicability of the proposed technique.

Keywords: *project selection, Monte Carlo simulation, stochastic dominance, multicriteria analysis*

1. INTRODUCTION

Selection of a project or a portfolio of projects constitutes one of the main problems that managers are faced with. Decision of selecting an engineering, construction or R&D project is often fundamental for business survival. Such decisions usually involve prediction of future outcomes considering different alternatives. As these predictions are not known with certainty, so project managers often have to face some degree of uncertainty. The fact of matter is that modern businesses face a more severe and challenging environment than ever before. The increasing volatility in interest and exchange rates, lifting trade barriers and development of new technologies in electronics, nanotechnology, biotechnology result in a high level of uncertainty in managerial decision-making.

Various objectives are usually considered for when projects are evaluated, including economic desirability, technical, environmental, social and/or political factors. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, so a multiple criteria decision-making problem arises. It should be noticed that evaluation criteria could be of various nature. While financial measures (Net Present Value, Internal Rate of Return, Profitability Index) are of quantitative type, the ones that reflect technical, environmental or social objectives are usually of qualitative nature.

Numerous techniques have been proposed in recent years for project selection problems. Heidenberger and Stummer [2] give a survey of quantitative techniques for R&D project selection and resource allocation problems. Most of procedures listed in that paper can be applied for evaluating construction and engineering projects as well. Utility function approach is often employed for solving such a problem. E.g., Moselhi and Deb [3], Wong et al. [4] use this methodology. They propose methods for estimating single-criteria utility functions and aggregating them into a multi-attribute utility function. Thus, both multiple criteria and risk can be considered. The main assumption of this approach is that it is possible determine decision maker's utility functions with respect to criteria. In fact, however, such analysis is usually inconvenient and time consuming. It requires asking the decision maker to make a lot of hypothetical choices between alternatives that often have no practical reality. As a result, such techniques are often recognized as exacting and demanding by decision makers.

Analytic Hierarchy Procedure ([5], [6]), outranking relation ([7], [8]), or goal programming approach ([9], [10]) is also proposed for project selection problems. As AHP technique is based on exploiting decision maker's subjective evaluations formulated for each pair of projects and for each criterion, so its applications are restricted to problems with relatively small number of alternative projects. In order to apply techniques based on outranking relation, thorough analysis of decision maker's preferences have to be conducted. Such study precedes the final analysis and, like in approaches based on utility function, is very absorbing for the decision maker. Finally, goal-programming techniques attempt to find a solution that is as close as possible to goals specified by the decision maker. Unfortunately, it is usually not easy to consider risk using this approach.

In this paper an interactive multiple criteria decision-making technique is applied for a project selection problem. The methodology exploits the STEM method approach ([1]) and uses stochastic dominance rules for comparing uncertain outcomes. Thus, both multiple criteria and risk are considered while alternate projects are analysed. The procedure exploits interactive approach that is widely used in decision problems under certainty, but is rarely used in problems involving risk. Such approach is much less demanding for the decision makers than approaches based on an a priori basis (e.g. techniques based of utility function or outranking relation) and is usually accepted by them.

The paper is organized as follows. Section 2 formulates the decision problem and presents the proposed methodology. Next section presents a numerical example. Last section gives conclusions.

2. METHODOLOGY

Let us consider a project selection problem in which A is the set of alternate projects: $a_1, \ldots, a_m$, X is the set of decision criteria: $X_1, \ldots, X_n$, and E is the set of evaluations of projects with respect to criteria: $X_{11}, \ldots, X_{m\,n}$. The decision maker has to choose only one project. It is assumed that each criterion is defined in such a way, that larger values are preferred to smaller ones.

Following procedure can be used for solving problem formulated above:

1. Generation of projects' evaluations.
2. Comparing projects with respect to criteria.
3. Selection of a final solution employing interactive approach.

Various techniques can be used for generating evaluations of projects with respect to criteria. Simulation is an efficient and powerful tool for analysing economic desirability of alternate projects, as it makes possible to consider uncertainties relative to various aspects of the problem. If, for example, a construction or manufacturing project is analysed, uncertainties relative to availability of resources, market prices, demand can be considered. On the other hand, in projects with R&D elements activity durations are much more sensitive to misevaluation. In such cases simulation may provide the dates of the project's milestone occurrences, which determine the set of cash flows during project's life cycle. As simulation experiments are performed, series of observations is obtained for a considered criterion. These observations can be easily transformed to a probability distribution.

In order to analyse projects' performances with respect to criteria that are qualitative or subjective in nature, experts' assessments may be analysed. A 10-point scale may be utilized with 10 assigned to the maximum value that is desirable, and 1 to the least desirable one. If l experts are asked for assessing projects then l evaluations are obtained for each project. Assuming equal probabilities for each assessment, probability distribution is obtained for each project. Such distributions, however, are different in nature to the previous ones, as they are defined on ordinal scale.

Once projects' evaluations are generated, relations between alternative projects with respect to criteria can be analysed. In this study stochastic dominance rules are employed for comparing uncertain outcomes. It is assumed that the decision maker is risk averse. Such supposition is usually taken in finance and corresponds to the results of experiments of Kahneman and Tversky [11] showing that decision makers are usually risk averse in relation to criteria defined in the domain of gains. Two groups of stochastic dominance rules can be considered. The first one groups First Degree Stochastic Dominance (FSD) and Second Degree Stochastic Dominance (SSD) rules. These rules can be applied for providing ranking of preferences among real-valued outcomes, such as income, wealth or rates of return. Ordinal First Degree Stochastic Dominance (OFSD) and Ordinal Second Degree Stochastic Dominance (OSSD) rules compose the second group. These rules can be applied for providing ranking of preferences among variables of ordinal nature.

Let us start with real-valued outcomes. Assume $F_{ik}(x)$ and $F_{jk}(x)$ are right-continuous cumulative distribution functions representing evaluations of a_i and a_j respectively over criterion X_k:

$F_{ik}(x) = \Pr\{X_{ik} \le x\}$ $F_{jk}(x) = \Pr\{X_{jk} \le x\}$

First-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) relations are defined as follows:

X_{ik} dominates X_{jk} by FSD rule ($X_{ik} \succ_{\text{FSD}} X_{jk}$) if and only if

$F_{ik}(x) \neq F_{jk}(x)$ and $H_1(x) = F_{ik}(x) - F_{jk}(x) \le 0$ for all $x \in \mathrm{R}$

X_{ik} dominates X_{jk} by SSD rule ($X_{ik} \succ_{\text{SSD}} X_{jk}$) if and only if

$$F_{ik}(x) \neq F_{jk}(x) \quad \text{and} \quad H_2(x) = \int_{-\infty}^{x} H_1(y)dy \le 0 \quad \text{for all } x \in \mathrm{R}$$

Let us now consider a random variable X_{iq} is defined by (e_{q1}, …, e_{qz}, p_{iq1}, …, p_{iqz}), where e_{q1}, …, e_{qz} are z real numbers, such that $e_{ql} < e_{ql+1}$ for all $l = 1, \ldots, z-1$, and p_{iq1}, …, p_{iqz} are the probability measures. The variable X_{jq} is defined similarly with p_{jq1}, …, p_{jqz} replacing p_{iq1}, …, p_{iqz}. If the outcomes can be ranked in order of preferences, i.e. the decision maker prefers $e_{q\,l+1}$ over $e_{q\,l}$ for all $l = 1, \ldots, z-1$ then Ordinal First Degree Stochastic Dominance (OFSD) rule can be used:

X_{iq} dominates X_{jq} by OFSD rule ($X_{iq} \succ_{\text{OFSD}} X_{jq}$) if and only if

$$\sum_{l=1}^{s} p_{i\,q\,l} \le \sum_{l=1}^{s} p_{j\,q\,l} \quad \text{for all } s = 1, \ldots, z$$

Let us assume that the decision maker adds additional information and indicates that the outcome is improved more by switching from $e_{q\,l}$ to $e_{q\,l+1}$ than from $e_{q\,l+1}$ to $e_{q\,l+2}$ for all $l = 1, \ldots, z-2$. In such case Ordinal Second Degree Stochastic Dominance (OSSD) rule can be employed:

X_{iq} dominates X_{jq} by OSSD rule ($X_{iq} \succ_{\text{OSSD}} X_{jq}$) if and only if

$$\sum_{r=1}^{s}\sum_{l=1}^{r} p_{i\,q\,l} \le \sum_{r=1}^{s}\sum_{l=1}^{r} p_{j\,q\,l} \quad \text{for all } s = 1, \ldots, z$$

FSD and OFSD rules are equivalent to the expected utility maximization rule for all decision makers preferring larger outcomes, while SSD and OSSD rules are equivalent to the expected utility maximization rule for all risk-averse decision makers preferring larger outcomes ([11], [12]).

The procedure presented here uses interactive technique for solving project selection problem. The method is based on the approach proposed in the STEM technique [1], which uses the ideal solution concept. Such solution is composed of maximum values of all criteria that are individually attainable within the set of decision alternatives. In the STEM method candidate alternative is generated and presented to the decision maker in each step. It is the one that is closest to the ideal solution according to the mini-max rule. If the decision maker accepts the proposal, then the procedure ends, otherwise the decision maker is asked to define the margins of relaxation for these criteria, whose values are already satisfactory. Then the decision maker generates new set of alternatives taking into account the restrictions defined. The procedure continues until an alternative with satisfactory criteria evaluations is found. The technique employed in this study adopts similar approach for solving decision-making problems under risk. The number of alternatives measures the distance from the ideal solution with evaluations dominating the evaluation of the considered alternative according to stochastic dominance relations.

Let μ_{ik} be average evaluation of alternative a_i with respect to X_k. The operation of the proposed procedure is as follows:

1. $l := 1$, $A_1 := A$, $K := \{ 1, ..., m \}$;
2. Identify candidate alternative a_i:

$$a_i := \arg \min_{a_j \in A_l} \max_{k \in K} \{d_{jk}^l\}$$

where d_{jk}^l is the number of alternatives $a_i \in A_l$ such that the evaluation of a_i dominate the evaluation of a_j with respect to criterion X_k according to stochastic dominance rules:

$$d_{jk}^l = \operatorname{card} D_{jk}^l$$

$$D_{jk}^l = \{a_i : a_i \in A_l ; F_{ik} \succ_{SD} F_{jk}\}$$

where $\succ_{SD}$ means FSD/SSD or OFSD/OSSD relation.

3. Present the data to the decision maker:
   - the average evaluations of the candidate alternative a_i with respect to all criteria μ_{ik}, $k = 1, ..., m$,
   - the values of d_{ik}^l for $k = 1, ..., m$,
   - the maximal average evaluations μ_k^* for $k = 1, ..., m$:

$$\mu_k^* = \max_{i: a_i \in A_l} \{\mu_{ik}\}$$

4. Ask the decision maker whether he/she is satisfied with the candidate alternative. If the answer is YES – the final solution is alternative a_i – go to 8, else – go to 5.
5. Ask the decision maker whether the candidate alternative is satisfactory with respect to at least one criterion. If the answer is YES – go to 6, else – it is impossible to find an alternative with satisfactory evaluations by the procedure – go to 8.
6. Ask the decision maker to select criterion with respect to which the candidate alternative is satisfactory for him/her, say criterion X_k and to define δ_k – the limit of concessions, which can be made on average evaluations of the X_k.
7. Generate the set $A_{l+1} := \{a_j: a_j \in A_l, \mu_{jk} \geq \delta_k \}$, assume $l := l + 1$, $K := K \setminus \{ k \}$, if $K = \varnothing$ then $K = \{ 1, ..., m \}$, go to 3.
8. The end of procedure.

More detailed description of the procedure is presented in [14].

3. NUMERICAL EXAMPLE

To illustrate the proposed technique let us consider a manufacturing company operating on a growth market. Management board decided to purchase a new production facility to increase production capacity. Ten alternate projects are considered. All proposals are viable from a standpoint that output from any of these alternatives meets product specification. A decision for selecting a project has to be made based on the following criteria:

- X_1 – net present value,
- X_2 – reliability and technical service,
- X_3 – technical novelty,
- X_4 – compatibility with existing facilities.

Simulation technique is applied for generating distributional evaluations of projects with respect to criterion X_1. The economic life for all projects is assumed to be 5 years. Based on past experience and data provided by facilities' manufacturers, analysts has determined probability distributions for:

- initial investments,
- salvage values,
- production costs per unit,
- fixed costs,
- demand,
- market prices.

Next, a series of experiments has been performed and probability distributions describing NPV for all projects have been obtained. Table 1 presents results of simulation experiments.

Criteria X_2, X_3 and X_4 are of qualitative nature. Ten experts have been asked for evaluating projects in relation to these criteria on the scale form 1 to 10. As a result, series of assessments for each project and for each criterion has been obtained. These assessments have been transformed to probability distributions. Table 2 presents experts assessments obtained for project a_1 and criterion X_2, while table 3 shows the corresponding probability distribution.

Next, stochastic dominance rules have been applied for comparing projects with respect to criteria. FSD/SSD rules have been used for criterion X_1, while OFSD/OSSD rules have been employed for criteria X_2, X_3 and X_4. Results are shown in tables 4, 5, 6 and 7.

Table 1. Results of simulation experiments

Project	NPV (mean)
1	1413.84
2	1183.06
3	1139.12
4	1244.56
5	979.66
6	1137.93
7	1208.61
8	1432.72
9	1211.81
10	1226.72

Table 2. Experts assessments of project a_1 on criterion X_2

Evaluation	Number of experts
1	
2	
3	
4	
5	1
6	2
7	2
8	3
9	2
10	

Table 3. Distributional evaluation of project a_1 on criterion X_2

Evaluation	Probability
1	0,0
2	0,0
3	0,0
4	0,0
5	0,1
6	0,2
7	0,2
8	0,3
9	0,2
10	0,0

Table 4. FSD/SSD relations between projects' evaluations with respect to criterion X_1

	$\mu_{i\,1}$	$X_{1\,1}$	$X_{2\,1}$	$X_{3\,1}$	$X_{4\,1}$	$X_{5\,1}$	$X_{6\,1}$	$X_{7\,1}$	$X_{8\,1}$	$X_{9\,1}$	$X_{10\,1}$
$X_{1\,1}$	1226.72		FSD		FSD		FSD	SSD	FSD		FSD
$X_{2\,1}$	979.66										
$X_{3\,1}$	1432.72	SSD	FSD		FSD		FSD	FSD	FSD		FSD
$X_{4\,1}$	1208.61		FSD				FSD				FSD
$X_{5\,1}$	1244.56	SSD	FSD		FSD		FSD	FSD	SSD		FSD
$X_{6\,1}$	1137.93		FSD								
$X_{7\,1}$	1211.81		FSD		SSD		FSD		FSD		
$X_{8\,1}$	1183.06		FSD								
$X_{9\,1}$	1413.84	FSD	FSD		FSD		FSD	FSD	FSD		FSD
$X_{10\,1}$	1139.12		FSD				SSD				

Table 5. OFSD/OSSD relations between projects' evaluations with respect to criterion X_2

	μ_{i2}	X_{12}	X_{22}	X_{32}	X_{42}	X_{52}	X_{62}	X_{72}	X_{82}	X_{92}	X_{102}
X_{12}	7.3		OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	
X_{22}	3.0			OFSD		OSSD					
X_{32}	2.8										
X_{42}	5.3		OFSD	OFSD		OFSD		OFSD			
X_{52}	2.9										
X_{62}	7.9	OFSD	OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	OSSD
X_{72}	4.5		OFSD	OFSD		OFSD					
X_{82}	6.8		OFSD	OFSD	OFSD	OFSD		OFSD			
X_{92}	6.9		OFSD	OFSD	OFSD	OFSD		OFSD			
X_{102}	7.8	OFSD	OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	

Table 6. OFSD/OSSD relations between projects' evaluations with respect to criterion X_3

	μ_{i3}	X_{13}	X_{23}	X_{33}	X_{43}	X_{53}	X_{63}	X_{73}	X_{83}	X_{93}	X_{103}
X_{13}	3.4										
X_{23}	4.9	OFSD			OSSD						OFSD
X_{33}	7.0	OFSD	OFSD		OFSD	OSSD	OSSD			OFSD	OFSD
X_{43}	4.6	OFSD									OFSD
X_{53}	6.4	OFSD	OFSD		OFSD		OFSD			OFSD	OFSD
X_{63}	5.9	OFSD	OFSD		OFSD					OFSD	OFSD
X_{73}	7.5	OFSD	OFSD		OFSD	OFSD	OFSD		OSSD	OFSD	OFSD
X_{83}	7.2	OFSD	OFSD		OFSD						OFSD
X_{93}	5.4	OFSD	OSSD		OFSD						OFSD
X_{103}	4.1	OFSD									

Table 7. OFSD/OSSD relations between projects' evaluations with respect to criterion X_4

	μ_{i4}	X_{14}	X_{24}	X_{34}	X_{44}	X_{54}	X_{64}	X_{74}	X_{84}	X_{94}	X_{104}
X_{14}	8.2		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	OFSD
X_{24}	2.6										
X_{34}	5.3		OFSD			OFSD		OFSD		OSSD	
X_{44}	8.0		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	OFSD
X_{54}	4.3		OFSD					OSSD			
X_{64}	6.6		OFSD	OFSD		OFSD		OFSD	OFSD	OFSD	
X_{74}	3.9		OFSD								
X_{84}	5.7		OFSD			OFSD		OFSD		OFSD	
X_{94}	4.7		OFSD					OSSD			
X_{104}	7.2		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	

The dialog with the decision maker proceeds as follows:

Iteration 1:

1. $l = 1$, $A_1 = A$, $K = \{1, 2, 3, 4\}$.
2. Alternative a_8 is selected as a candidate alternative.
3. Following data are presented to the decision maker:
   $\mu_{81} = 1183.06$, $\mu_{82} = 6.8$, $\mu_{83} = 7.2$, $\mu_{84} = 5.7$
   $\mu_1^* = 1432.72$, $\mu_2^* = 7.9$, $\mu_3^* = 7.5$, $\mu_4^* = 8.2$
   $d_8^1{}_1 = 5$, $d_8^1{}_2 = 3$, $d_8^1{}_3 = 1$, $d_8^1{}_4 = 4$;
4. Let us assume that the candidate alternative is not satisfactory for the decision maker;
5. Let us assume that the candidate alternative is satisfactory for the decision maker with respect to X_3;
6. The decision maker defines $\delta_3 = 4.5$ as the minimum average evaluation with respect to X_3;
7. $A_2 = \{ a_j: a_j \in A_1, \mu_{j3} \geq 4.5 \} = \{ a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9 \}$, $l = 2$, $K = \{1, 2, 4\}$.

Iteration 2

2. Alternative a_4 is selected as a candidate alternative;
3. Following data are presented to the decision maker:

μ_{41} = 1208.61, μ_{42} = 5.3, μ_{43} = 4.6, μ_{44} = 8.0
μ_1^* = 1432.72, μ_1^* = 7.9, μ_3^* = 7.5, μ_4^* = 8.0
$d_4^2{}_1$ = 4, $d_4^2{}_2$ = 3, $d_4^2{}_3$ = 7, $d_4^2{}_4$ = 0;

4. Let us assume that the candidate alternative is not satisfactory for the decision maker;
5. Let us assume that the candidate alternative is satisfactory for the decision maker with respect to X_4;
6. The decision maker defines δ_4 = 4.5 as the minimum average evaluation with respect to X_4;
7. $A_3 = \{ a_j: a_j \in A_2, \mu_{j4} \geq 4{,}5 \} = \{ a_3, a_4, a_6, a_8, a_9 \}$, $l = 3$, $K = \{1, 2\}$.

Iteration 3

2. Alternative a_9 is selected as a candidate alternative;
3. Following data are presented to the decision maker:
   μ_{91} = 1413.84, μ_{92} = 6.9, μ_{93} = 5.4, μ_{94} = 4.7
   μ_1^* = 1432.72, μ_1^* = 7.9, μ_3^* = 7.2, μ_4^* = 8.0
   $d_9^3{}_1$ = 0, $d_9^3{}_2$ = 1, $d_9^3{}_3$ = 2, $d_9^3{}_4$ = 4;
4. Let us assume that the decision maker accepts the candidate alternative as a final solution.
8. End of the procedure.

4. CONCLUSIONS

In this study a new methodology for a project selection problem is proposed. The method combines interactive approach commonly used in multicriteria analysis with stochastic dominance rules that are often employed for comparing uncertain outputs. There are several advantages of the proposed technique. First, the decision maker is able to consider various criteria. Second, both quantitative and qualitative data can be analysed. Finally, the procedure permits the consideration of risk that the decision maker has to face.

Although the example given in this paper illustrates an implementation for selecting production facility, the method can also be used to provide a similar support for selection construction, R&D, social and others projects.

References

[1] Benayoun R., de Montgolfier J., Tergny J. and Larichev C. Linear Programming with Multiple Objective Functions: Step Method (STEM), *Mathematical Programming*, 8, 1971, pp.366-375.
[2] Heidenberger K. and Stummer Ch. Research and Development Project Selection and Resource Allocation: a Review of Quantitative Modelling Approaches, *International Journal of Management Reviews*, 1, 1999, pp.197-224.
[3] Moselhi O. and Deb B. Project Selection Considering Risk, *Construction Management and Economics*, 11, 1993, pp.45-52.
[4] Wong E.T.T., Norman G. and Flanagan R. A Fuzzy Stochastic Technique for Project Selection, *Construction Management and Economics*, 18, 2000, pp.407-414.
[5] Ferrari P. A Method for Choosing from among Alternative Transportation Projects, *European Journal of Operational Research*, 150, 2003, pp.194-203.
[6] Kearns G.S. A Multi-Objective, Multi-Criteria Approach for Evaluating IT Investments: Results from Two Case Studies, *Information Resources Management Journal*, 17, 2004, pp.37-62.
[7] Costa J.P., Melo P., Godinho P. and Dias L.C. The AGAP System: a GDSS for Project Analysis and Evaluation, *European Journal of Operational Research*, 145, 2003, pp.287-303.
[8] Mavrotas G., Diakoulaki D. and Capros P. Combined MCDA-IP Approach for Project Selection in Electricity Market, *Annals of Operations Research*, 120, 2003, pp.159-170.
[9] Lee J.W. and Kim S.H. Using Analytic Network Process and Goal Programming for Independent Information System Project Selection, *Computers & Operations Research*, 27, 2000, pp.367-382.
[10] de Oliveira F., Volpi N.M.P. and Sanquetta C.R. Goal Programming in Planning Problem, *Applied Mathematics and Computation*, 140, 2003, pp.165-178.
[11] Kahneman D., Tversky A. Prospect Theory: an Analysis of Decisions under Risk, *Econometrica*, 47, 1979, pp.263-291.
[12] Hadar J., Russel W.R. Rules for Ordering Uncertain Prospects, *The American Economic Review*, 59, 1969, pp.25-34.
[13] Spector Y., Leshno M., Ben Horin M. Stochastic Dominance in an Ordinal World, *European Journal of Operational Research*, 93, 1996, pp.620-627.
[14] Nowak M. Interactive Approach in Multicriteria Analysis Based on Stochastic Dominance, *Control & Cybernetics*, 33, 2004, pp.463-476.

APPLICATION OF A GENERAL MODEL OF MULTIMODAL TRANSPORTATION IN LOGISTICS

Olga Lingaitienė, Vytautas Lingaitis

Vilnius Gediminas Technical University
Basanavičiaus g. 28B, Vilnius, Lithuania
Ph: (+370 5)-2744797. E-mail: vytautas.lingaitis@lra.lt

The requirements for transport services are exogenous and can be generated by the input-output model if it is available or determined from other sources observed needs or corrected previously observed needs. The choice of a particular transport facility or a group of facilities is exogenous and multimodal transhipments are admissible.
A suggested mathematical model is aimed at optimising multimodal transportation allowing us choose the most suitable transport facilities in each particular case.

Keywords: *logistic, model, multimodal transportation, optimisation*

1. INTRODUCTION

Economic development of any country is hardly possible without an effective transport system. The manufactured goods should be transported from an enterprise to the user at minimal time and expenses. Transport makes an essential part of any logistic system, which is closely linked, with other elements of logistics. It should be effectively used to allow achieving good results to the company in business.

Most firms use two or more kinds of transport facilities to ensure safe and timely delivery of goods. Large enterprises in Western Europe have special departments for coordinating cargo transportation by various means of transport. The latter are needed to maintain close links between manufactures and users. The need for coordination arose because of different capabilities and tariffs of various transport facilities. For instance, since air transport is not easily available, the coordination of its operation with motor transport is needed while loading and distributing the delivered goods. Similar examples relating to rail, land and pipeline transport may also be provided. This does not, however, apply to motor transport because it is much more advantageous in this respect. Having various transport facilities at his disposal, a manager should try to take the main advantages, for example, low cost of transportation of a particular means of transport in order to compensate low quality of services provided by some other transport facility. This is the main reason for transporting coal or grain by rail or water transport. Rail transport can make water transport more easily available, while using water transport for transporting goods over long distances allows us to save much money due to low tariffs.

The main goal of coordinating bodies is to gain an advantage from a particular transport facility while reducing its disadvantages. They should also consider all positive and negative aspects of various means of transport. For example, coordinating the operation of rail and water transport on a particular route will reduce the cost of transportation compared to using water transport alone. On the other hand, the delivery time will be shorter in the case of using a combined system than by transporting the cargo only by water transport and longer than carrying it by rail transport. A decision to use a combined system should be made taking into account the total cost of delivery.

A transport company is usually eager to cooperate with other firms if it cannot deliver the cargo to the place of destination alone. However, if it can do it itself, the firm does not want to collaborate with others.

Another problem arises when it is necessary to transfer cargo from one transport facility to another in multimodal transportation. This increases delivery time and expenses. The considered problem can be solved by the companies, which can transfer a particular transport facility with a cargo to another transport facility.

The need for a wider use of mathematical methods and models in transport arose because more goods had to be transported and rapid scientific and technological development brought about new

possibilities in this area. This, in turn, gave a strong impetus to solve the problems of planning and management in transport by new more advanced methods. Mathematical models in transport are aimed at evaluating its performance. Mathematical methods are used in the following main areas of transport now:

1. Drawing up optimal plans and controlling their fulfilment.
2. Solving the problems of mathematical programming in transportation including the following issues:
   - drawing up an optimal plan of shipments;
   - minimizing the expenses in transportation;
   - designing new traffic lines, etc.
3. Solving various technical and economic problems:
   - developing an optimal scheme using various technological systems;
   - optimal lay-out of installations;
   - choosing a rational technology;
   - planning and distributing optimal amounts of spare parts in the stockyards, etc.

2. A MODEL FOR MULTIMODAL TRANSPORTATION OF VARIOUS KINDS OF GOODS

Transport infrastructure of the state or a region is used most effectively in the context of strategic planning of traffic flows when overall expenses are the lowest. Even if an assumption that many factors do not allow goods to be transported at the lowest expenses is true, this is also valid for a case when the government controls shipments and the developed model is based on the reduced expenses. The expenses make a basis of the model and may have variable components such as costs, delays, power consumption, etc.

Let a network have a set of nodes *N*, a set of branches *A*, $A \subset N \times N \times M$ a range of transport facilities *M* and a set of cargo transfers *T*, $T \subset A \times A$. Let us denote the numerical value of the sets by n_N, n_A, n_M and n_T. Every branch *a*, $a \in A$ is associated with the cost function $s_a(.)$ which depends on the size of the cargo on the branch or, probably, on the cargo size of other network branches. In a similar way, cost function $s_t(.)$ is associated with any cargo transfer *t*, $t \in T$.

Goods transported in a multimodal network are denoted by the index *p*, $p \in P$, where *P* is a set of all goods having the value of n_p. Any product is sent from the node of origin *o*, $o \in O \subseteq N$ to the destination node *d*, $d \in D \subseteq N$. The demand for any kind of goods for all pairs of (O/*D)* nodes is determined in the O/*D* matrix including a subset of various transport facilities to be used only for a considered case. It is assumed that the demand for and the choice of particular transport facilities are determined exogenously. Let $g^{m(p)}$ be a matrix of the demand for the product $p \in P$, where $m(p)$ is a subset of means of transport belonging to a set $M(p)$, which is a set of subsets of all transport facilities used to deliver product *p*.

The flow of goods *p* in a multimodal network is denoted by *vp* and is made up of the flows of the considered goods found on the network branches and cargo transfer branches.

$$v = \begin{pmatrix} \left(v_a^p\right),\ a \in A \\ \left(v_t^p\right),\ t \in T \end{pmatrix} \tag{1}$$

The total flow of goods in a multimodal network is denoted by $v = (vp),\ p \in P$ and is $n_p(n_A + n_T)$ – dimensional vector.

Average cost functions, $s_a^p(v)$ on branches and $s_t^p(v)$ on cargo transfer branches, correspond to a given flow vector *v*. Average cost functions of the goods *p* are denoted similarly to those of the flow *vp*, *sp*, $v \in p$, where

$$s^p = \begin{pmatrix} \left(s_a^p\right),\ a \in A \\ \left(s_t^p\right),\ t \in T \end{pmatrix} \tag{2}$$

and $s = (sp),\ p \in P$ is $n_p\left(n_A \times n_T\right)$ – dimensional vector of average cost functions.

Overall costs of the flow of goods p, $p \in P$ on cargo transfer branch t, $t \in T$ are the product $s_a^p(v)\, v_a^p$; overall costs of the flow on cargo transfer branch t, $t \in T$, are $s_t^p(v)\, v_t^p$. Overall costs of all flows of goods in a multimodal network are the function F that is to be minimized:

$$F = \sum_{p \in P}\left(\sum_{a \in A} s_a^p(v) v_n^p + \sum_{t \in T} s_t^p(v) v_t^p\right) \tag{3}$$

satisfying the stability and non-negative character of the flows in the set. The following notation is used to define the constraints of the above multimodal network for transporting various kinds of goods. Let $K_{od}^{m(p)}$ be a set of routes leading from the node of origin o, $o \in O$ to a destination node d, $d \in D$, when only transport facilities from $m(p) \in M(p),\ p \in P$ are used. Then, the equation for the flows will be as follows:

$$\begin{aligned} &\sum_{k \in K_{od}^{m(p)}} h_k = g_{od}^{m(p)}, \\ &o \in O,\quad d \in D,\quad m(p) \in M(p),\quad p \in P, \end{aligned} \tag{4}$$

where h_k is the flow for the route k, non-negativity constrains:

$$h_k \geq 0,\ k \in K_{od}^{m(p)},\ o \in O,\ d \in D,\ m(p) \in M(p),\ p \in P. \tag{5}$$

Let Ω be a set of flows v satisfying (4) and (5). Since the flow equation is defined in the space of flow routes, let us use the following relationship between the branch and route flows for the sake of convenience:

$$v_a^p = \sum_{k \in K^p} \delta_{ak} h_k,\ a \in A,\ p \in P, \tag{6}$$

where $K^p = \bigcup_{m(p) \in M(p)} \bigcup_{o \in O} \bigcup_{d \in D} K_{od}^{m(p)}$ is a set of routes o that may be used for delivering p

$$\delta_{ak} = \begin{cases} 1, \text{ when } a \in k \\ 0 \text{ differently} \end{cases}$$

is an indicator function defining the branches of a particular route. It also applies to the branches of cargo transfer:

$$v_t^p = \sum_{k \in K^p} \delta_{tk} h_k,\ t \in T,\ p \in P, \tag{7}$$

where

$$\delta_{ak} = \begin{cases} 1 \text{ when } t \in T \\ 0 \text{ differently.} \end{cases}$$

Cargo transfer t is on the route k, if two branches determining the transfer refer to this route. Finally, minimizing the objective function (3), and satisfying the constraints of (4) – (5) as well as the

constraints according to the definition in (6) – (7) obtain an optimal multimodal distribution model of various kinds of goods.

A described model is of a general character and may be applied to define the demand in various ways. Though the model is used when the choice of transport facilities allowing referring the demand for product g^p to a particular subset of a set of transport facilities has been made 'a priori', a possibility remains to transport goods by all available means of transport, if the need arises. This means that $m(p)$ is a set of all transport facilities of a network, while $M(p)$ has only one component, which is $m(p)$ in this case. The model is flexible allowing us to describe intermodal traffic as well. The transfer of cargo from one transport facility to another may be made only at particular nodes of a network and the particular means of transport may be used. The model is also adequate when various large investment scenarios are compared.

It is assumed that the demand for goods is exogenously assigned but the choice of the haulier or a particular transport has not been introduced in the expression yet. Therefore, we assume that the behaviour of the sender is reflected in the matrix of origin and destination nodes and in the details of transport facility selection. However, it should be noted that if some information about the senders and their transport facilities is available, it could be introduced into the model, with the appropriately defined subsets of admissible means of transport in the respective O/D matrix. The ultimate flows of transport facilities are known, while precise data about the hauliers is actually not available. The above model allows us to describe the infrastructure, transport means and services and prescribe the particular kinds of goods to be carried by several means of transport simultaneously. This allows us to describe a competition in terms of the goods to be carried and the available services, which is relevant for determining network extension scenarios. Though the goal is to offer a method of strategic planning available to the whole country, the model is sufficiently flexible to be used in describing the infrastructure for a single haulier. In other words, a suggested model is capable of describing a large multimodal system for transportation of various goods for strategic planning. However, it may also be used for the analysis of the cargo carried by one haulier.

3. A GENERAL MATHEMATICAL MODEL FOR MULTIMODAL TRANSPORTATION

A mathematical model is aimed at optimising multimodal transportation based on using various means of transport. The objective function of the model used to determine the minimal costs and minimal time of delivery as well as minimal pollution of the environment as a constant for particular transport facilities and minimal costs of cargo insurance will be as follows:

$$Z_{\min} = \min\left(\sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} x_{ij} + \sum_{k=1}^{l} \overline{V}_k + \sum_{k=1}^{l} \overline{T}_k + \sum_{k=1}^{l} \overline{D}_k \right) \tag{8}$$

where C_{ij} is the cost (Lt) of delivering a container from the i-th loading place to the j-th place of destination $(i = 1 \div m, \quad j = 1 \div n)$;

x_{ij} the number of containers (units) to be carried from the i-th loading place to the j-th place of destination $(i = 1 \div m, \quad j = 1 \div n)$;

$\overline{V}_k$ is the average cost of an hour of container transportation (Lt) $(k = 1 \div l)$;

$\overline{T}_k$ is the average cost of transport facility (Lt) in terms of the environment pollution $(k = 1 \div l)$;

$\overline{D}_k$ is the average insurance cost of cargo (Lt) carried by a particular kind of transport facilities $(k = 1 \div l)$.

The limiting conditions of the mathematical model for a balanced transportation problem are expressed in the following way:

$$\begin{cases} \sum_{j=1}^{n} x_{1j} \le b_1 \\ \sum_{j=1}^{n} x_{2j} \le b_2 \\ \ldots\ldots\ldots\ldots \\ \sum_{j=1}^{n} x_{mj} \le b_m \end{cases} \quad (9) \qquad \begin{cases} \sum_{i=1}^{m} x_{i1} = a_1 \\ \sum_{i=1}^{m} x_{i2} = a_2 \\ \ldots\ldots\ldots\ldots \\ \sum_{i=1}^{m} x_{in} = a_n \end{cases} \quad (10)$$

$x_{ij} \ge 0$, when $i = 1 \div m$

$j = 1 \div n,$

moreover,

$$\sum_{i=1}^{m} b_i = \sum_{j=1}^{n} a_j \quad (11)$$

where b_1, b_2, ... b_m are containers (units) at destination places (demand).

If the condition (11) is not satisfied, then an imaginary place of loading or destination is introduced to obtain a balanced transportation problem.

$\sum_{K=1}^{l} \overline{V}_k$ is the average cost of container delivery;

$\sum_{K=1}^{l} \overline{T}_k$ is the average cost of using a particular kind of transport facilities in terms of the environment pollution;

$\sum_{K=1}^{l} \overline{D}_k$ is the average cost of cargo insurance for a particular kind of transport facilities, i.e. all three components of an objective function depend on x_{ij} which is the number of containers (units) carried from the i-th loading place to the j-th place of destination and, thus, on the number of hauls.

For example, containers may be carried by rail, motor or sea transport, while the number of containers in a haul varies. Therefore, when calculating average expenses for different modes of transportation, the number of hauls should be taken into consideration.

4. CONCLUSION

A mathematical model aimed at optimising multimodal transportation based on the use of various kinds of transport facilities and allowing us to choose the most suitable means of transport and services in any particular case is offered in the present paper.

References

[1] Bauersox D. J., Closs D.J. *Logistics. An Integrated Chain of Shipments*. Moscow, 2001. 639 p.
[2] Fumero F., Vercellis C. Synchronized Development of Production, Inventory and Distribution Schedules, *Transportation Science*, 33, 1999, pp.330-340.
[3] Mazūra M. Predicting Major Trends of Transportation Development, *Transport Engineering*, Vol.XXI, No 2, 2002.
[4] Schary P.B., Skjott-Larsen T. *Managing the Global Supply Chain*. 1995. 395 p.
[5] Baublys A. *An Introduction to the Theory of Transport Systems*. Vilnius: Technika, 1997. 298 p.

THE ANALYSIS OF APARTMENT HOUSE CONSTRUCTION INVESTMENTS EFFICIENCY APPLYING MATHEMATICAL MODELLING

Leonas Ustinovichius[1], Edita Šarkienė[2]

Vilnius Gediminas Technical University
Civil Engineering Faculty
Department of Construction Technology and Management
Saulėtekio al. 11, LT-10223, Vilnius 40, Lithuania
[1]E-mail: leonasu@st.vtu.lt
[2]E-mail: Edita.Sarkiene@adm.vtu.lt

In the paper the application of mathematical modelling to evaluating the efficiency and risk of investment projects is discussed.

Keywords: *apartment house, construction, investment, mathematical modelling*

1. INTRODUCTION

In real estate sector, especially in construction or purchasing of commercial buildings or apartment house, adequate evaluation of market development and property management is of paramount importance. To ensure the reliability of the investment projects, which is closely associated with the appropriate research into the problems of market and property management and processing of the data obtained, it is necessary to define a set of criteria for the appropriate building selection. A comprehensive analysis of reliable market data is the most important factor for developing the construction investment projects [25, 27, 29] as well as for selecting a property management project and the appropriate processing of attributes by various mathematical models.

The method of simulation is widely used in solving the problems of strategic planning [16] and financing of large industrial companies [2, 4, 5, 6, 7, 14], as well as in organizing the work of small corporations [11, 23, 26], and developing strategies of construction management and in construction planning [17, 24]. The considered method is also applied to simulation of building processes [1, 3, 8, 15, 21, 22, 26, 30] and making financial solutions by construction firms [12, 19]. In each case it is necessary to analyse the initial data [9, 18].

The state of macroeconomics in the country also has an indirect impact on real estate market, implying that the individuals and firms engaged in real estate business experience its effects [20]. The economic situation and legislative basis of the state determine their activities in this area. The better the macroeconomic indices, the better the situation on real estate market.

Any particular case of mathematical modelling is very specific being dependent to a large extent on the particular area of application. In very few cases, application of a model in a particular scientific field or area of practical activities may be extended to other areas without making essential changes. Most of the economic models are discrete, implying that the initial data and the results obtained are discrete values. In the suggested model, the most probable variation intervals of the parameters are taken as a basis of modelling. Opportunities of such approach it has been proved in Lee et al. [13]. The modelling is aimed at determining zones relating to the quality of decisions in the area of investment.

2. A METHOD OF DETERMINING VARIOUS RISK ZONES OF INVESTMENTS

Mathematical modelling can be used for determining the efficiency of the investment projects [28]. A quantitative method offered for evaluating the efficiency of investment in the apartment house purchase, decoration and sale is given below. In developing this method much attention is paid to the accuracy of the initial data and investment risk analysis. Notations: k – grade (category) of a building; $1 \le k \le q$ ($k \in N$), q – the total number of a premises of various grades (categories); P (k) – building selling price; $P_{\min}(k)$, $P_{\max}(k)$ – minimum and maximum price; $A_{\min}(k)$, $A_{\max}(k)$ – minimum and

maximum decoration cost (the initial purchase cost included); $\overline{P}(k)$, $\overline{A}(k)$ – average prices, respectively.

Based on the statistical data $P_{min}(k)$, $P_{max}(k)$, $A_{min}(k)$, $A_{max}(k)$, where $k=k_{min}$, $k_{min}+1$, …, k_{max}, interpolation polynomials of $n = k_{max}–k_{min}$ degree, are obtained, which are written as $a_n k^n + a_{n-1}k^{n-1} + ... + a_1 k + a_0$ for all dependent $P_{min}(k)$, $P_{max}(k)$, $\overline{P}(k)$, $A(k)$, $A_{min}(k)$, $A_{max}(k)$, where variable k is changing continuously, rather than discretely: $k_{min} \le k \le k_{max}$. This set is denoted by *K*. All functions given above are usually the increasing functions of the argument *k*.

Determining zones of various investment risk exposure. Risk zones may be defined as risk – free, standard risk, high-risk zones and a zone of losses. Their detailed analysis is given below.

Risk – free zone of investment. This is an area where the minimum selling price of premises $P_{min}(k)$ is higher than the maximum price of finished building $A_{max}(k)$ (initial purchase price included), i.e. a set K_+ of values k satisfying this inequality, $P_{min}(k) - A_{max}(k) > 0$. This set may be either empty $\varnothing$ or representing a union of separate intervals of $k \in [k_{min}, k_{max}]$.

Algorithm for determining risk – free zone K_+. The algorithm considered is represented as a series of steps:

1. The real roots (if any) $k_1 < k_2 < ... < k_l \quad (l \le n)$, belonging to the interval $[k_{min}, k_{max}]$: $k_i \in [k_{min}, k_{max}]$ (i=1, …, l) are found for polynomial $P_{min}(k) - A_{max}(k) = 0$.

2. At all the intervals (k_{min}, k_1), (k_1, k_2), …, (k_l, k_{max}) signs of the difference $P_{min}(k) - A_{max}(k)$ are determined. To assess the continuity of the function $P_{min}(k) - A_{max}(k)$, it is sufficient to find the sign, i.e. to determine the expression value at the points of each interval.

3. The intervals with a positive difference $P_{min}(k) - A_{max}(k)$ (if any) are selected from the intervals obtained. It is a set K_+.

If a set K_+ coincides with the interval [kmin, kmax], then the whole interval $k_{min} \le k \le k_{max}$ is a risk – free investment zone. In this case, no other zones are sought for.

In Fig. 1 various ways of determining the particular risk-free zones are graphically illustrated.

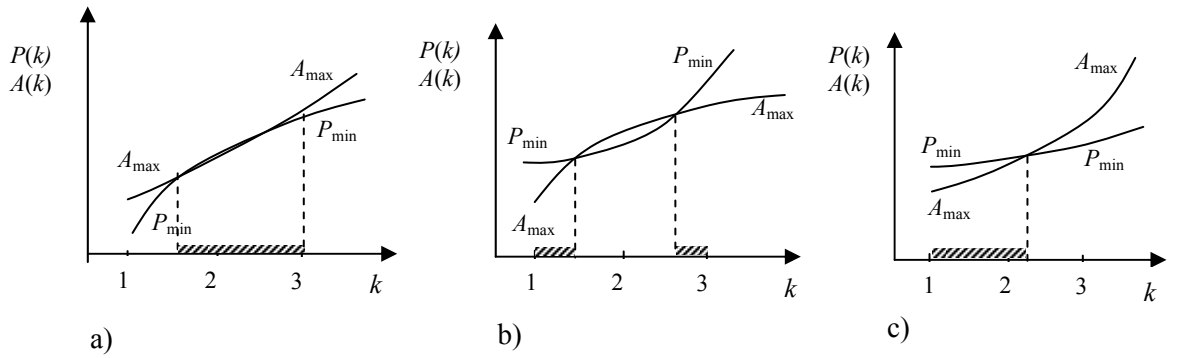


Figure 1. *The determination of risk-free zones*

Standard risk zone of investment $K_=$. This is zone $\overline{K}$, where an average selling price $\overline{P}(k)$ is higher than an average decoration price $\overline{A}(k)$ (initial purchase cost included), except for risk – free investment zone K_+: $K_= = \overline{K} \setminus K_+$.

The determining of a standard risk zone is shown in Fig. 2.

Algorithm for determining zone $K_=$. It consists of the following steps:

1. Real roots (if any) $\overline{k}_1 < \overline{k}_2 < ... < \overline{k}_m \quad (m \le n)$ of the polynomial $\overline{P}(k) - \overline{A}(k) = 0$ of the interval $[k_{min}, k_{max}]$: $\overline{k}_j \in [k_{min}, k_{max}]$ $(j = 1,...,m)$ are determined.

2. In all the intervals $(k_{min}, \overline{k}_1), (\overline{k}_1, \overline{k}_2), ..., (\overline{k_m}, k_{max})$ the differential signs of $\overline{P}(k) - \overline{A}(k)$ are determined, i.e. the differential signs at least at one point of every interval are found.

3. The intervals with a positive $\overline{P}(k) - \overline{A}(k)$ difference are chosen from the intervals obtained. This is zone $\overline{K}$.

4. The intersections of the intervals in zone K_+ are singled out from zone $\overline{K}$ intervals, i.e. $K_= = \overline{K} \setminus K_+$ is found (Fig. 2).

If zone $\overline{K}$ matches all the intervals $k_{\min} \le k \le k_{\max}$, then the search for investment zones is over.

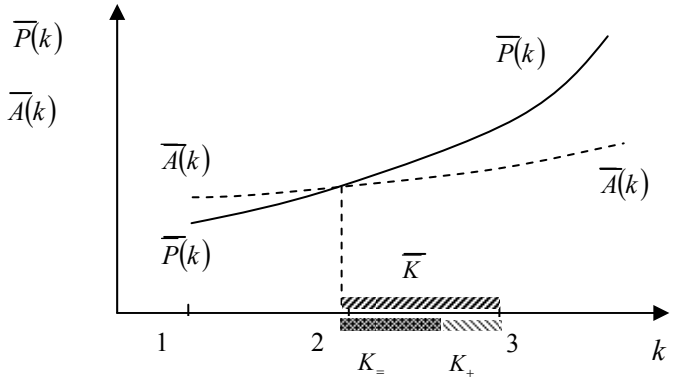


Figure 2. *Minimum risk investment zone*

High-risk investment zone K_0 and zone of losses K_-. These two zones may be defined simultaneously, or K_0 may be determined after K_-.

Zone of investment losses K_- (if any) is a zone where the maximum selling price of premises $P_{\max}(k)$ is lower than the minimum decoration cost (primary purchase price included) $A_{\min}$ (Fig. 3).

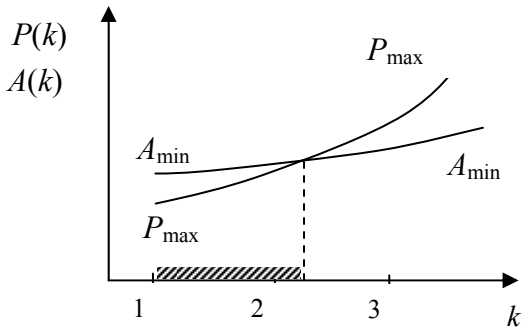


Figure 3. *Determination of zone of losses*

An algorithmn for determining zone K_- is similar to that for defining K_+: it is based on the intervals where the difference $A_{\min}(k) - P_{\max}(k)$ is positive.

A zone of high risk K_0 is such an area, where the mean selling price of the spaces $\overline{P}(k)$ is lower than the average price of the decoraited spaces $\overline{A}(k)$ with respect to the initial price (except for zone K_-). K_0 may be found as the difference between the interval $K = \{k_{\min} \le k \le k_{\max}\}$ and the earlier obtained sets $K_0 = K \setminus (K_+ \cup K_= \cup K_-)$. It is assumed that these are no other investment zones, i.e. $K = K_+ \cup K_= \cup K_- \cup K_0$. A set K_0, similar to $K_=$, may be an empty set Ø.

The above zone K_0 may be defined, and the intervals may be determined in a similar way as for zone $K_=$, where $\overline{P}(k) - \overline{A}(k)$ difference is negative. A set K_- (or, perhaps, and earlier defined sets K_+ and $K_=$) may be singled out from the obtained intervals.

3. THE ANALYSIS OF INVESTMENT IN LITHUANIA

Recently, the real estate market in Lithuania has become more brisk. The need for modern newly – built apartments is great. However, the quality of the premises (spaces) does not always meet the requirements. The rent and market price of the premises largely depend on the quality of the particular building. Buildings are divided into three groups (class) according to construction quality: A, B and C [10].

The requirements for apartment house of the class A include air conditioners, modern lifts, a large parking area, good communication lines, 24 hour guard, accessibility for transport. B class apartment house are of sufficiently high quality, however, they may lack lifts, air conditioners or sufficient parking space. C class apartment houses are of satisfactory quality, being located in old buildings. They often do not meet any of the requirements for A class buildings.

In fact, the selling price of real estate on the market had been rising for the whole period of its existence (from 1990 to 1999). It can be accounted for high inflation rate, interest rate higher than that in the bank, profitability of investments, real estate shortage, etc. Since the middle of 1999 the prices have sharply fallen. From the first quarter of 2000 they are remaining stable up to the present time.

Analysis of apartment house decoration, initial purchase and selling prices in the city of Vilnius is given. On the basis of the calculations made, the table and cost graphs were drawn showing the dependence of the estimated cost of 1 m^2 of the total apartment space on the grade of a apartment house (Fig. 4). The graph is rather subjective, because cost estimation of building finishing is a complicated problem, associated with individual, often unique features of the particular buildings. Therefore, the costs are estimated in terms of the intervals separating the maximum and minimum costs. Further, cost level in graphs is represented as bars (not lines).

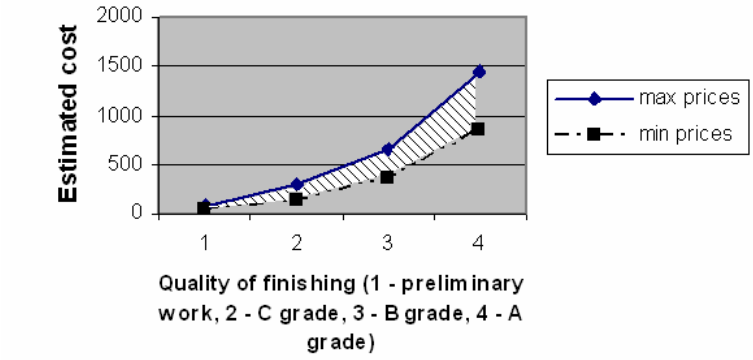


Figure 4. *Cost of apartment house decoration*

Cost analysis of apartment houses is given. The cost of 1 m^2 apartment house space in a decorated building depends on its grade (A, B, C) as well as location. The city area may be divided into zones of buildings practically of similar grades. However, there will be some differences between the buildings of the same grade, depending on the location of a particular building. This is why costs of apartment house space are represented in terms of intervals (separating the maximum and minimum prices).

Initial purchase price of non – decorat apartment house. The price of such apartments depends primarily on their location. A division of the city areas is similar to that used for selling price analysis.

4. A MATHEMATICAL MODEL FOR COST ANALYSIS OF PURCHASING, DECORATION AND SALE OF APARTMENT HOUSE SPACES IN VILNIUS

Let us demonstrate the application of the suggested method to the determining of various types of investment zones by considering the available data on various Vilnius districts. The apartment premises analysed belong to three various categories, therefore the interpolation 2-nd degree polynomials have been used. The problem with more than three categories or with other numbers may be solved in a similar way. In addition to the main variable k (grade of premises), a model may include some other variables r (e.g. a district for investment).

Example

For the values P_1, P_2, P_3 and A_1, A_2, A_3, the expression $P_{\min}(k) - A_{\max}(k)$ – was calculated and a risk-free investment zone K_+ was found.

For the values $\overline{P_1}$, $\overline{P_2}$, $\overline{P_3}$, and $\overline{A_1}$, $\overline{A_2}$, $\overline{A_3}$, the expression $\overline{P}(k) - \overline{A}(k)$ was calculated, and a zone of normal risk investment $K_=$ was found. It is evident that other investment zones do not exist.

By collecting the statistical data and grouping the districts with similar conditions of investment, it is possible to introduce a generalized district factor r into a model of identifying various investment zones, in addition to the factor K determining grade of spaces.

Based on a correlation analysis of the data, major relationships were derived, which make a model for determining the cost of decoration purchase and sale of Vilnius apartment house (Table 1).

Table 1. A set of relationship to determine the effectiveness of decoration

F-test	Total square error	Model application	Model (relationship) (In the given models k=2, 3, 4 values are used; r – district No; $1 \le r \le 14$)
12,45	92,60	Maximum decoration cost	$A_{max} = 130 + 275k$
58,,80	99,80	Minimum decoration cost	$A_{min} = 207 + 140k$
20,67	95,40	Average decoration cost	$\overline{A} = 163 + 210k$
53,36	94,70	Maximum selling price of premises	$P_{max} = -103 + 3900r + 275k$
49,85	94,30	Minimum selling price of premises	$P_{min} = 1807 + 1050r + 140k$
22,09	88,00	Average selling price of premises	$\overline{P} = 1963 + 1400r + 210k$

Models for determining risk zones of investment in buildings. A set of relationships obtained can be used for developing mathematical models for determining various types of investment risk zones.

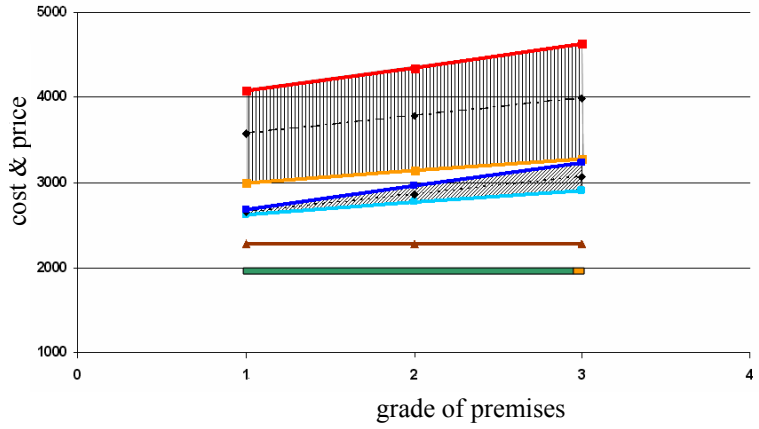
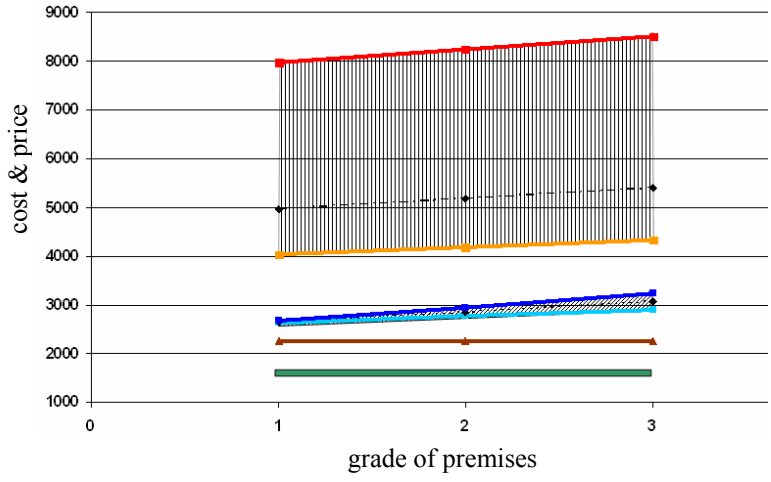
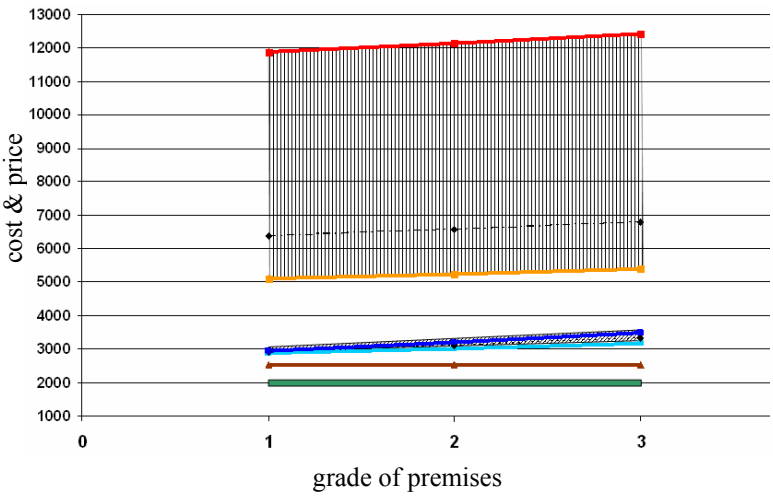
By determining a risk-free investment zone based on the main factor expressed as $P_{\min}(k) - A_{\max}(k) > 0$. In a similar way, models for determining normal risk, high risk and unprofitable (losses) zones were derived (Table 2).

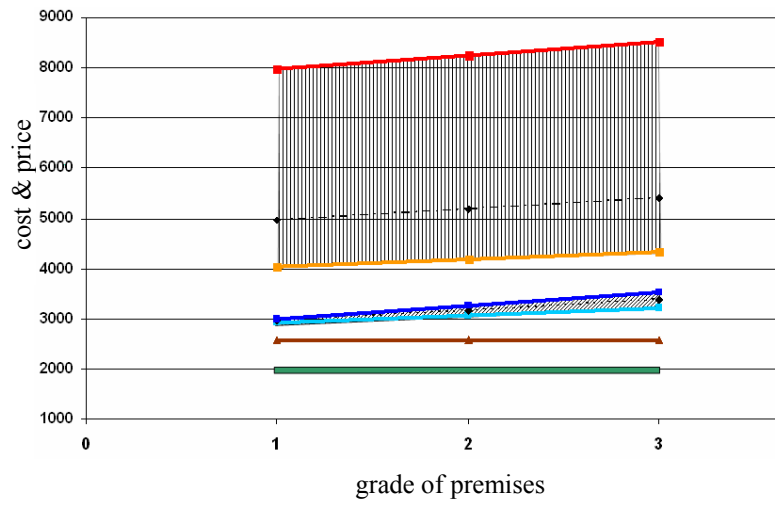
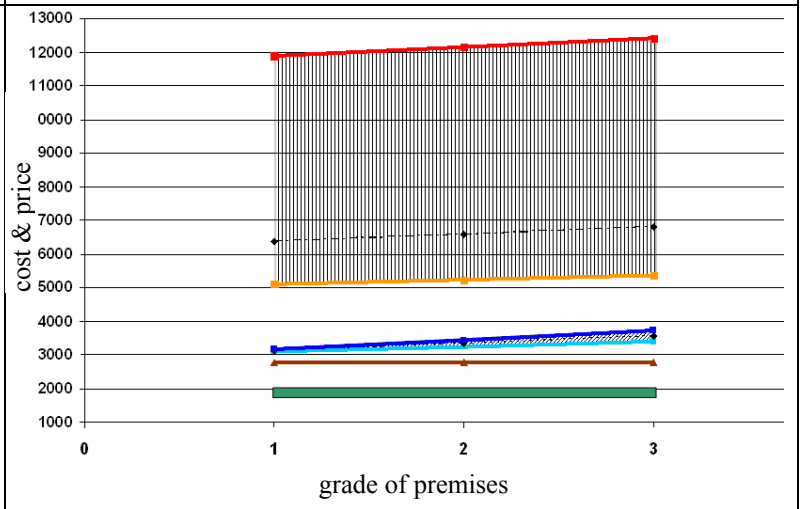
Table 2. Models for determining risk zones

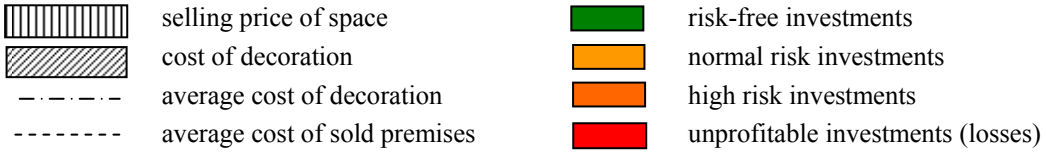
Nr.	Model application	Model expression
1.	Risk – free investment zones	$P_{min} - A_{max} = 1807 + 1050r + 140k - 130 + 275k$;
2.	Normal risk zones	$\overline{P}(k) - \overline{A}(k) = 1963 + 1400r - 163 + 210k$
3.	High risk and losses zones	$A_{min} - P_{max} = 207 + 140k - (-103 + 3900r + 275k)$

By applying the defined mathematical models, the graphs of distribution of various investment risk zones in Vilnius districts were plotted (graphs for individual districts are shown in Table 3). Optimisation of the received mathematical models is possible by applying multiattribute decision-making approach [31]

Table 3. Graphs of distribution of investment risks in different districts

R	District	The graphs
1	Modern residential districts (Seskine, Baltupiai, Lazdynai, Karoliniskes)	
2	Antakalnis	
3	Other short streets in Senamiestis district	

4	Zverynas	
5	Gediminas Av., Didzioji, Pilies, Vokieciu str.	



The analysis of the graphs obtained allows us to conclude that, taking into account the investment risks, the effect of investments may be determined. Several groups of districts may be identified with respect to the type of investment:

- for districts r = 8;10;13;14 (which are the most fashionable and prestigious districts of Vilnius) practically any kind of decoration of the purchased spaces of any rate is effective, because all investments are in a risk-free zone. The first-rate decoration work is preferable, however, medium-rate work will also pay;
- for districts r = 2;3;4;5;9, a risk-free zone embraces spaces of grade A. However, the investment into a medium-rate decoration will also pay off;
- in districts r = 7;11;12 risk-free and profitable investments are associated with average grade spaces. The investments into higher grade spaces are also effective, however, in this case, the initial investments are considerably larger;
- for the investments into buildings in districts r = 1,6 to be effective, a more detailed analysis of the particular cases is needed. Zones of normal risk are characteristic of these districts.

5. CONCLUSION

The suggested technique allows for computer-aided determination of risk zones in making investments in profitable real estate. The available database of various types of premises and typical districts of the city provides a possibility of determining the most probable risk zones for investment in particular projects quickly and reliably.

The model used in the present work allows for including other criteria determining the investment risk. The calculations made for various districts of Vilnius proved the effectiveness of the described method.

Solving actual problems of selecting the best variants of construction and reconstruction investment projects validated the developed methods. The investment projects selected have been implemented.

References

[1] Alkoc E., Erbatur P. Productivity Improvement in Concreting Operations through Simulation Models, *Building Research and Information*, 25(2), 1997, pp.82-91.

[2] Burton R. M., Damon W. W., Obel B. An Organizational Model of Integrated Budgeting for Short-Run Operations and Long-Run Investment, *Journal of the Operational Research Society*, 30, 1979, pp.575-585.

[3] Cheng M. Y., O'Connor J. T. Simulation Analysis of Process Piping Construction. In: *Automation and Robotics in Construction, Vol. X*. Amsterdam: Elsevier, 1993, pp.519-545.

[4] Damon W. W., Schramm R. A Simultaneous Decision Model for Production, Marketing and Finance, *Management Science*, 19(2), 1972, pp.161-172.

[5] Dhrymes P., Kurz M. Investment, Dividends, and External Finance Behaviour of Firms. In: *Determination Investment Behavior* /R. Ferber, Ed. New York: Columbia University Press, 1967.

[6] Guerard J. B., Stone B. K. Strategic Planning and the Investment-Financing Behaviour of Major Industrial Companies, *Journal of the Operational Research Society*, 38(12), 1987, pp.1039-1050.

[7] Hamilton W. F., Moses M. A. An Optimization Model for Corporate Financial Planning, *Operations Research*, 21(3), 1973, pp. 677-692.

[8] Huang R. Y., Halpin D. Dynamic Interfaces Simulation for Construction Operations (DISCO). In: *Automation and Robotics in Construction, Vol. X.* Amsterdam: Elsevier, 1993, pp.503-513.

[9] Jenkins L., Anderson M. A Multivariate Statistical Approach to Reducing the Number of Variables in Data Envelopment Analysis, *European Journal of Operational Research*, 147(1), 2003, pp.51-61.

[10] Joint-stock company "Ober – Haus", 2004. Real estate databases.

[11] Kim N., Han J. K., Srivastava R. K. A Dynamic IT Adoption Model for SOHO Market: PC Generational Decisions with Technological Expectations, *Management Science*, 48(2), 2002, pp.222-240.

[12] Lam K. C., Runesos G. Modeling Financial Decisions in Construction Firms, *Construction Management and Economics,* 17(5), 1999, pp.589-602.

[13] Lee H., Tanaka H. Upper And Lower Approximation Models In Interval Regression Using Regression Quantile Techniques, *European Journal of Operational Research*, 116(3), 1999, pp.653-666.

[14] McCabe G. M. The Empirical Relationship between Investment and Financing: a New Look. *Journal of Financial and Quantitative Analysis*, 14(1), 1979, pp.119-135.

[15] Moselhi O., Hanson S. Computer Simulation of Concrete Slab-on-Grade Construction. In: *Automation and Robotics in Construction, Vol. XI.* Amsterdam: Elsevier, pp.125-157.

[16] Mosmans A., Praet J. C., Dumont Ch. A Decision Support System for the Budgeting of the Belgian Health Care System, *European Journal of Operational Research*, 139(2), 2002, pp.449-460.

[17] Ng S. T., Mak M. M., Skitmore R. M., Vamam M. The Predictive Ability of Bromilow's Time-Cost Model, *Construction Management and Economics*, 19(2), 2001, pp.165-173.

[18] Olinsky A., Chen Sh., Harlow L. The Comparative Efficacy of Imputation Methods for Missing Data in Structural Equation Modeling, *European Journal of Operational Research*, 151(1), 2003, pp. 53-79.

[19] Peterson P., Benesh G. A Reexamination of the Empirical Relationship between Investment and Financing Decisions, *Journal of Financial & Quantitative Analysis*, 18(4), 1983, pp.439-454.

[20] Prorvich V. Basic Principles of Evaluating Urban Territories. Moscow: Publishing house "Delo", 1998. 335 p. (in Russian).

[21] Senior B. A. Late-Time Computation for Task Chains Using Discrete-Event Simulation, *Journal of Construction Engineering and Management*, 121(4), 1995, pp.397-403.

[22] Shi J., AbouRizk S. M. Resource-Based Modeling for Construction Simulation, *Journal of Construction Engineering and Management,* 123(1), 1997, pp.26-33.
[23] Sinha R. K., Chandrashekaran M. A Split Hazard Model for Analyzing the Diffusion of Innovations, *Journal of Marketing Research*, 29(1), 1992, pp.116-127.
[24] Skitmore M., Ng T. Australian Projects Time-Cost Analysis: Statistical Analysis of Intertemporal Trends, *Construction Management and Economics*, 19(5), 2001, pp.455-458.
[25] Stasiulionis A., Ustinovichius L., Zavadskas E. K. Market's Multicriteria Based Development of Commercial Property in Baltic Countries, *Bridges*, 21(4), 2002, pp.31-38. (In Lithuanian).
[26] Sutcliffe V. M. Use of Technology Improves Competitiveness, *Managing Technology,* 41(3), 1996, pp.10-11.
[27] Tarasevich E. *The Analysis of Investments into Real Estate*. St. Petersburg: MKC, 2000. 428 p. (In Russian).
[28] Ustinovichius L., Podvezko V. A Mathematical Modelling Method of Determing Investment Efficiency in Construction. In: *Modelling and Simulation of Buisness Systems: Proceedings of the International Conference held in Kaunas, Lithuania 13-14th May 2003*. ISBN 9955-09-420-6, 2003, pp.160-164.
[29] Ustinovičius L., Stasiulionis A. Evaluation of Siting of Commercial Enterprises from Various Perspectives, *Journal of Civil Engineering and Management,* 7(6), 2001, pp.474-480. Vilnius: Technika. (In Lithuanian)
[30] Vanegas J. A., Opdenbosch A. Using Simulation and Visualisation Technologies to Strengthen the Design Construction Interface. In: *Proceedings of the 1994 Winter Simulation Conference*, 1994, pp.1137-1181.
[31] Zavadskas E. K., Peldschus F., Ustinovichius L. Development of Software for Multiple Criteria Evaluation, *Informatica*, 14(2), 2003, pp.259-272. (Institute of Mathematics and Informatics Lithuanian Academy of Science)

THE OPERATION OF THE GAUGE CHANGING FACILITY OF THE NEW RAILWAY LINE RAIL BALTICA

Jonas Jonaitis

Vilnius Gediminas Technical University
Faculty of Transport Engineering
Department of Transport Management
Plytines Str. 27-407, Vilnius, LT-2016, Lithuania
Ph: (+370)-2744781. Fax: (+370)-2745059. E-mail:Jonas.Jonaitis@ti.vtu.lt

This article describes the operation mode for the trains gauge changing facilities. These facilities enables the trains specially constructed or adapted for the gauge changing to run on the two gauge systems that will coexist in Lithuania, namely European Standard (UIC) gauge 1435mm and Wide (Russian) gauge 1520mm.
Several gauge-changing systems are available in the international market. The description below is based on the Talgo system. This system is state of the art and well proven. It operates on the Spanish – French Border (Irún/Hendaye) as well as on the connections of the Madrid – Seville Highs Speed Line (1435 mm gauge) and Spanish conventional rail network (1668mm) in Cordoba and Seville.

Keywords: *gauge changing facility, auxiliary locomotives, draggers*

1. INTRODUCTION

The railway line of Rail Baltica can be divided in two sub-sections:

1. Polish / Lithuanian border – Mauručiai Subsection (68 km). The Government of the Republic of Lithuania already approves the alignment of this sub-section;
2. Mauručiai – Kėdainiai Subsection (by-pass of Kaunas). Following three alignment alternatives were considered for this subsection:
   1. Eastern by-pass 1 (75.5). Crossing the river Nemunas over the Kaunas Sea dam and continuing northwards through Neveronys. Construction of a new interchange station in Palemonas;
   2. Eastern by-pass 2 (73.9 km). Crossing the river Nemunas over the Kaunas Sea dam and continuing northwards through Karmėlava. Construction of a new station close to Taikos Avenue (the station will serve only the new line, no interchange will be available);
   3. Western by-pass (62 km); construction of a new 2.024 km long viaduct to cross of the river Nemunas; construction of a new interchange station in Mauručiai.

This article describes the operation mode for the trains gauge changing facilities. These facilities enables the trains specially constructed or adapted for the gauge changing to run on the two gauge systems that will coexist in Lithuania, namely European Standard (UIC) gauge 1435mm and Wide (Russian) gauge 1520mm.

Several gauge-changing systems are available in the international market.

The description below is based on the Talgo system. This system is state of the art and well proven. It operates on the Spanish – French Border (Irún/Hendaye) as well as on the connections of the Madrid – Seville Highs Speed Line (1435 mm gauge) and Spanish conventional rail network (1668mm) in Cordoba and Seville.

2. LOCATION AND FACILITIES

The gauge changing facility will be located on the special track close to the Logistic Node. It will be installed between two turnouts separated by 167 m (point to point distance).

The facility itself will be installed in a pit 15.5x5x1.45m inside specially built building 22x9m and 8m headroom.

Two inspection pits will be located on the two accesses outside of the building. The inspection pits will be 6x4m and 1.45 m deep. The main objective of the pits will be to provide the possibility of axle inspection before entering in the gauge changing facility.

Two stub tracks will be located in the two sides of the gauge changing facility. The goal of these stub tracks will be to provide the possibility for the moving away of the locomotive in case that it is not suited for gauge changing.

3. OPERATION

The gauge changing will be done automatically in the following way (see figures on the next page):

1. The train enters into the gauge changing facility from the wider gauge track (Figure 1).
2. After the train has entered into the changing facility, the track rails descend and lose the contact with the train wheels; the vehicle is supported on the special guides (the axle does not support any load) (Figure 2).
3. The locks, which fix the wheel axle, are removed by means of another special guide located on the gauge changing facility frame (Figure 3).
4. At this moment the wheels are free for lateral movement. Either the guides push the wheel outside or a hydraulic piston pushes them inside (according the direction of train movement through the facility) until the wheel is in the position that corresponds to the new gauge (Figure 4).
5. The locks are activated and the new wheel positions are fixed (Figure 5).
6. Finally, the train is gradually placed on the rising track rails and the wheels start supporting the train.

The vehicle is than prepared to run on the new gauge (Figure 6).

4. ALTERNATIVES

This system permits two different modes of coach traction through the changing facility.

The movement of the train through the changing facility is done without a locomotive. This implies that the front locomotive should be uncoupled and moved away. Alternative traction is needed to move the train through the facility.

The following two possibilities are available:

1. Auxiliary locomotives that push the train until its head have passed through the changing facility.
2. A dragger to pull the train until its head has passed through the facility.

On both cases, after the train head has passed through it is coupled to the locomotive, which waits on the other side of the changing facility.

Either two auxiliary locomotives or two draggers are required in order for the system to be two way operative. A mixed system (one auxiliary locomotive and one dragger) is also possible.

The following sections describe the main characteristics of the two systems.

4.1. Auxiliary Locomotives

The auxiliary locomotive will push the train until its head has passed through the changing facility and can be coupled to the locomotive, which will be waiting on the other side.

In order to make the system more agile it would be convenient to construct an additional stub track which would be used by the auxiliary locomotive between the passing of two trains.

The stub tracks both for the auxiliary and for the main locomotive will be necessary on each side of the changing facility.

4.2. Draggers

The dragger will pull and pull the train until its head has passed through the changing facility and can be coupled to the locomotive which be waiting on the other side.

The dragger can be operated via remote control.

The dragger runs on the rail base and cannot be passed through the turnouts. Due to this fact the minimum length required for the train should be approximately 100m. Thus, when the dragger reaches the turnout point the first vehicle of the train will be already through the gauge changing facility and so can be coupled to the locomotive. In case of Talgo coaches the train should consist of at least 8 coaches.

Besides the dragger itself, its functioning implies the installation of four electrical motors, four reducers, control panel, power and control cabling and ducts. This system also implies substantial civil works, namely concrete slab track along the whole dragger course.

The system is prepared for outdoor operation and there are no lengths limitations.

Investment cost for two draggers of 120m lengths is approximately 190,000 Euro (VAT excluded). The cost of associated civil works is approximately 120,000 Euro (VAT excluded).

Operation of the Gauge Changing Facility

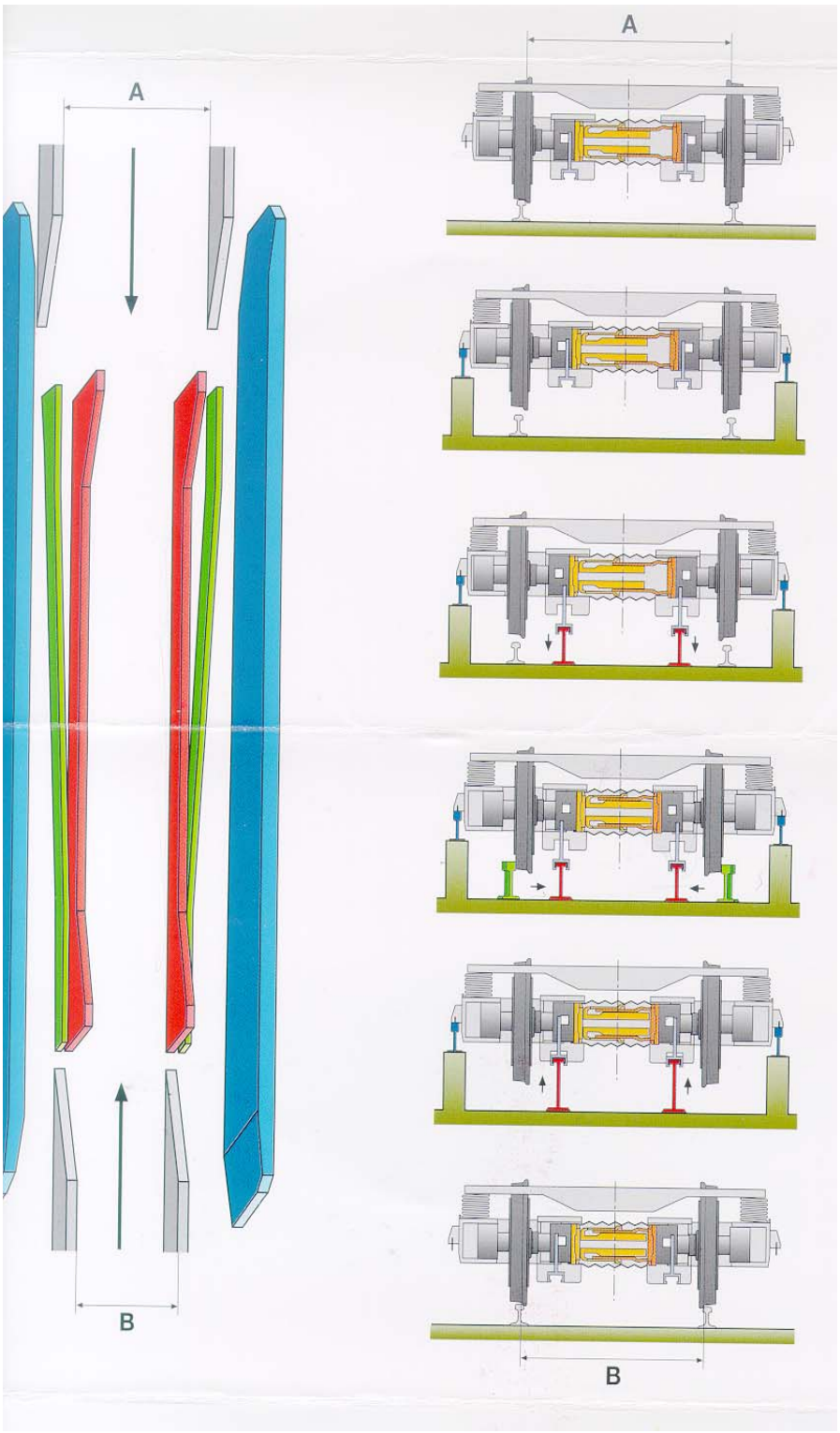


Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

5. CONCLUSIONS

1. The trains gauge changing facilities enables the trains specially constructed or adapted for the gauge changing to run on the two gauge systems that will coexist in Lithuania, namely European Standard (UIC) gauge 1435mm and Wide (Russian) gauge 1520mm.
2. Connection of the new "Rail Baltica" line to the existing wide gauge line Kaunas - Kybartai by means of implementation of the Gauge Changing Facility in Mauručiai Area.
3. Talgo system permits two different modes of coach traction through the changing facility.
4. The auxiliary locomotive will push the train until its head has passed through the changing facility and can be coupled to the locomotive, which will be waiting on the other side.
5. The dragger will pull and pull the train until its head has passed through the changing facility and can be coupled to the locomotive which be waiting on the other side.

References

[1] Pre-feasibility studies for the European Gauge Railway Link from the Polish Border to Kaunas: GOPA–Consultants (Status Report, September 2000) and AB Kelprojektas and TRRI (Assessment Report, January 2003).
[2] Logistic and Multimodality, Intelligent Transport Systems and Inter-Operability Development Concept for the Kaunas Logistic Node, Phare Programme Nº. LI 9702, November 2000, HPC/UNICONSULT/Spiekermann/ EDI Management.
[3] European standard railway line PL/LT border – Kaunas. Construction justification. Transport Road Research Institute (Lithuania), 1998.
[4] European standard railway line Polish/Lithuanian border – Kaunas. Special Plan. Transport Road Research Institute (Lithuania), 1999.
[5] European Union directive 96/48/EB, defining trans-European high-speed railways system interaction.
[6] Traffic Forecast on the TEN Pan-European Transport Corridors of Helsinki, NEA Company, Netherlands.
[7] "Building Construction Justification. Summary" Transport Ministry of Lithuania State. Enterprise "Transport and Road Research Institute", Kaunas 1998.
[8] "Obligatory Documents for Technical Design. Special Plan. Summary." Ministry of Transport and Communications of the Republic of Lithuania Transport Investment Directorate, Kaunas 1999.

RETROFITTED REAR SUSPENSION EFFICIENCY

Marijonas Bogdevičius, Raimundas Junevičius

Vilnius Gediminas Technical University
Transport Engineering Faculty
Department of Transport Technological Equipment
Plytinės g.27, Lt-10105, Vilnius-16, Lithuania
Ph: (+370 5) 274 47 82. E-mail: rj@ti.vtu.lt

It is popular to retrofit cargo van to passenger mini Bus. Such retrofitting is based on cargo vans, gross weight up to 5t and intended for 10 – 22 passenger seats. Usually the retrofitters in order to improve vehicle ride and passenger comfort are upgrading suspensions. The main aim of this investigation is to compare ride differences of the retrofitted rear vehicle suspension and to evaluate vehicle dynamic characteristic improvement. Three types of a quarter vehicle rear suspensions dynamic models are presented. The first one is a typical cargo van leaf spring suspension, the second most popular retrofitted suspension with additionally mounted air chamber; the third one has modified leaf spring at one end fixed to the vehicle body through an air chamber. As the road disturbance is used speed reduction bump. Mathematical simulation is made with Maple using Runge-Kutta method.
Paper presents variation of the different suspensions natural frequencies; quarter vehicle body accelerations and air spring pressure dependences on natural frequencies of quarter vehicle rear suspension; quarter vehicle vertical body accelerations in respect to time. Dynamic characteristics of all three vehicles rear suspensions are compared and the results are listed.

Keywords: *vehicle, rear suspension, dynamics, numerical methods*

1. INTRODUCTION

Rear suspension structure influences on the characteristics of the vehicle, i.e. not only on comfortable and safe driving, but also on the payload volume in the passenger and baggage sections. Since the space for the elements of suspension is scarce, their layout shall be as compact as possible, but also system shall be functional. Pivot elements of the wheel shall turn the wheel in the direction perpendicular to the direction of the vehicle movement as little as possible (not to increase the rutting). Wheel shall change inclination angle to road surface as little as possible. The durability of joints and wear of tyres are influenced by the positioning of all elements of the suspension. Smooth operation of the suspension elements governs on the kinematical and dynamic characteristics of the vehicle suspension.

Vehicles are upgrading, their driving speed and acceleration increase, therefore, can be lost wheel contact with the road surface, reduced adhesion coefficient and increased the braking distance. High suspension elements speed and acceleration can be a cause of contact with vehicle's body.

In case of improving passengers' comfort in a cabin, safety characteristics are decreased, and vice versa, when the safety characteristics are improved, the drivers and passengers' comfort are decreased.

Comfort and safety arrangement is one of the main problems faced by manufacturers. Over the world minibuses are manufactured by retrofitters or bodybuilders. Retrofitting is usually carried out on the base of a cargo van; therefore, to improve passengers' comfort retrofitters are upgrading parent suspension system.

The most popular retrofitting method among manufactures is to set an additional elastic element, for example, an air spring, into the bus suspension.

In this paper there are compared three suspension systems: the first one is a typical cargo van leaf spring suspension, the second most popular retrofitted suspension with additionally mounted air spring; the third one has modified leaf spring at one end fixed to the vehicle body through an air spring. As the road disturbance is used speed reduction bump. Mathematical simulation is made with Maple program using the third order Runge – Kutta method. All simulation results are listed in a text below.

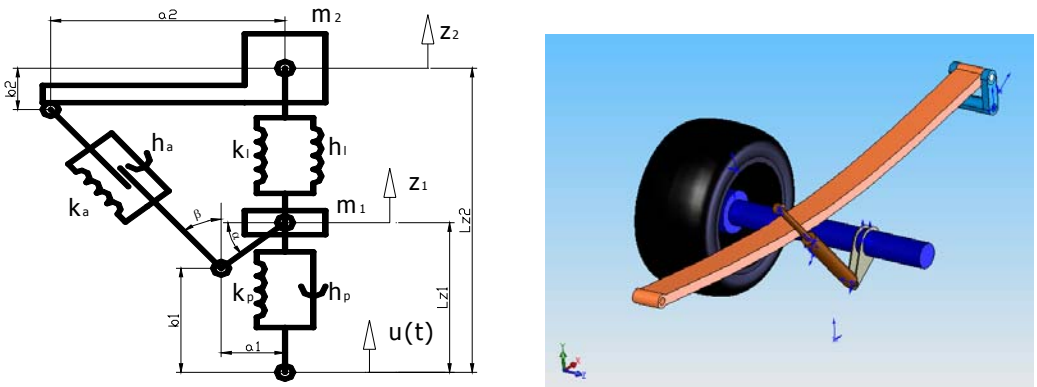
2. SUSPENSIONS DESCRIPTIONS

Leaf spring suspensions usually are modifying [1], [2], [3], in two ways: one, additional elements are adding into the suspension system; the second, suspension structure is modifying and a new type of leaf spring and elastic elements are mounting. These structural solutions are not

complicated. However, to implement the solutions properly, in the first case, additional brackets shall be mounted on the vehicle axis and the body where the air spring is attached; also additional equipment shall be mounted to keep pressure in air spring. Two, a completely new leaf spring shall be mounted; the body of the bus shall be reinforced since the spring fastening points are changed; possible displacement of the axis shall be limited according to the body of minibus; additional equipment shall be mounted to keep pressure in air spring. The first model Fig. 1 a, b is a typical suspension of basic vehicle on the basis of which modifications were carrying out. Suspensions of this type are using in the vehicles of Mercedes Benz Sprinter, VW LT, Iveco Daily, the gross mass of which does not exceed 3,500 – 4,200 kg. The structure of the suspension is not complicated. It consists of the following: half of the axle mass, mass of the wheel and hub, spring, and a damper.

The leaf spring is fastened to the body by the cylindrical joint at one end. While the vehicle axis moves vertically, this end may revolve only on its axis.

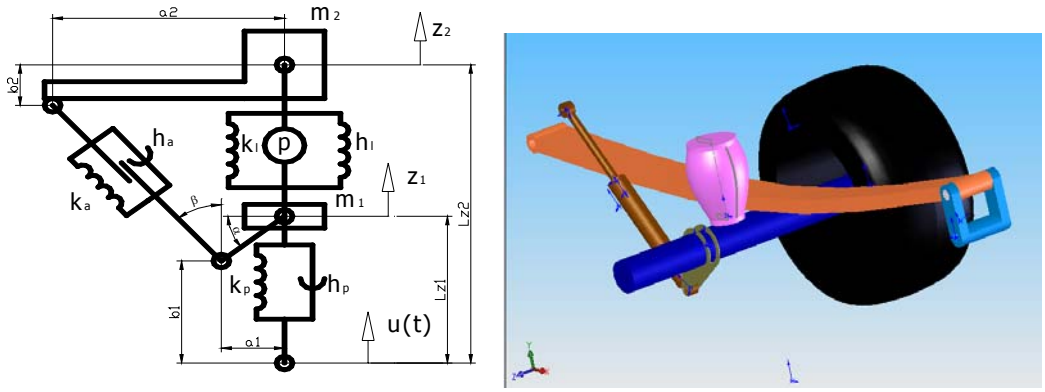
The other end of the spring is attached to the body through an additional cylindrical joint and a rod. The latter structural solution enables to move the end of the spring longitudinally in cases when the spring is deformed (straightened). The vehicle axis is stationary to the spring; therefore, when the spring is deformed, longitudinal wheel displacement occurs. The position of each element is limited by the other components of suspension; therefore, the elements of suspension as well as the whole set of elements may move only in a certain space. This longitudinal displacement is not included in dynamic model so mass m_1 goes only in vertical direction.



a) b)

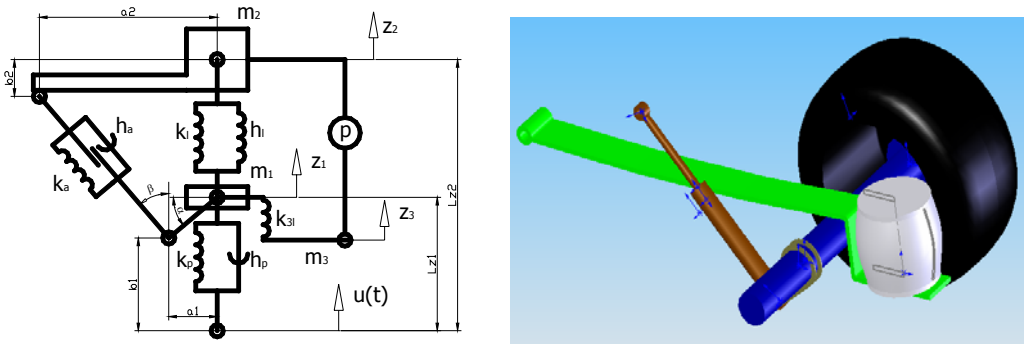
Figure 1. *Dynamic a) and the 3d b) models of the first vehicle rear spring suspension*

The second structure of the rear spring suspension Fig. 2 a, b is an upgraded structure of the first spring suspension (Fig. 1 a, b). It is comprised of the half of axle mass, wheel and hub mass, leaf spring, damper and an additionally introduced elastic element: air spring, the bottom of which is attached to the rear axis of the bus, and the top is fixed to the body of the bus. The position of each element is limited by the other components of suspension; therefore, the elements of suspension as well as the whole set of elements may move only in a certain space. This longitudinal displacement is not included in dynamic model so mass m_1 goes only in vertical direction.



a) b)

Figure 2. *Dynamic a) and the 3d b) models of the second vehicle rear spring suspension*



a) b)

Figure 3. *Dynamic a) and the 3d b) models of the third t vehicle rear spring suspension*

The third structure of the rear spring suspension is modified firs type suspension. This Suspension has new profile leaf spring at one end fixed to vehicle body. Another leaf spring end has a fixation plate for an air spring top of which is fixed to the vehicle body. The position of each element is limited by the other components of suspension; therefore, the elements of suspension as well as the whole set of elements may move only in a certain space. This longitudinal displacement is not included in dynamic model so mass m_1 goes only in vertical direction.

Both modified suspensions models characteristics are compared with traditional van suspension model characteristics (the first case).

3. MATHEMATICAL MODELS

The first model equations:

$$m_1\ddot{z}_1 = \left(-c_p\cdot\left(\dot{z}_1-\dot{u}_t\right)\right)-k_1\cdot\left(z_1-u_t\right)+F_a-h_l\cdot\left(\dot{z}_2-\dot{z}_1\right)-k_l\cdot\left(z_2-z_1\right)-m_1\cdot 9{,}81; \quad (1)$$

$$m_2\ddot{z}_2 = -F_a-h_l\cdot\left(\dot{z}_2-\dot{z}_1\right)-k_3\cdot\left(z_2-z_1\right)-m_2\cdot 9{,}81; \quad (2)$$

The second model equations:

$$m_1\ddot{z}_1 = -h_p\cdot\left(\dot{z}_1-\dot{u}_t\right)-k_p\cdot\left(z_1-u_t\right)+F_a-h_l\cdot\left(\dot{z}_2-\dot{z}_1\right)-k_l\cdot\left(z_2-z_1\right)- -m_1\cdot 9{,}81-p\cdot S_0; \quad (3)$$

$$m_2\ddot{z}_2 = -F_a-h_l\cdot\left(\dot{z}_2-\dot{z}_1\right)-k_3\cdot\left(z_2-z_1\right)+p\cdot S_0-m_2\cdot 9{,}81; \quad (4)$$

$$\dot{p} = \frac{-\gamma\cdot S_0\cdot p\cdot\left(\dot{z}_2-\dot{z}_1\right)}{V_0+S_0\cdot\left(z_2-z_1\right)}; \quad (5)$$

The third model equations:

$$m_1\ddot{z}_1 = -h_p\cdot\left(\dot{z}_1-\dot{u}_t\right)-k_p\cdot\left(z_1-u_t\right)+F_a-h_l\cdot\left(\dot{z}_2-\dot{z}_1\right)-k_l\cdot\left(z_2-z_1\right)- -k_{31}\cdot\left(z_1-z_3\right)-m_1\cdot 9{,}81; \quad (6)$$

$$m_2\ddot{z}_2 = -F_a-h_l\cdot\left(\dot{z}_2-\dot{z}_1\right)-k_l\cdot\left(z_2-z_1\right)+p\cdot S_0-m_2\cdot 9{,}81); \quad (7)$$

$$m_3\ddot{z}_3 = -k_{31}\cdot\left(z_3-z_1\right)-p\cdot S_0-m_3\cdot 9{,}81; \quad (8)$$

$$\dot{p} = \frac{-\gamma \cdot S_0 \cdot p \cdot (\dot{z}_1 - \dot{z}_3)}{V_0 + S_0 \cdot (z_1 - z_3)}; \tag{9}$$

There $\dot{p}$ – spring air pressure change, γ – adiabatic coefficient, g – gravity constant.

Shock absorber is fixed to vehicle body by cylindrical joint in one end and on another end is fixed to vehicle axel, which can travel only in vertical direction. Dimensions a_1 and a_2 are constant so when vehicle axel travels in vertical direction linear dimension b_1, b_2 and angular dimension α variation occurs. There dimensions b_1 and b_2 are dimensions from the horizontal road pavement to shock absorber fixing points, α - angular dimension between shock absorber rod and vertical line.

Equation describing starting shock absorber length:

$$L_0 = \sqrt{a^2 + (b_2 - b_1 + z0_3 - z0_1)^2}; \tag{10}$$

There $z0_1$ and $z0_3$ starting coordinates. Length of shock absorber is variable so equation 14 has time depending variables $z_i(t)$. The derivative has the second form:

$$L = \sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}; \tag{11}$$

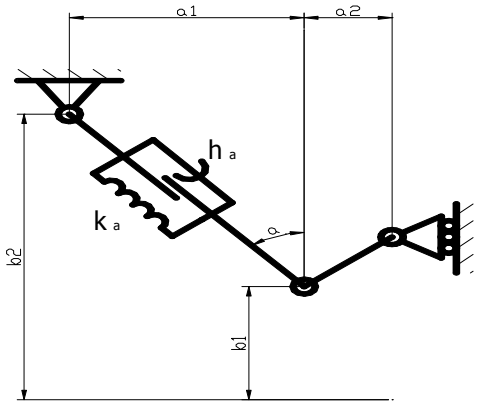


Figure 4. *Shock absorber model*

Shock absorber length change:

$$\Delta L = L - L_0; \tag{12}$$

Shock absorber length changing speed is described by equation:

$$\Delta \dot{L} = \frac{(b_2 - b_1 + z_3 - z_1) \cdot (\dot{z}_2 - \dot{z}_1)}{\sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}}; \tag{13}$$

Shock absorber damping force:

$$F_1 = c_2 \frac{(b_2 - b_1 + z_3 - z_1) \cdot (\dot{z}_2 - \dot{z}_1)}{\sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}} + k_2 \cdot \Delta L - F_0 \sqrt{\frac{(b_2 - b_1 + z_3 - z_1) \cdot (\dot{z}_2 - \dot{z}_1)}{\sqrt{a^2 + (b_2 - b_1 + z_3 - z_1)^2}}}; \tag{14}$$

Shock absorber tilt angle:

$$\cos\alpha = \frac{b_2 - b_1 + z_3 - z_1}{L}; \tag{15}$$

Shock absorber damping force including tilt angle:

$$F_a = F_1 \cos\alpha ; \quad (16)$$

4. ROAD PROFILE

Road surface is described as speed reduction bump (Fig. 5) [4]. Vehicle moving speeds are: 20 km/h, 50 km/h, 90 km/h;

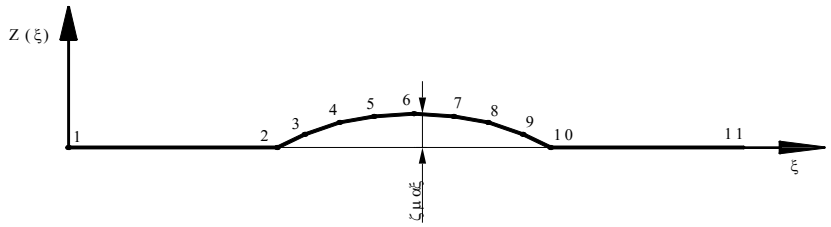


Figure 5. *Speed reduction bump profile (z_{max}=0.05m)*

5. SIMULATION RESULTS

Table 1. The highest amplitude frequencies of suspension characteristic points natural vibrations

Number degree of freedom	Suspension No 1 natural frequencies of vibrations, Hz	Suspension No 2 natural frequencies of vibrations, Hz	Suspension No 3 natural frequencies of vibrations, Hz
1	23,8	23.6	135,8
2	23,8	23.6	135,8
3	2,39	0.00	20,5
4	2,39	2.70	20,5
5	-	2.70	2,03
6	-		2,03
7	-	-	0,00

Table 2. Highest amplitudes values of the bus air spring pressure

Volume of air spring, m^3	Frequency, Hz	Pressure, MPa	Scheme No
0,003	2,72	12,568	2
0,03	2,45	1,258	2
0,3	2,42	0,126	2
0,003	2,10	9,379	3
0,03	1,70	1,059	3
0,3	1,60	0,109	3

Table 3. The highest values of the bus body acceleration when the volume of the air spring changes

Volume of air spring, m^3	Frequency, Hz	Vertical acceleration m/s^2	Scheme No
0,003	2,71	0.0653	2
0,03	2,41	0.0539	2
0,3	2,38	0.0526	2
0,003	2,00	0.0396	3
0,03	1,60	0.0294	3
0,3	1,50	0.0281	3

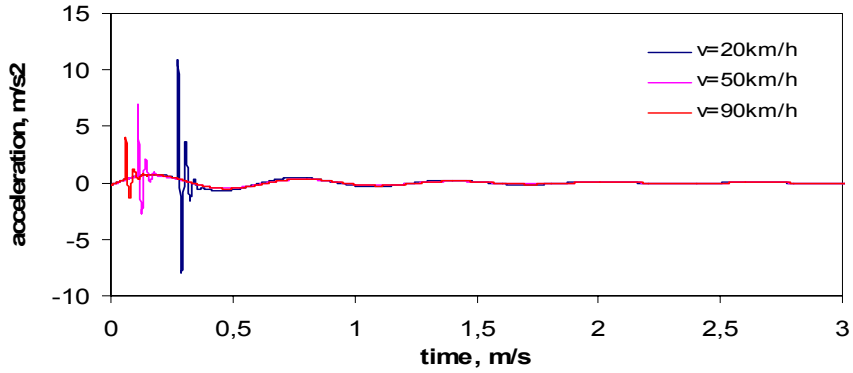


Figure 6. *The first suspension model acceleration – time dependence*

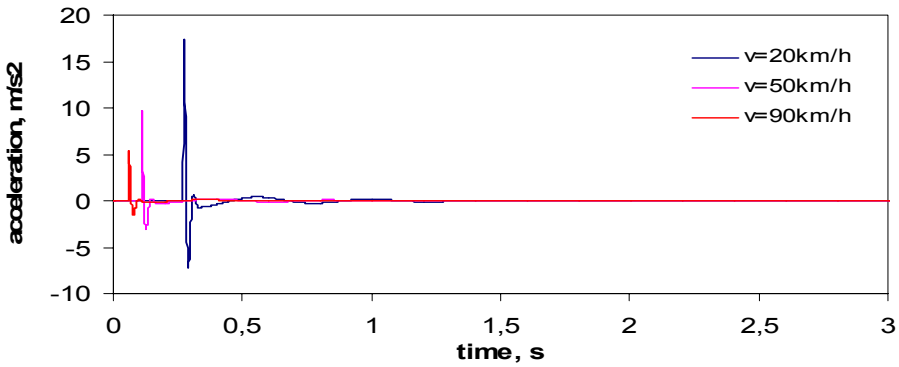


Figure 7. *The second suspension model acceleration – time dependence*

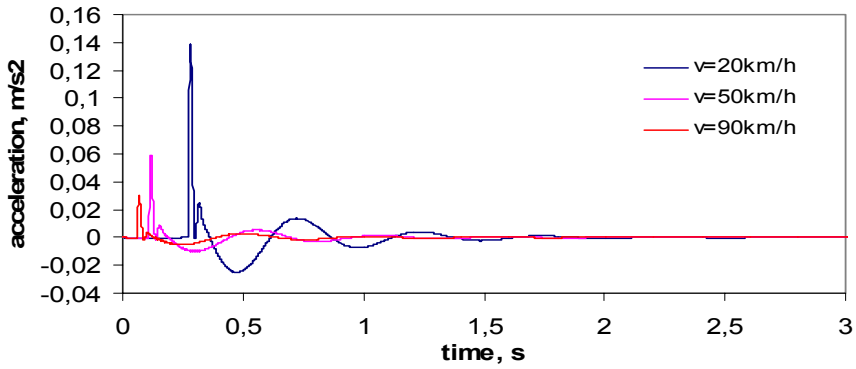


Figure 8. *The third suspension model acceleration – time dependence*

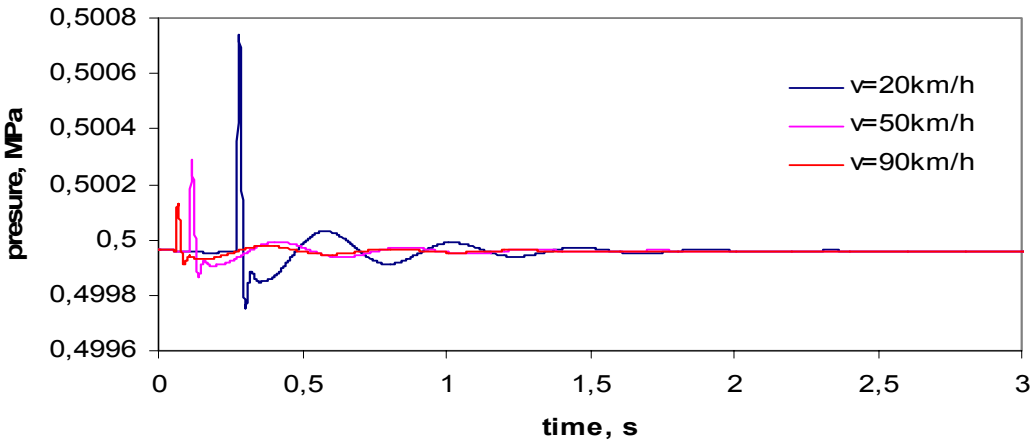


Figure 9. *The second suspension model air spring pressure – time dependence*

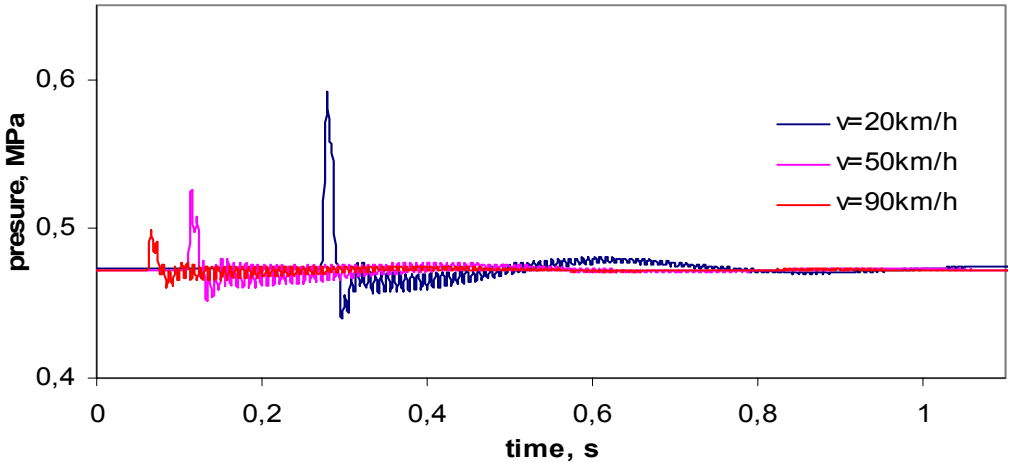


Figure 10. *The third suspension model air spring pressure – time dependence*

6. CONCLUSIONS

1. Comparing three bus suspensions, there where noticed that the first natural frequencies amplitude of all three suspensions vitiates about 2 Hz. Body acceleration amplitude of the third suspension model and suspension system natural frequencies are lower than the first and the second suspension systems. Results also show that suspension rigidity increasing (the second suspension model) increases natural frequencies.
2. Increasing air spring volume capacity decreases vertical acceleration (from 0,0653 m/s^2 to 0,0529 m/s^2 in the second suspension and from 0,0396 m/s^2 to 0,0281 m/s^2 in the third suspension model) and natural frequency range (from 2,71 Hz to 2,38 Hz in the second suspension and from 2,00 Hz to 1,50 Hz in the third suspension model). All that means that comfort characteristics increases when air spring volume increases.
3. Overcoming road pavement disturbance vertical body accelerations depends on suspension rigidity. The second suspension has the highest-level rigidity so accelerations are topless. The third suspension model has special construction so accelerations are small.
4. Simulation results show that suspension modifications not always are effective. The best retrofitting results are in those cases when suspension system elements characteristics are not the same as in original suspension system.

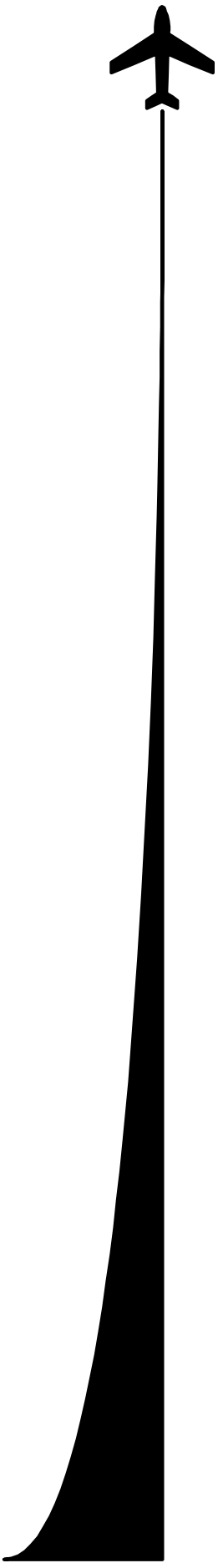
References

[1] Bogdevičius M., Junevičius R. Investigation of the Dynamic Processes of the Retrofitted Rear Suspension of the Vehicle. In: *Transport.* Vilnius: Technika, 2004, Vol. XIX, No 6, pp.262-268.

[2] Bogdevičius M., Prentkovskis O. Simulation of Transport Vehicle Interaction with Road Fence. In: *Transport.* Vilnius: Technika, 1999, No 6 (14), pp. 289-296.

[3] Prentkovskis O. *Interaction between the Vehicle and Obstacles: Summary of Doctoral Dissertation: Technological Sciences, Transport Engineering (03T).* Vilnius: Technika, 2000. 56 p.

[4] Aladjev V., Bogdevicius M. *Maple 6: Solution of Mathematical, Statistical, Engineering and Physical Problems.* Moscow: BINOM, 2001, 850 p. CD-ROM, ISBN 5-93308-085-X.



Session 3

Intelligent Transport System

MODELLING OF INDIRECT VISUAL TRANSFER COLLECTED BY CAR DRIVER

Krzysztof Olejnik

Motor Transport Institute
Jagiellońska Str. 80, 03-301 Warszawa, Poland
E-mail: krzysztofo@its.waw.pl

In the paper the establishment to create mathematical model of indirect visual transfer from car surroundings, transmitting by mirrors the vehicle equipped with is shown. It served to create an analytical program in C++ programming language, using Open GL library, operating under Microsoft Windows system. Research and cognitive possibilities are discussed which elaborated the computer program. Examples of calculations' results together with the graphic illustration of the received results are presented.

Keywords: *modelling, visibility, indirect visual transfer*

INTRODUCTION

Because of existing of non-translucent elements in vehicle cabs driver is not able to observe directly the areas, which are covered by these elements and which are essential for unthreatened participation in the movement [1, 4]. Figure 1 is illustrating the problem.

Figure 1. *Real tested object – presentation of problem*

To support the driver in this range, the mirrors are used which enable to decrease the areas being around the vehicle but not possible to be observed. In Regulation No 46 EKG UN [3] the following cases are described: present binding demands and the procedure of researches of the real object in the range of assertion of indirect visibility of surroundings of the vehicle through the mirrors the vehicle is equipped with.

Figure 2. *Real tested object – inside and outside view*

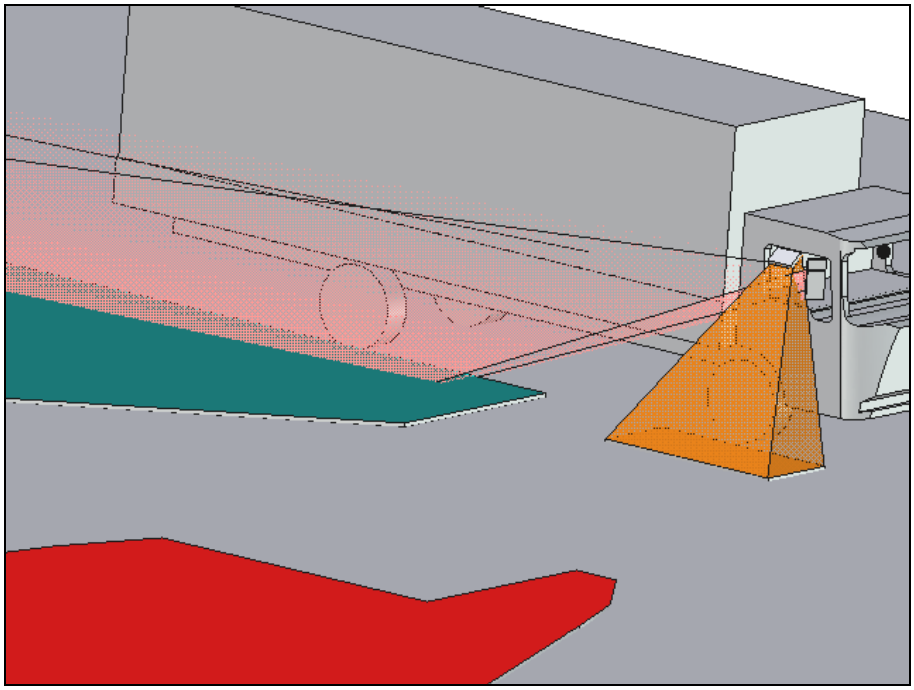


Figure 3. *Model of real tested object – monitoring minimal area*

The testing object is the scheme: Driver – Vehicle – Surroundings. The testing object is the visual (optical) indirect transfer from the vehicle surroundings in the range of lengths of waves which values corresponding with values of the light, seen by the man, transferred by mirrors the vehicle is equipped with. The testing object is presented on the Figure 1 and 2. The scheme of the testing object is presented on the Figure 3.

MODELLING OF SURROUNDINGS OBSERVATION FROM THE POST OF THE DRIVER

To make the searches the mathematical model of testing object was created. This model was used to write the computer calculation programme for the computer of the PC class. The mathematical model imitates:

- driver' s eyes by the „black points" placed in the three-dimensional space – Cartesian scheme, dextroprotatory, rectangular,
- solid of the vehicle, described in this space by the non-translucent and translucent surfaces,
- mirrors with known features, placed on the vehicle solid,
- the space surrounding the vehicle placed on the horizontal surface.

The eyes points are two points lying on the horizontal line, in the distance measured between them equals with 65 mms. Their position in the vehicle solid corresponds with situation of driver's eyes where the driver is in the normal position to drive a car.

Two points enable to imitate the real two-eye seeing.

The vehicle solid is placed inside of cuboids, which walls mark the contour of vehicle. The walls of this cuboids were led through the most moved forward elements of the vehicle (with exception of mirrors, their supports and lamps): on sides, forward, backwards, downwards, upwards.

Contour of the vehicle solid can be placed between the surfaces, where the distances between them are included in the section of values:

- on the length: 3000 mms – 18000 mms,
- on the width: 1500 mms – 2600 mms,
- on the height: 1200 mms – 4000 mms.

The front of the vehicle is placed in the opposite direction against the turn of **Ox** axis.

Transparent surfaces of vehicle solid have the coefficient of the total transparency (measured in the normal direction to surface) for the range of values if visible light – at least 70%. However, non-transparent surfaces have the value of the coefficient of total transparency below 70% and are treated as the total optical obstacles.

Mirrors are the surfaces made from the segment of sphere by cutting its fragment in the result of penetration of cuboids with sphere. Longitudinal axis of cuboids goes through the centre of the ball, from which the segment of sphere was cut. The length of sphere rays is included in the range of values: from 200 mms $\div \infty$ (till immensity).

Remaining characteristics of mirror, such as: height and width have the values equal to values of chords of bows of circles, on which the segment of the sphere was rested.

The system of coordinates (against the vehicle) is placed in the following way:

- vertical surface **Oxz** goes by the longitudinal axis of vehicle,
- vertical surface **Oyz** perpendicular to surface **Oxz** goes by „eyes points",
- horizontal surface **Oxy** lies on the road surface, on which the vehicle stands.

On the horizontal surface **Oxy** areas in the vehicle surroundings are imitated, which according to the bind rules driver should have possibility to observe them. The line of horizon is imitated on the surface **O'yz** parallel to the surface **Oyz**. The surface **O'yz** is placed behind the vehicle in the distance from the surface **Oyz** with given value.

The line of horizon is imitated by the level line marked above the surface **Oxy** on the height where its value is the same as the value of the height of the upper part of the considered mirror, measured from the surface **Oxy**. The scheme of the testing object and the model of the real object are presented on the drawings no 3 and no 4.

In the worked out model the possibility of realization of limitations fixed by present binding rules in the range of the indirect visual transfer was taken into account.

Mathematical description of the designation of area expanse (and its location), comprised by driver's eyesight, looking at the surroundings by the mirrors, in the elementary shape reduced to a rule of finding the equations of the straight lines, which are the mirror reflection of the straight lines, connecting the eyes-points with freely chosen point on the mirror surface in the three-dimensional space.

The mirror in the model can be freely set - what responds the real adjustment. It can also be freely placed against the vehicle, what enables to imitate its location such as in the real object.

The eyes-points can be also freely placed in the model solid of the vehicle.

Having given points **A**, **B**, **C** in the space which imitate:

- **A** – the centre of the sphere (sphere, on which there is the surface of the mirror),
- **B** – one of the eyes-points,
- **C** – the point on the mirror, on which the observer's eyesight was directed.

We are looking for the equations of the straight line **CE**.

On the Figure 5 location of the mentioned was illustrated. Leading the line p through the point B, perpendicularly to the line l, marked the coordinates of the point D on the line **l**. Because the vectors of the line **l** and the line **p** are not of the zero value, so on the base of characteristics of the scalar product of the vectors of these lines it appears that in the case when the scalar product of vectors gives the zero result so the line **l** and the line **p** are perpendicular.

The common cutting point of the lines **l** and **p** was marked as **D**. However the common point of lines **l** and **k** was marked as **E**. Found point **D** (x_D,y_D, z_D) permits to mark the coordinates of the point **E** (x_E, y_E, z_E) which is symmetrical to the point **B** in relation to the line **l**. Coordinates of the point E because of the symmetry towards the line **l** describe the following equations:

$$x_E = 2 \bullet x_D - x_B$$

$$y_E = 2 \bullet y_D - y_B$$

$$z_E = 2 \bullet z_D - z_B$$

Then the points **C** and **E** mark the straight-line **k** in the space.

If we know the equation of the straight-line **k** we can calculate the coordinates of the point of spiking of the surfaces Oxy or O'yz by this straight line.

Points of spiking of these surfaces by the straight lines **k** which are turned aside on the whole surface of the mirror mark the place and the extensiveness of the area observed by one eye for the given location and adjustment of the mirror. In the same way we should act to mark the area observed with the second eye.

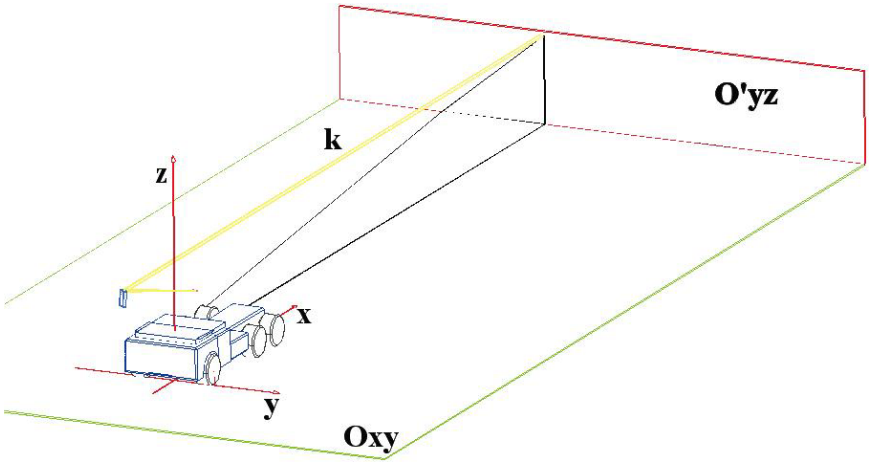


Figure 4. *Arrangements of eyes points and mirror position in coordinate system*

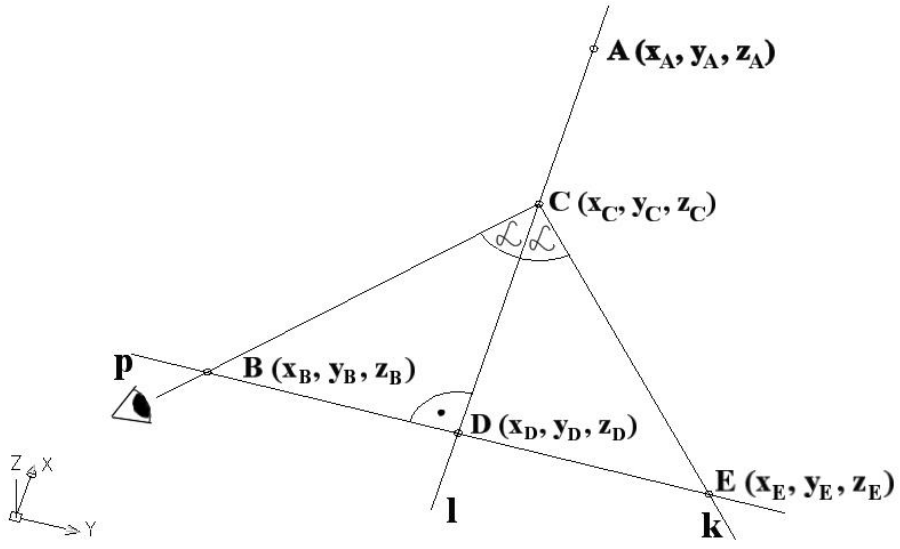


Figure 5. *Elementary problem of reflection in mirror*

Changing the value of coordinates of the point **A** in the way where the point **A** moves on the surface of the sphere and where the ray of this sphere marks the segment **AC** and the centre of this sphere marks the point **C** we direct the mirror in such a way to point the observer's eyesight to the area placed against this vehicle, which the observer wants to watch.
Marking around the vehicle the area on the surfaces Oxy and **O'yz**, for example being in agreement with the binding rules or also expectation we can define:

- if for the given mirror and its placement on the vehicle the driver can take in a view the required area,
- what conditions should be fulfilled (height, width, the ray of curvature of the mirror, the parameters of its placement on the vehicle, arrangement) to enable the driver to take in a view the given area for the definite vehicle,
- limits of possibilities to use the mirror in the indirect seeing of areas of the vehicle surroundings for the definite category of the vehicle and constructional solutions,
- sensitiveness of the testing object (which is the function of many variables) for the particular variables.

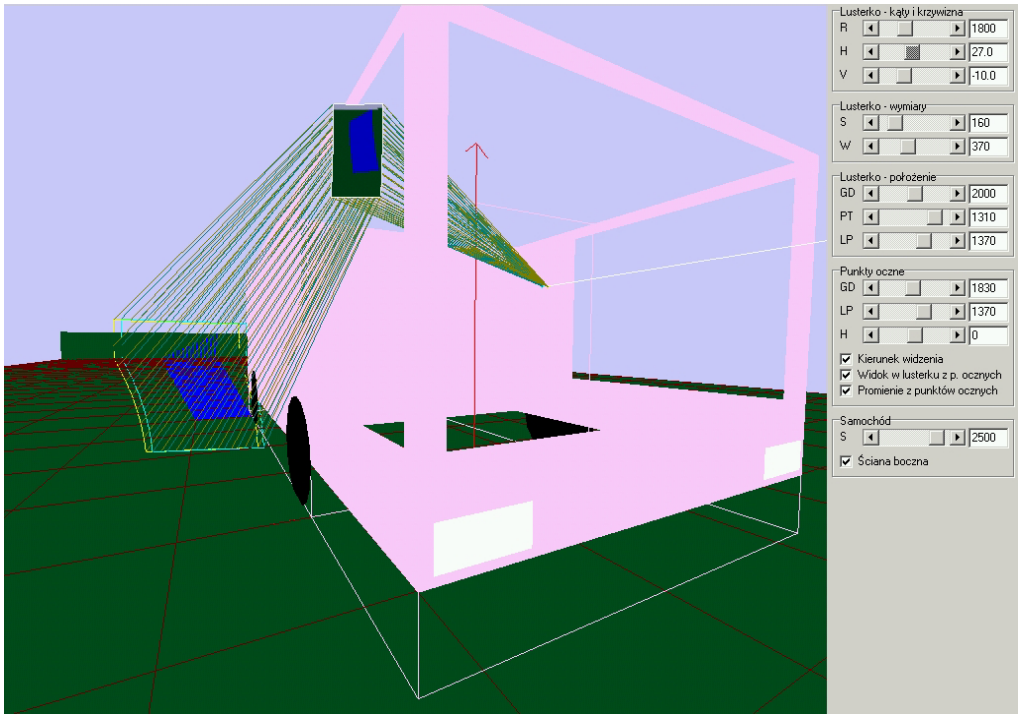


Figure 6. *Example of a screen received on the basis of software calculations*

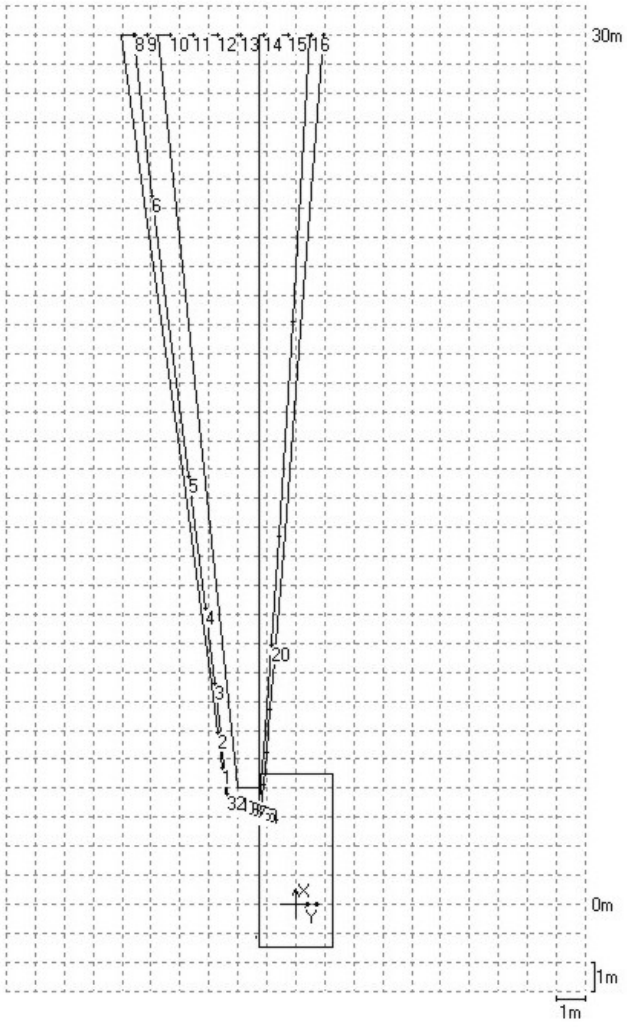
The above described mathematical model of visual transfer from the vehicle surroundings transmitted through the mirrors was used to create the calculation programme in the programming language C++, where Open GL library was used, acting under Microsoft Windows system [2]. On the Figure 6 as the example of the picture seen by the programme operator on the screen of the computer monitor was presented. In the definite range of the values it is possible to:

- increase or decrease the presented object what simplifies watching of details,
- change the direction of watching.

Attendance of the programme lies in giving the values of such sizes as for example: width of the vehicle, location and extensiveness of transparent elements. Besides below please find the list of the cases which location against the vehicle is given:

- eyes-points,
- areas which the driver should observe,
- mirror which we investigate (its width, height and the ray of curvature).

Next changing the values of angles of the mirror adjustment in the vertical and in the level we check if the area comprised by the mirrors with the driver's eyesight covers fully the area qualified by the rules or given as the result of other limitations.



Eyes points
X: 0 Y: 700 Z: 1800

Seeing angle: 0

Mirror
X: -1120 Y: -1370 Z: 2140
R: 1800 Horizontal angle: 29,5

Vertical angle: -11,5
Width: 140 Height: 300
Distance from overall dimension: 170

Points limiting watching area

Point	Eye	X	Y
1	L	4711	-2556
2	L	5916	-2699
3	P	7620	-2800
4	P	10234	-3116
5	P	14742	-3684
6	P	24445	-4945
7	P	30000	-5609
8	P	30000	-5553
9	L	30000	-5142
10	L	30000	-4334
11	L	30000	-3527
12	L	30000	-2719
13	L	30000	-1910
14	L	30000	-1099
15	L	30000	-285
16	L	30000	534
17	P	30000	940
18	L	20114	-127
19	L	12676	-590
20	L	8962	-834
21	P	6726	-874
22	P	5213	-1009
23	P	4128	-1112
24	P	3309	-1195
25	P	3370	-1335
26	P	3431	-1478
27	P	3492	-1622
28	P	3552	-1769
29	P	3611	-1919
30	P	3670	-2071
31	P	3728	-2226
32	P	3786	-2385

Figure 7. *Example of the received results of calculations and their graphic illustration*

The results of the programme calculations are presented graphically as the virtual picture of reality on the computer monitor. On Figure 6 there is an example of the received picture on the monitor, generated by the programme with the results of observation.

The programme presents in the tabular form, calculated with the given step, for the accepted parameters the values of coordinates of the points on the surfaces **Oxy** or **O'yz**. Additionally, there is possibility to draught the areas comprised with eyesight.

Figure 7 presents the example of the received results of calculations and their graphic illustration.

SUMMARY

The worked out model of the visual transfer form the vehicle surroundings transmitted by the mirror enables leading of the virtual searches of the real object. Necessary data such as: position of the eyes-points in the real vehicle, distribution of the mirrors and their features, width of vehicle, must be

measured in the vehicle and brought into the programme. Estimation of the fulfilment of the demands by the vehicle is much less arduous than in the real searches.

Besides the following cases appear:

- possibilities of testing of susceptibility of the model for the particular variables,
- qualification of limits of possibilities of the mirror's use to see indirectly the areas of the vehicle surroundings.

References

[1] Olejnik K. *Doctor's trial „The research under outside visibility from a driver position in an aspect of constriction quality verifications".* Lublin: Technical University of Lublin, 2003.

[2] Olejnik K. Lack of visual transmission and safety – operating problems of trucks. In: *Journal of International Conference „Maintenance 2004".* Prague, 2004, pp.69-75.

[3] Regulations No46 ECE UN. *Uniform provisions concerning the approval of the rear – view mirrors of motor vehicles with regard to the installation of rear - view mirrors.*

[4] Regulations No71 ECE UN. *Uniform provisions concerning the approval of agricultural tractors with regard to the driver's field of vision.*

IT-SECURITY PROTECTION AND AUDIT CONCEPT FOR ATC IT-SYSTEMS (SAIFIT)

Jörg Kundler

Nassmühle 11a
63796 Kahl am Main
Ph: +49 179 4617377
E-mail: joerg.kundler@t-online.de

We found out that no relevant standard for ATC IT-Security do exist. An own Standard for IT Security Protection and Audit Concept to measure IT-Security for ATC Systems is developed. ATC Safety aspects are clearly defined. The idea of the paper is as follows - to be able to measure IT-Security based on a defined and uniform standard for basic and high level protection.
The goals and benefits of the IT Security Protection and Audit Concept for ATC IT-Systems are as follows:

- Establishing a IT-Security Standard for ATC Systems
- Differentiating between different categories of ATC Systems and Protection Level
- Making IT-Security measurable and performing a regular benchmark process based on the IT Security Standard
- Establishing IT Security Standard into the overall ATC System Life Cycle
- Making IT-Security visible and showing a trend analysis during the life cycle.

The ATC IT Security Standard has to satisfy all possible requirements and to guarantee an overall ATC security level and to describe all related subject areas like: Technical Infrastructure, Facility Management and Building, IT-System, Networking, Telecommunication.
The IT Security Protection and Audit Concept for ATC IT-Systems are in operational use since year 2001. Now this process of IT Security Inspection is a strong established process in ATC and we have to collect data and experience over several years. All ATC Centre, Tower Locations, central function and most part of the surveillance and navigation installations are inspected. This database is important to calculate and to derive forecast information and possible trends in IT-Security. The database is also important to perform a risk analysis.

Keywords: *ATC security standard, audit concept, measurement method, tool support, reporting*

1. PROBLEM DESCRIPTION

Particularly the ATC Business Processes are highly depending on IT-Systems and their availability, data existence and integrity. So every day the role of IT-Security will increase.

During different projects and development activities we detect that for each single action a safety and/or security concept was performed based on the method of protection level and risk analysis. Especially during the construction period of a new ATC Centre and during the realization of the IT Security and Safety Concept the following questions turned up:

- What security activities have to be taken for the relevant IT systems?
- How to measure IT-Security, how to perform benchmarks?
- Does a special IT-Security standard for ATC systems exist? What is the right benchmark?
- How to realize, IT-Security measures shall be performed during project and life cycle?

We discovered that no relevant standard for ATC IT-Security does exist. Also the basic Protection Standard of the BSI (Bundesamt für Informationssicherheit = German Federal Administration for IT Security) did not help and didn't contain relevant and concert Security Measures. Based on the Method of Protection and Risk Analysis it was possible to define the related Protection Level and to detect the actual risk, to compare these risks based on the own Security and Safety Value Scale and to establish the related activities. It was not possible to compare the reached security level based on a defined standard and to perform a regular measurement process. Additionally it was also not possible to define the necessary security protection level for the related objects. To realize an overall security standard involves high cost. In that case it was required to create different categories of security levels.

2. SAFETY AND SECURITY MANAGEMENT

Based on the international requirements and documentation it is necessary to establish in ATC organization an independent Safety and Security Management. This requirement is based on the following fundamental documents and guidelines:

- EATCHIP Safety Policy
- Eurocontrol Safety Regulatory Requirements (ESARR)
  ESARR 1 Safety Oversight in ATM
  ESARR 2 Reporting and Assessment of Safety Occurrences in ATM
  ESARR 3 Use of Safety Management System by ATM Service Provider
  ESARR 4 Risk Assessment and Mitigation in ATM
  ESARR 5 Safety Regulatory Requiring for ATM Services Personnel
  ESARR 6 Software in ATM Systems
- Handbook for Safety and Security Management
- Rules for Safety and Security.

The Safety and Security Management is based on normative – strategic – operational Level. The normative Level is based on the legal requirements and documents from Eurocontrol and Government. Deriving from these baselines each company and especially each ATM organization creates his Mission Statement, which is normally published in the company handbook.

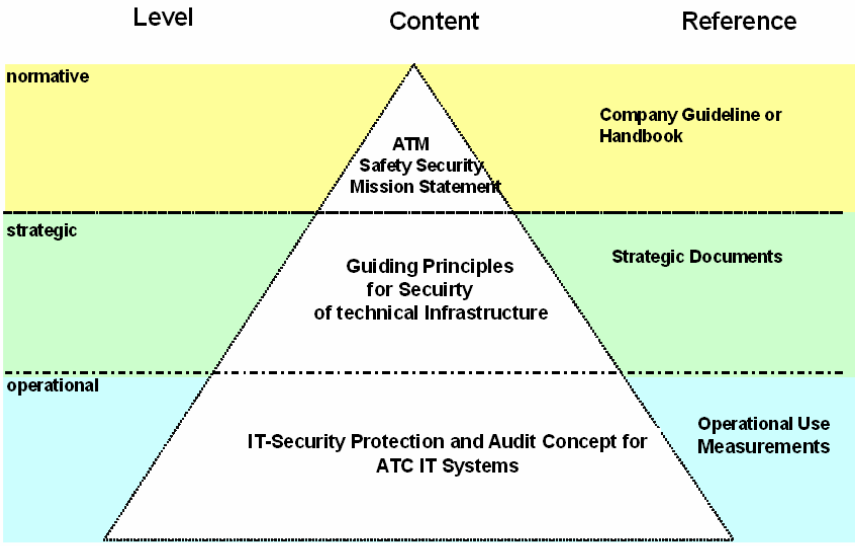


Figure 1. *Overview of Different Levels of Safety Security Management*

The next management level has a direct impact to the related strategy and a next step of concretisation, for example detailed guiding principles for security of the technical infrastructure that are described in Chapter 3.1. This brief description will concentrate on the operational level, especially describing the methodology and using of the IT-Security Protection and Audit Concept for ATC IT Systems (SAIFIT). This concept and the ATC IT Security Standard were developed in year 1999. In 2001 the measurement methodology and toolbox was created to perform IT Security Measures and to visualize the results. Subsequently it was performed some IT Security Measures in case of prototyping. Since 2001 the SAIFIT concept and toolbox is being in operational use and up to now all ATC centre, Tower locations and most part of radar navigation equipments are being measured by SAIFIT.

The safety and security management covers the following areas:

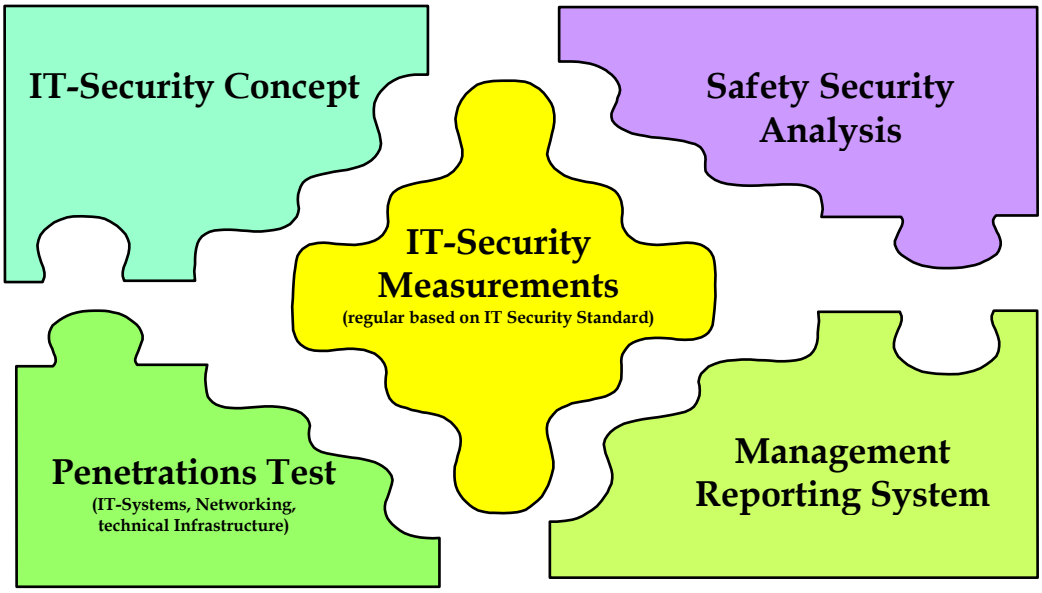


Figure 2. *Structure of Safety and Security Management*

Important is that all parts of an overall safety and security management are covered and have the same level of business reputation, standards and tool support. In this chapter only a short overview of the different parts will be given. This document will concentrate on the IT-Security Protection and Audit Concept for ATC IT-Systems (SAIFIT), which is the basic rule to perform IT-Security Measurements.

2.1. Safety Security Mission Statement and Guidelines

Based on the Safety Security Mission Statement it is possible to divert the following statements for the organization of the Security for IT Systems and technical Infrastructure:

- For each technical system the necessary and reached Security Level should be defined.
- For all new technical systems and in case of changes of the technical systems before operational use, the system to the Safety Security Protection level should be assessed and the system function to the related Safety Security criticality should be classified
- The reached Safety Security Level for each system function should be defined too.
- Safety Security Analysis should be performed regularly and documented, to approve that all aspects have been taken into account and the reached Safety Security level is described.

Based on the Safety Security Mission Statement of the high management level, guidelines for security of technical Infrastructure are worked out. All employees must work based on these guidelines. The task was developed based on the Mission Statement additionally concrete guidelines, rules, handling instructions and tools which support safety and security analysis and measurements.

General rules for a Safety Security Guideline can be as follows:

The protection of live should be the highest company goal for all employees.

- Safety and Security is a management task and Safety Security Management is a separate management Process.
- Each Employee is responsible for Safety and Security.
- The safety and security requirements for technical infrastructure based on the defined criticality of systems and risk classification.
- All operational used systems of the technical infrastructure are to fulfil at least the defined Basic Protection Level.
- The Safety Security Level is to be visible and must be measured.
  Basis for the Safety and Security Management is an overall procedure that reflects all relevant aspects.

- Emergency Management is a part of the planning process.
- The responsibility for budget of safety security activities of technical infrastructure is included in the budgets of projects or system management.

The Safety and Security Management is a separate Organization under the responsibility of Managing Director. The unit has the competence for Safety and Security Methods, guidelines and directions. This unit approves all Safety and Security Concepts or Risk Analysis. The operational responsibility remains by the special division that are performing the System or Product Management.

2.2. Safety Security Concept and Analysis

The following figure describes the steps of an IT-Security Concept:

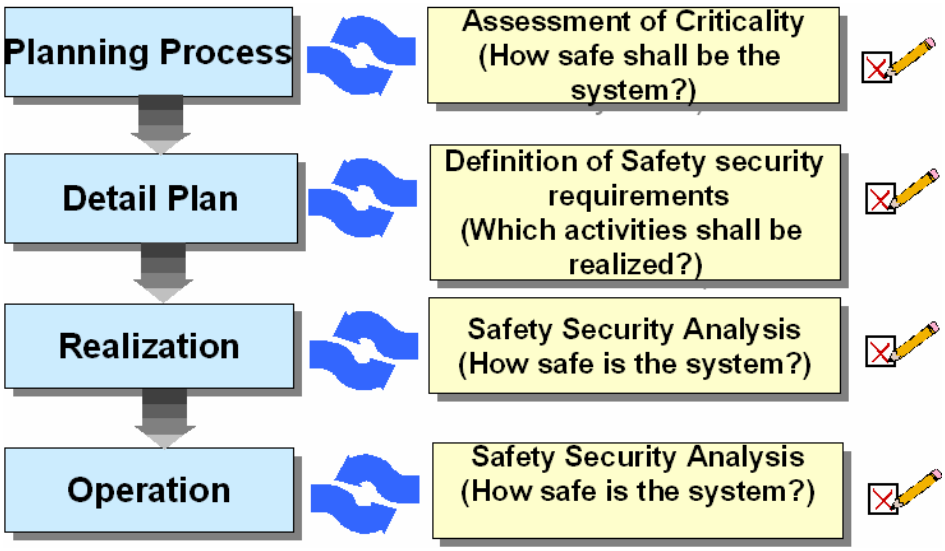


Figure 3. *Safety Security Lifecycle Model*

The **Safety Security Analysis** is based on the method of risk analysis. The Safety Security Analysis includes also the analysis of critical components. This analysis covers the complete system and environment. The environment includes all purposes with regards to human factors, proceedings and technical objects.

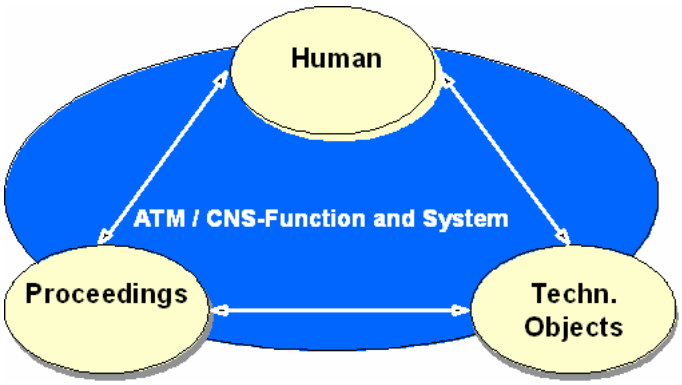


Figure 4. *Areas of Safety Security Analysis*

For new or planned technical system it is necessary to perform a risk analysis. In this part of analysis it is to clarify which influence will be on the ATM safety or security system or components failures or loss of operation. The result defines criticality classes that are “Must”-requirements for the system development and project.

In case of existing technical systems the Safety Security Analysis identifies which possible risks are available in the existing system and how safe the system is. The result is the defined risk classes, which are the basis for the development of safety or security actions. The risk analysis is performed based on the following steps:

- Refinement or breakdown into smaller functional parts of the systems
- Definition of possible threats
- Definition of the maximum of damage
- Definition of the probability to the damage occurrence
- To assign to a risk class.

2.3. Need of Value Scales

The defined threats are described in detail, like the concrete specification of threat, probability of occurrences, frequency and description of impacts and consequences. For these descriptions different value scales that give orientation and guideline for the assignment of different categories are necessary.

Each company has to define their own value scales, because the scales depend on various rules, like national government rules or company guidelines. For example the scale for description of damages shall contain the possible maximum damage if the threat occurred and divide the damage into different classes from catastrophic to insignificant. The following figure describes an example for a value scale of damages.

Degree of Damage Ascpect of Damage	Unessential	Less	Medium	Large	Catastrophic
Consequences for Person	No	Impact of Well being	Injury single person	Deathsingle or Injury lot of person	Death lot of person
Impact of Mission	No	Less	Medium	Large	Unable to act
Material Damage	up to xx €	up to xx €	up to xx €	up to xx €	up to xx €
Impact of national Economy	up to xx €	up to xx €	up to xx €	up to xx €	up to xx €
Damage of Image	No	Temporary Impact of reputation	Long term Impact of reputation	Enduring lost of confidence in particular functions	Complet lost of confidence
Violation of Law / Rules Internal Impact of damage	No No	Internal direction Employee	Official Rules / Order Group of employee	Law Devision	Enduring violation of laws Complete Company
Category	0	1	2	3	4

Figure 5. *Value Scale for threat analysis and definition of damage effects*

The process of probability definition for the damage occurrences creates very difficult, because in practical use less or no information about different probability for threats and damages is available. The employees have no own knowledge or personal experiences. Additionally the probability is very low. The suggestion is to hold a workshop with different long-term experts for the definition of probability. Also helpful is the use of probability scale, which describes the different probability categories. For purposes of technical infrastructure we suggest to use databases of insurance companies.

2.4. Penetration Test

Penetration Tests are specialist tests, which have the aim to break in into IT-Systems, or technical infrastructures like to break into a special IT-System or network or buildings. These tests can be also combined. We recommend performing this kind of penetration test before operational use of an important IT-System or ATC centre. Normally is useful to perform the penetration test by a certified external company, which is specialist on this kind of penetration test. This kind of test gives a last

feedback and conformation about the overall IT Security and covers the complete parts of Safety Security Management – human resources, procedures and technical security activities. This test is to be professionally prepared, especially from the legal point of view. The test performer must have a clear instruction and guidelines for the practical duration of tests, have a formal authorization and documentation. The penetration test is to be performed under confidential conditions.

IT-Security measurement and reporting system is described in detail in the next chapters.

3. METHODOLOGY OF IT SECURITY PROTECTION AND AUDIT CONCEPT FOR ATC IT SYSTEMS

The basic idea is to make IT-Security measurable and visible based on an integrative scale with the help of the ATC Basic IT Security Standard. To be in a position performing IT-security benchmarks between defined categories. The IT Security Protection and Audit Concept for ATC IT-Systems describe the operational level of doing.

The goal is to create variations of needed security levels and activities in order to establish the right security level and activities for the right and needed objects and functions; to establish the security process stringent and practical oriented; to develop own standard and protection and audit concept to measure IT-Security for ATC Systems.

Operational ATC Safety aspects are clearly defined. But for IT-Security of IT-Systems, technical Infrastructure and Telecommunication an overall planning process and standards do not exist. Every single project realizes its own measures. The IT-Security protection level is also depending on the development of the market and from new threats. The idea was to be able to measure IT-Security based on a defined and integrated standard for basic and high level protection.

For the audit process a special tool generates the audit checklists. This list includes the specific security requirements for the basic and higher protection level. In this way is safeguarded that the ATC Security Standard will be fulfilled and the auditing organization will hand out a measures list of activities.

3.1. Goals and Benefits

The goals and benefits of the IT Security Protection and Audit Concept for ATC IT-Systems are as follows:

- To establish an integrated IT-Security Standard for ATC Systems.
  This standard is the basis for the IT Security Measurements and covers all parts of technical infrastructure, like IT-Systems, Infrastructure, Networking and Telecommunication. The Standard derives Audit Categories and Audit Classes.
- Based on the IT Security Standard, which defines also the Basic Protection Level for all related categories and classes, we have an integrated scale.
- Differentiating between different categories of ATC Systems and Protection Level. So we can realize security goal-oriented and refined. So the realization of security activities can be done in the needed and goal-oriented way. So it is possible to use the financial budget for the right things.
- To make IT-Security measurable and to perform a regular benchmark process based on the IT Security Standard. We have also the possibility to perform security measurements. Based on the defined audit categories and classes it will be also possible to perform benchmarks between the same categories.
- The concept will be used for planning and project phase and during the complete life cycle.
- The concept and the use of standard and tools are simple and are practical oriented.
- For atomisation reasons the concept and standard is supported by a special database and toolbox.

3.2. Structure Overview

The concept contains the development of IT-Security Standard, Audit and Inspection catalogue, related checklists, and special practical inspections activities.

Also the form and visualization of results are defined for different level of responsibilities. Important is the integration of a management reporting system, because it is necessary to implement a controlling process for the security management. To fulfil this requirement a complete ATC Security Toolbox is developed. This toolbox contains the following parts:

- Database for the ATC IT-Security Standard
- Generator to produce the related Inspections checklist for the right Inspection Category. This generator contains also the related actions and measures for fulfilment of the Basic or High Protection Level based on the ATC Security Standard
- Tool for the result visualization and automatically generation of Inspection report
- Management Reporting System.

With help of the ATC IT-Security Data Base it is possible to define the necessary protection need or requirement (planned target) and additionally to put the real protection level in practice (real target) for the related object. Based on that we are able to represent IT-Security conditions to assess an object and describe the delta between plan and real target. The results are collected into a central database and can be presented in different diagrams and charts.

The developed toolbox will fulfil the following functions:

- Giving information about security lacks of different operational function and you can derive the necessary protection level for this function
- Giving actual reliable information about the actual reached security level from the technical and organizational point of view
- Giving information about the needed target level of security and can be detected lack and overdoing of security activities
- Giving in an automated way audit and inspection list for security activities and describe their priority and efficiency

The IT Security Protection and Audit Concept for ATC IT Systems are structured in the following parts:

Part	**Task**	**Tool**
IT Security Standard	Definition of target security level	Access Data Base
Definition of Protection Level	Method of risk analysis based on different value scales for the definition of possible damages, risks, probability, risk class	Protection Analyser
Definition of Audit Inspection Areas	Assignment of measurement objects to the right categories and classes	Access Data Base
Generator of Audit Check List	Generation of the related audit list for the assigned audit category and class	Inspec Tre
Generator of Inspection List	Generation of the related inspection list for the assigned inspection category and class	Inspec Tre
Visualization of Measurements Audit Report	Visualization of the measurement actual results and comparison between actual and target level Report of the performed IT Security Measurement	Cstar
Management Reporting System	Regular reporting and controlling for high level management	Lotus Notes Application

3.3. Proceeding Description

Important was that the concept of IT Security measurements and the IT Security Standard to bring into the overall ATC System Life Cycle. To Start with Plan–Do–Check – Act steps of the life cycle.

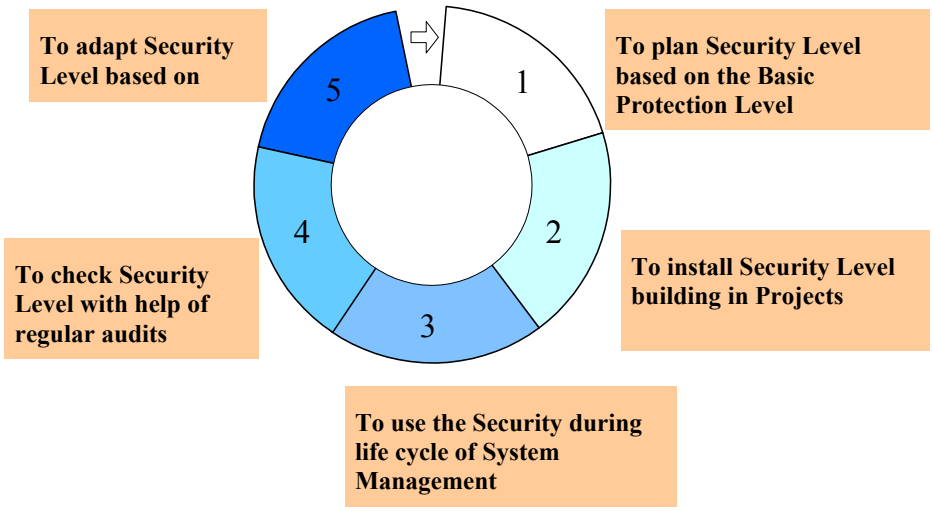


Figure 6. *Description of the Plan-Do-Check-Act Cycle*

Step 1–2:
It is essential that in IT-projects we are able to plan preventively all security requirements and activities. Based on the required fulfilment of the Basic Protection Level from the ATC IT Security Standard all projects can plan their security requirements. Each project leader is aware of the fulfilment of the Basic Protection Level he knows that it is a "Must" requirement and all requirements are to be implemented during the project phase. In that way the project leader can also plan the needed financial resources in the project budgets.

Step 3–5:
Start of the operational use of IT System after a technical and operational clearance. During this period a regular - every 2 years – SAIFIT Audit and Security Measurement will be performed. In this way it will be possible to check the reached security level at starting of operational use and during the complete life cycle of It Systems. It will be possible to get the information and impact about change and maintenance on the actual security level.

Based on the management decision all IT-System is to be regularly audited and measured by SAIFIT. In that way we have overall information about the reached security level and situation. Based on this information we can also perform a benchmark between the same Security categories, for example between the same categories of tower or Radar Navigation equipment. Additionally it is possible to derive information about the security systematic lacks or producing trend analysis. The general procedure of the SAIFIT audit and inspection concept is described in the following diagram.

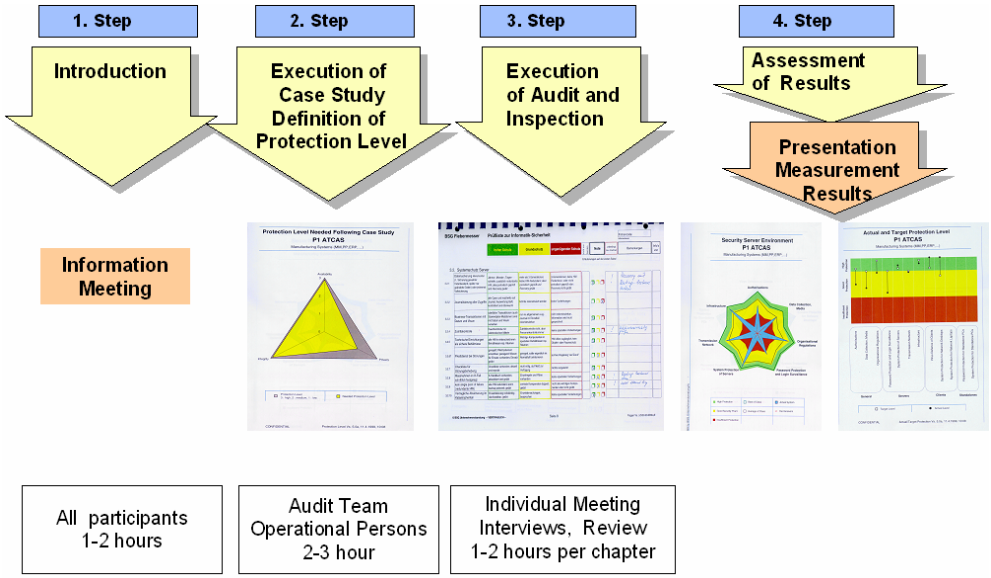


Figure 7. *SAIFIT Audit and Inspection Proceeding*

A very important rule is to perform the IT Security Audit and Inspection on the location side, which will be checked. The audit and inspection must be prepared on management level and must be supported by the local specialist. A "kick off meeting" with all participants should be performed. The participants introduce the goals and procedure of the IT Security Audit and Inspection. Generally it has to be pointed out, that the motivation of employees to support this audit is very high, because the employees are highly identified with Safety Security Mission statement and guideline principles. The motivation is - it is necessary to perform the IT Security audit and inspection as a method to help and not for personal checking.

In the next step the necessary level of detail or degree will be defined for each operational function and system. Based on this defined detailed level the possible damages and their effects will be collected. The tools for this work are our different value scale, which describes the damage and risk classes. As a result we shall have for each operational function the related protection level describing with the following criteria:

- Availability
- Reliability
- Maintainability
- Integrity
- Confidentiality.

This description is based on a workshop with the users and experts. The results describe only the types of level, High or Basic Protection Level. These two types of Protection levels are covered and described in detail by the ATC IT-Security Standard. The generated requirements for the related protection level from the IT-Security Standard represent the target state of IT-Security. In the next step the measuring of the actual IT-Security level will be performed. The measuring is based on the generated Audit and Inspection lists for the related protection level. After the measurement process the results will be represented in the following part:

- Representation of the actual reached level of IT Security for each chapter of the IT Security Standard
- Comparison between the target and actual level of IT-Security.

In the last step of proceeding the results of the IT Security Measurement will be presented. The presentation contains information about the detected actual Security Level, deviations between target and actual level and an action list of necessary activities for the realization of outstanding requirements.

4. STRUCTURE OF THE ATC IT SECURITY STANDARD

The major task is to define the right ATC class definition and the related IT-Security Protection Level because the realization of IT-Security Measures and their management over the system life cycle induces high costs. For that reason the first task was to divide ATC devices in different classes and protection levels.

In that way the ATC devices are divided into the following categories:

- Tower class Regional Access Airport (RAA)
- Tower class International Access Airport (IAA)
- Tower class Intercon Hub Gateway (IHG)
- ATC Centre (Approach, lower Airspace, Upper Airspace)
- Navigation and Surveillance Installations
- Computer Centre and Central ATC and Business Functions (System Management Central, Network Control Centre).

The Surveillance and Navigation Equipment is additionally defined in the following kind of equipment:

A – Operational Critical Equipment
ILS, important Radar stations, Radio Send-Receive Station
B – Operational Important Equipment
DVOR, DME, NDB, Radar stations
C – Operational non-critical Equipment
Outer marker, DVOR , DME*, VOR, NDB*

The ATC IT Security Standard has to satisfy all possible requirements and guarantee an overall ATC security and also to describe all related subject areas. The ATC IT Security describes the following chapters of audit categories:

- Technical Infrastructure
- Facility Management and Building
- IT-System
- Networking
- Telecommunication.

The ATC IT-Security Standard is the base for the inspection and auditing. The following picture summarizes the general structure of this standard.

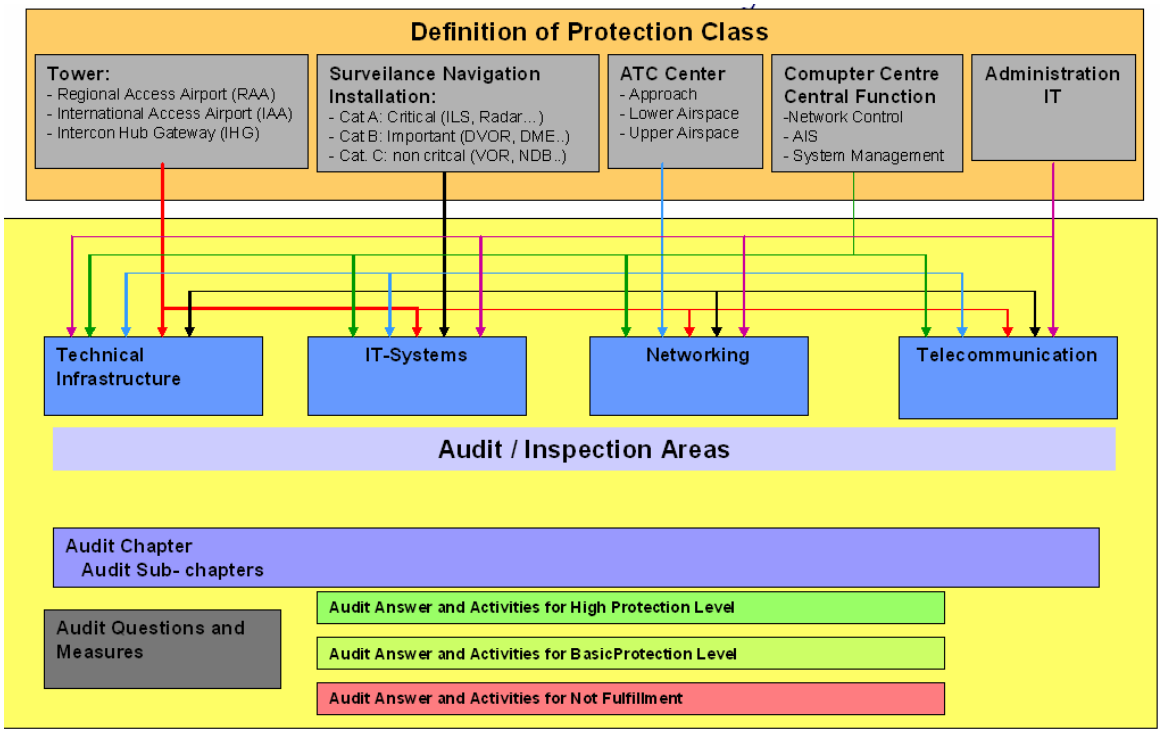


Figure 9. *Structure of the IT Security Standard*

For each of chapters that as an example are described in Figure 10 exist a certain number of special IT-Security requirements. These requirements will be used for the measurement, audit and inspection proceeding. The requirements have a direct relationship to the different classes of Protection level. The required protection level can be changed over the time period. For instance, if new threats appear on an unsafe time period, all requirements which are marked for the related ATC device as a Basic Protection Level are to be fulfilled. They should be realized preventively during projects or as a regular activity during the life cycle. The security requirement and measures and the related definition into the Basic or High Protection Level for each ATC device category are defined into a special Access Data Base. The requirements and measures are described clearly and in a measurable form. The database describes over 300 requirements starting from complex ATC Centre, special Tower requirements up to radar or navigation installations. Automatically it is possible to generate for a defined ATC category the related Basic Protection Security Requirements from the technical infrastructure or IT System or Networking telecommunication point of view.

The different Audit and Inspection areas contain the following chapters. For each of these chapters a number of special audit questions for the related protection level (Basic or High Protection Level) exist. Additionally there are given for each question related answers and actions for the fulfilment of Basic or High Protection or for the insufficient fulfilment of the standard.

Infrastructure:	IT-Systems:	Telecommunication:
Fire Detection /Protection	Access Authority	Architecture Networking
Access Protection	Access Level	Network Connection external
Custody	Access Logging	Network Connection internal
Video Monitoring	Monitoring	Network Organization
Water Detection / Protection	Backup Concept	Telephone Switchboard
Protection of thunderbolts, Overvoltage, Electromagnetic compatibility	Installation Process	Tele Working Places
	Test-Clearance-Inspection	System Access via dial-up connection
Air-conditioning	System Management Process	Modem
Supply Engineering	Data Protection Backup	Remote Access
Cabling	Virus Protection	Remote System Administration
Emergency Management		Notebooks
Personal Security		Mobil Working Places

Figure 10. *Overview of Audit chapters*

5. DESCRIPTION OF PROCESS MODELLING AND INFORMATION DATA BASE

The process model is described in the following Figure.

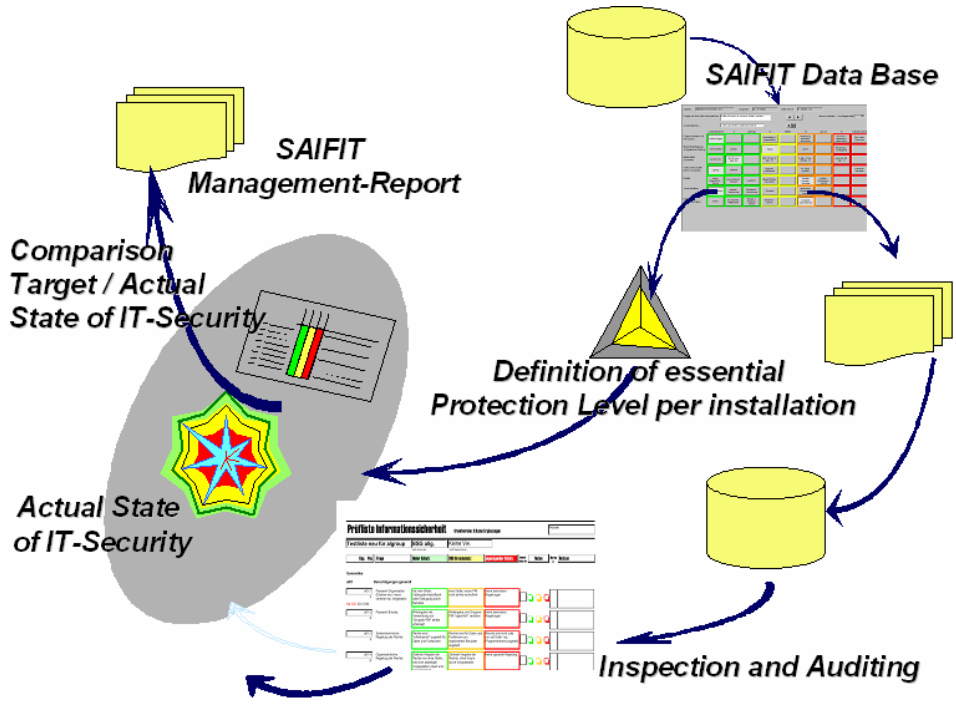


Figure 11. *Process Model of the IT Security Protection and Audit Concept for ATC IT Systems*

In the next steps we shall go through the data model and we'll describe a specific example.

1. Step Definition of ATC Class
Based on the definition for example the Tower on the Airport Riga will be assigned to the ATC Class Tower IAA - International Access Class. The Tower will be fulfilling the IT- Security Protection class.

2. Step Safety Security Analysis
A Safety Security Analysis will be performed for all ATC operational functions and systems. Based on this analysis and used value scale the result can be that the Tower will be fulfilling the IT Security Basic Protection Level. For each operational function the needed protection level is described for the criteria's: Availability, Reliability, Maintainability, Integrity and Confidentiality and is illustrated by different diagrams.

3. Step Generation of Audit and Inspection List
These lists will be generated from the SAIFIT Data Base that includes the ATC Security Standard for the different classes. For each audit areas (Figure 9) like IT-System or Telecommunication will be generated in an automatic way lists for each audit chapters (Figure 10). An example for a specific audit and Inspection lists is given in Annex A.

4. Step Performing Audit and Inspection
For all objects and IT Systems of the Tower Riga the audit and inspection can be performed based on the generated list. For this activity the SAIFIT database can be used on a standard notebook.

5. Step Visualization of Results
After the inspection and audit during a short internal review the results will be visible via special diagrams separate for each audit chapter. It is also important to give at the end of the session a fast feedback of the detected deviation from the standard or detected security lack. This feedback is shown on a Power Point presentation and using photos.

6. Step Workout of a detailed Report

7. Step Establishing on Management Reporting and Controlling

6. VISUALIZATION AND REPORTING OF RESULTS

The goal is to have at the end of the IT Security measurement a feedback session and to get an immediately feedback to the reached actual security and protection level, to show the deviation between the target and actual results, to be able to describe the detected lacks of security and not fulfilment of the IT Security standard. For that reason a special tool for the visualization of results was developed.

6.1. Visualization of IT Security Measurement Results

For each chapter of the IT Security Standard will be built two different types of diagrams. The first diagram will describe the following information:

The different coloured areas represent the various Protection Levels, Green – the High and Yellow – for the Basic Protection Level, the fulfilment of the Basic Level is a "Must" criteria and the Red area shows the insufficient level.

Each Green spike of the diagram represents the summary of a special chapter. The Blue spike indicates the actual result of IT-Security for the measured object. In an easy way you can see the reached fulfilment in relationship to the different Protection Level. The Red lines inside of the Blue star have a special and important function. These Red lines indicate issues that single requirement of chapter are not fulfilled. The length of this line depends on the number of insufficient single requirements. The Green and Black lines give information about the best of class or average of class in comparison or benchmark between measurements of the same class of objects, like between all Tower locations of the category International Access Airport. Based on this information we can benchmark the summarized information not only between national and / or between Tower locations on the international level.

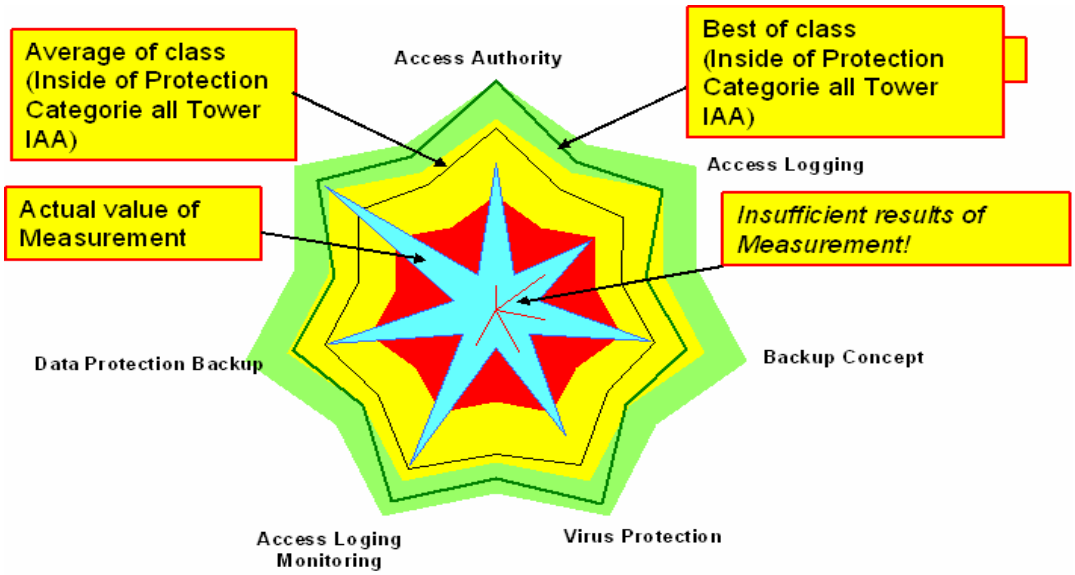


Figure 12. *Visualization of the actual measured IT Security results in relationship to the different Protection Levels*

The next kind of diagram gives some additional information. Especially the deviation between the required target level and the reached actual level will be visible. So it is easy to identify the related areas where there is a need for action or not. Also it is visible if the actual level is higher than the required, in that case may be there is an overdoing for the specific area or the required target level is too low.

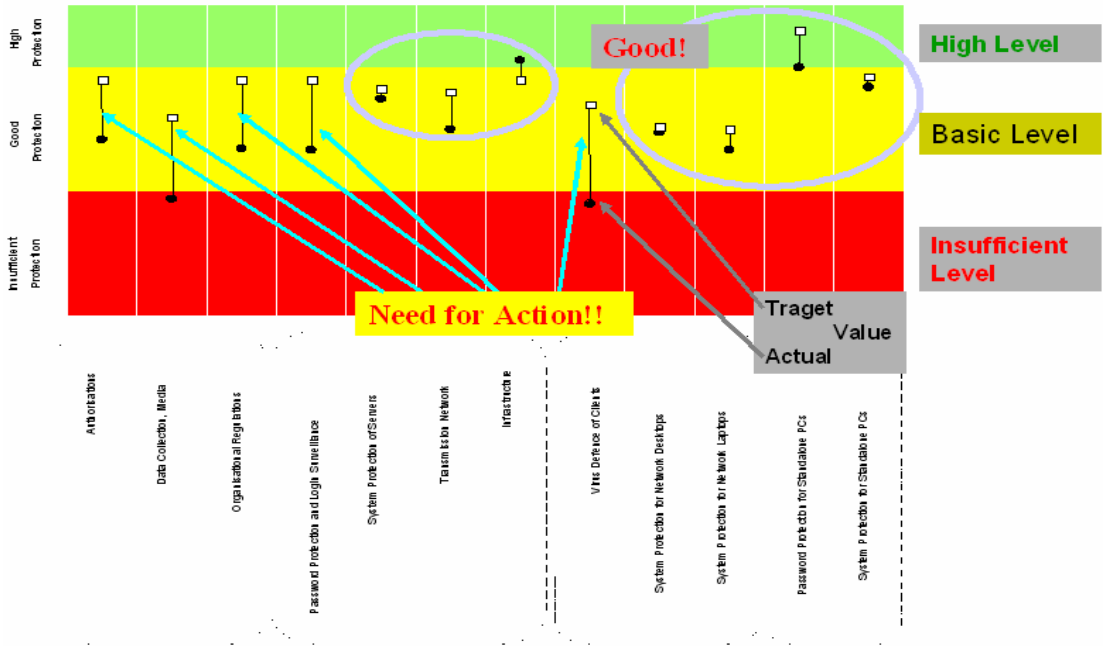


Figure 13. *Visualization of deviation between target and actual results*

The visualization is very sensitive and important part of our concept. From our point of view it is important to give an immediately feedback of the measured results. In that way presentation of results is a part of the SAIFIT concept and gives directly on the location side. It is our understanding that the information for all participants is open and during the result presentation all participants and the local management have the chance to get the same level of information and to make comments to the results. This concept is important for the motivation and acceptance of SAIFIT. The documentation, database and visualization of results are confidential information.

6.2. Structure of the Audit and Measurement Report

The audit and measurement report has a special role. This report contains all information, assessments and deviations. The information content is sensitive and confidential. Each report is marked as confidential. All reports contain a distribution number with the related names of distribution. The report is a closed document only for a defined number of persons. The report is handed out only in paper form or as a PDF file. The first chapter describes all general purposes, like the task mission, goals, scale and special conditions. The defined protection class, objects and audit areas (infrastructure, IT-Systems, Telecommunication) are documented. All objects, actions and audit / inspections topic are assigned to the IT Security Standard. This relationship is represented in table form. All used documents, information about the proceeding and involved people are listed in the report.

The second chapter contains the overview results of the audit and measurement. The two specific diagrams for each audit area describe the overview.

In the third part of report the results are described in detail. The detail results are sorted and arranged in the different chapter of the IT-Security Standard. For each audit area like Infrastructure or IT-Systems a separate chapter will be opened.

The detail description for each finding and observation contains the following information:

- Description of finding
- Reference number to audit and inspection list
- Reference number and requirement description of the IT-Security Standard
- Description of all recommendations
- Rating of recommended activities: short / medium / long term; responsible; Status

This chapter is the central part of report. A summary of the findings and the agreed actions will be transferred into the Management Reporting and controlling process.
The next part of report contains a collection of photos for the detected findings, lacks and deviations.

The report also covers the fulfilled and documented audit check lists which were generated from the database containing the IT-Security Standard.

6.3. Management Reporting

The following Management Reporting System will satisfy the high Management Level like Managing Directors, Head of ATC Locations and Head of main divisions. The sequence of reporting can be once a quarter or once a half-year. With the help of this management reporting system will fulfil a basic requirement from the Safety Security Mission Statement.

The goal of the management reporting system summarizes the results of the IT Security Measurements. The results are visualized and commented for each measurement. Additionally the diverted actions and controlling of these actions must be possible. The reporting must show in a clearly way where activity is necessary and is to be informed by different levels of management.

Possible reported information for the Managing Director level is shown in Annex A.

Based on the requirements to the reporting system of the operational management level it is needed to deliver information on a more detailed level and in a more described form.

In that way the detailed information is delivered about the following:

- Comments to the measurements:
  - Description of reasons for deviation Plan / Actual and suggestions
- Assessment of Protection Level like new condition based of new laws or ATC rules, new risks of technology etc.
- New factors of influence, new changes of systems and their impact on the protection level
- Assessment of Threat Analysis
  - Definition of new threats
  - Changes of the occurrence probability
- Visualization and comments of IT Security Measurements
- Safety Security related incidents and their description

- Duration of Safety Security actions
- Incidents against the Basic Protection Level for all related areas and description of derived security actions
- Action controlling

The reporting of this information can be performed with the help of structured Tables and Figures. An example of reporting for the operational management level is given in the Annex B.

7. CONCLUSION

The IT Security Standard and Measurements are being in use since 2001. The most part of the locations, central functions and installations measured by the SAIFIT Program is based on the Security Standard. A certain number of employees were trained in the SAIFIT Program in use of toolbox, IT-Security Standard and proceeding of IT Security measurements. The Project Managers have the knowledge about the Security Standard. In that way the projects are able to plan security based on the standard during the requirement phase and able to realize security requirements during the design and realization phase. Based on this proceeding the IT Security Standard is built into the IT-System from the start up. During the life cycle of IT-System the responsible System Managers know that the regular IT Security Measurements will be performed every 2 years and the System Management is responsible for the security during the operation. Do to the training session the key players from different locations have the understanding and motivation for the IT Security measurements? It is important to make understandable that the measurements are not to control persons, but the goal is to implement a consistency and different security level based on the required protection level for IT-Systems. The measurement proceeding is established in the normal project and operation process and it has positive feedback and practical benefits from operational divisions.

Based on the certain number of performed measurements on different locations a large database for the ATC and Business Support Systems is available. Do to this experience the methodology and IT Security Standard were regular updated? The new know-how is brought in new versions of the database. The proceeding and tools are more sophisticated.

IT-Security measurements will be performed on the following:

- Tower location during around 2 days
- ATC Centre locations and central functions during around 3 days
- Surveillance Navigation Installations during 4-5 hours.

Based of the measured results we are able to derive the following kind of deviations from the security standard:

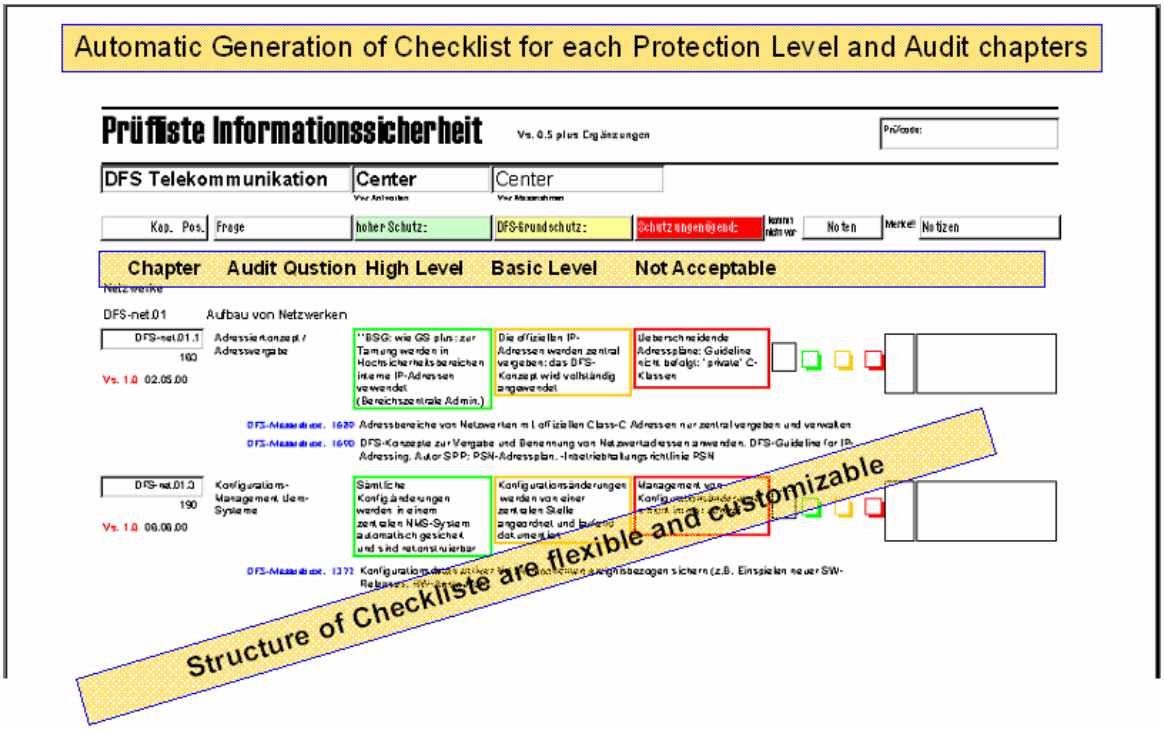
1. Deviations and deficiencies depending on the location point of view, especially in the infrastructure area
2. Lack and deficiencies in the IT-Systems, especially in use of standard IT Systems for different location that can be a systematic defect which has impact to different ATC locations
3. Deviations that appear during the life cycle of operation, especially during different maintenance or update activities.

With the help of SAIFIT we are able to give information about the actual security level and necessary protection level for the different kinds of ATC objects. We are able to measure the IT-Security in a short time. The database contains all detail information about the fulfilments or deviations from the IT Security Standards or other inspected defects. Based on these information and experiences it is possible to perform a benchmark between the same classes of objects from the different point of view (between locations, ATC classes or IT-Systems). Additionally we are able to make forecasts and trend analysis. So we are able to act preventively.

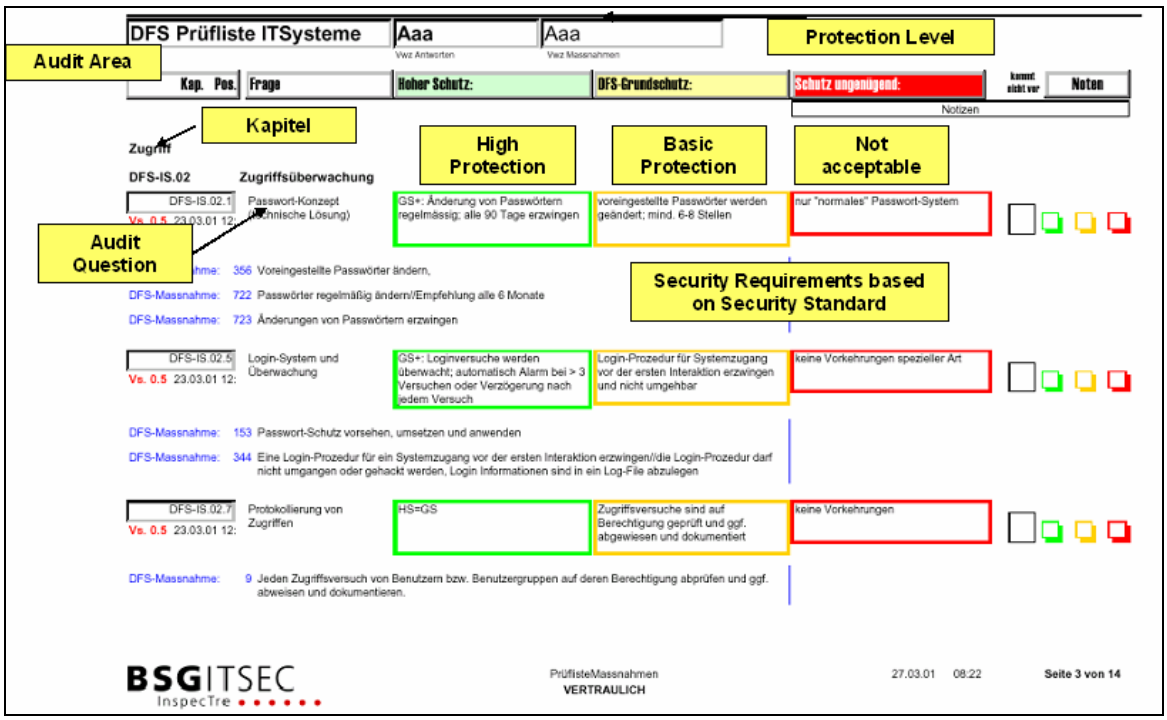
With respect to the Single European Sky Program of Euro control it will be interesting to perform a benchmark process on a higher level, for instance, measurements and a benchmark process among different Air Navigation Service Providers or among different IT Service Providers for the Business Support Systems.

8. Annex A – Example and Structure of Audit and Inspection List

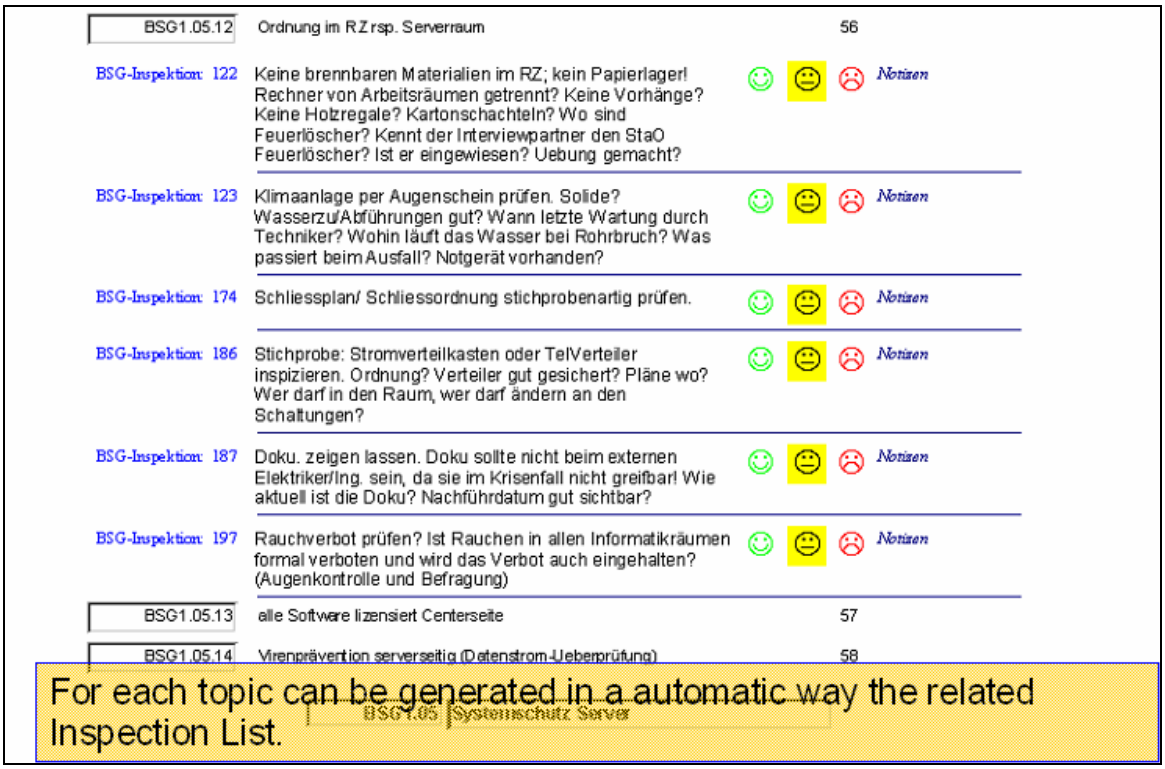
- Example for an Audit List



- Structure of an Audit List

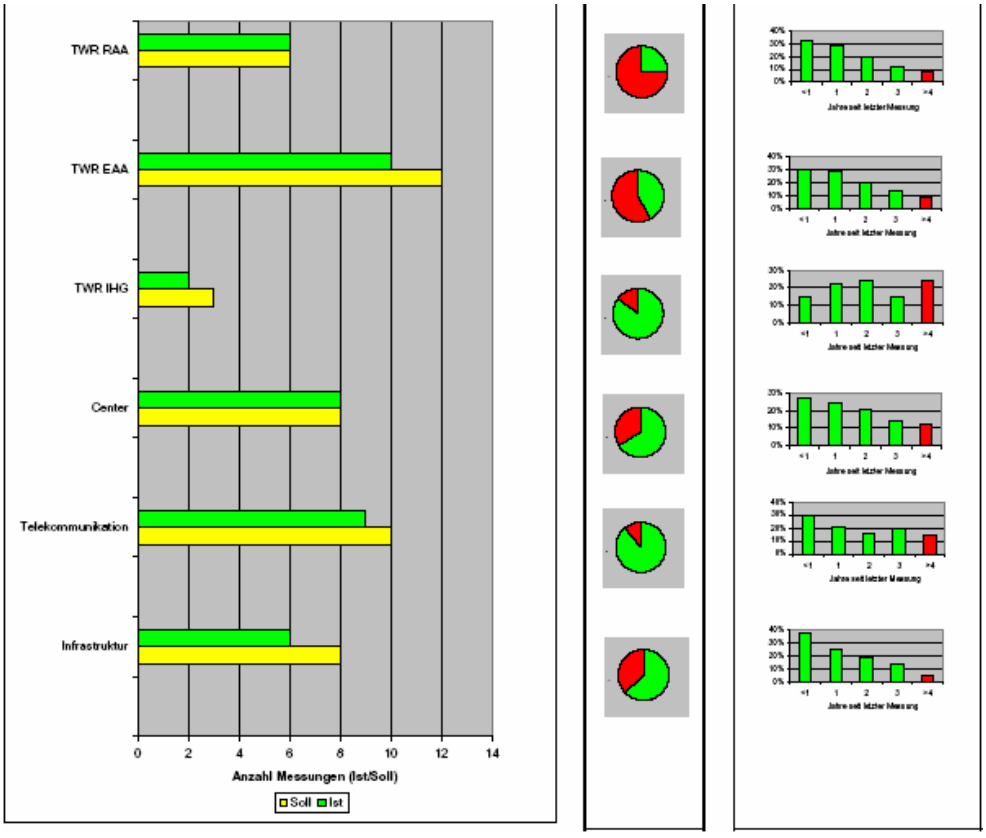


- Example for an Inspection List

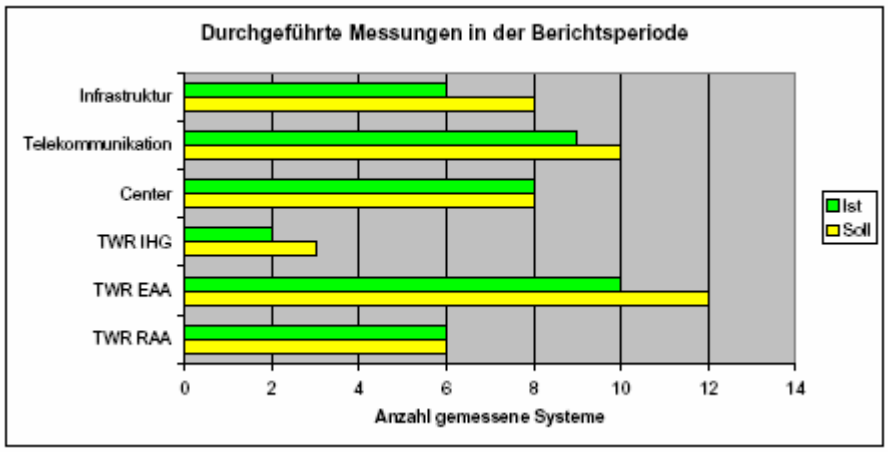


9. Annex B - Reporting Slides for Managing Director Level

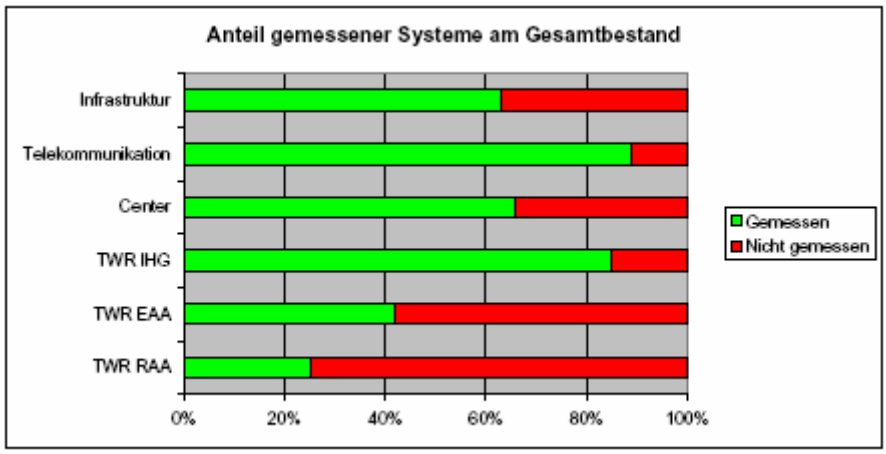
- Performed IT-Security Measurements inside of the reporting year



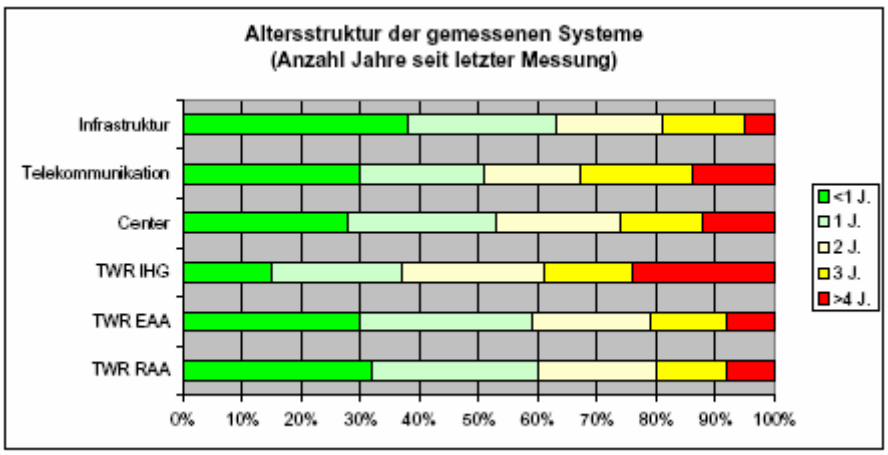
- Number of performed IT-Security Measurements Plan / Actual



- Proportion of number measured IT-Systems to the complete number

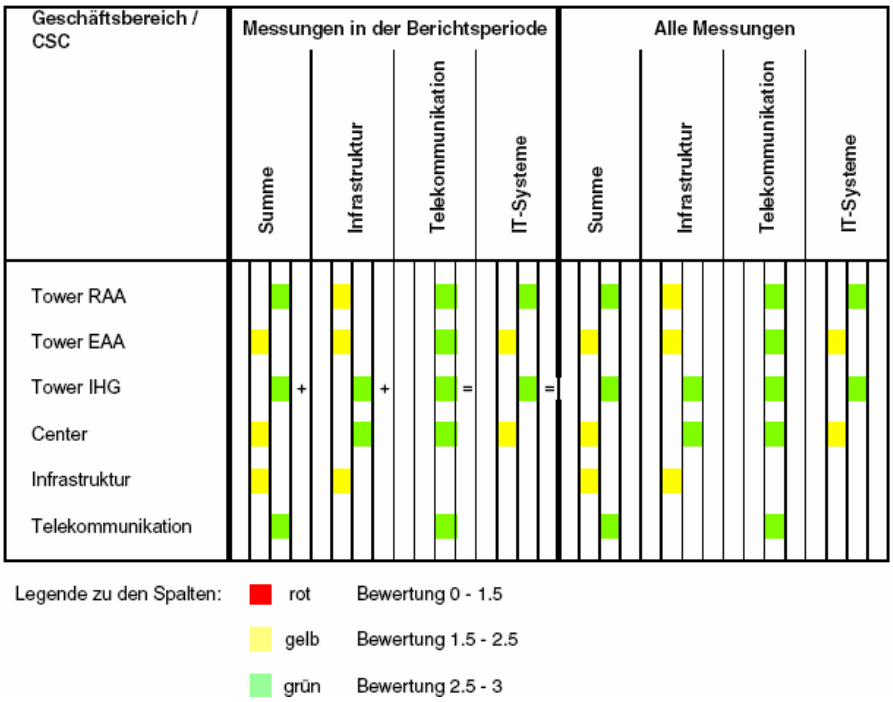


- Ageing Structure of IT-Security Measurements



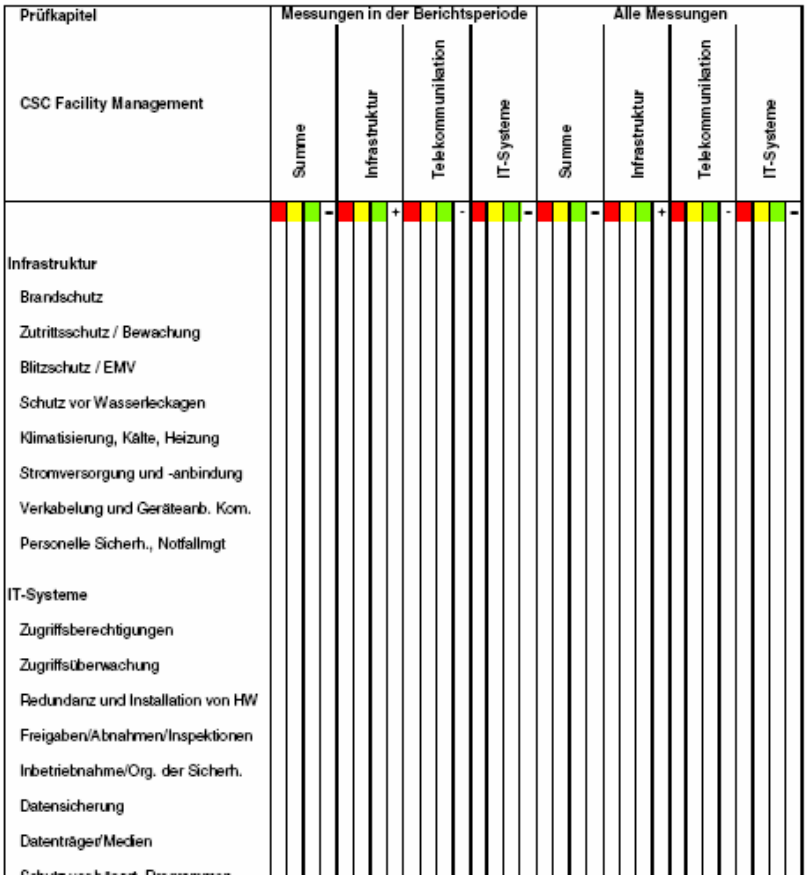
10. Annex C- Reporting Slides for Operational Management Level

- Presentation of Measurement Results



Remark: These results can be also breakdown from:
- the location point of view for each ATC Centre or Tower or Radar Navigation Installation
- the audit categories point of view like Infrastructure or IT-systems or networking or telecommunication

Example:



LOCATION AND CONTROL OF CARGO AND VEHICLES WITH NEW TECHNOLOGIES

Nijole Batarliene

Vilnius Gediminas Technical University
Plytines Str. 27, LT-10105, Vilnius-16, Lithuania
Ph: +370 2744778. Fax: +370 2745059
E-mail: nijbat@ti.vtu.lt; n.batarliene@post.skynet.lt

This paper presents several ideas of effective transport systems technologies, technological solutions in systems for identification objects on the road.
In the article is theoretically shown the coherence of new technologies and new possibilities for location and control of cargo and vehicles with systems of navigation and positioning system. The expansion of Internet connectivity by GSM-GPRS network to transport elements allows using of new possibilities of differential GPS (GNSS) techniques and applications.

Keywords: *cargo, technologies, location, vehicle, control*

1. INTRODUCTION

Rapid development of teleinformatics makes an influence on the development of telematic system. We can distinguish many systems that help to drivers and transport clients.

At present telematic solutions are used in road transport. Transport telematics consists of the following aspects:

- Transmission of information to and from a vehicle (Telecommunication);
- Processing of information (Information Technology);
- Information usage for safe transport and effective usage of already existing technologies' solutions.

Such changeable light boards as navigation systems, the Internet, mobile network are just few examples of telematics usage in road transport.

2. PERFORMANCE PARAMETERS DEFINITION

The first step in addressing the ITS architecture requirements should be the analysis and establishment of performance parameters in telematics applications, in co-operation with the end-users.

The methodology for the definition and measurement of the following individual system parameters is being developed in frame of the ITS architecture:

- Reliability – the ability to perform required function under given conditions for a given time interval.
- Safety – risk analysis, risk classification, risk tolerability matrix, etc.
- Availability – the ability to perform the required function at the initialisation of the intended operation.
- Integrity – the ability to provide timely and valid alerts to the user when a system must not be used for the intended operation.
- Continuity – the ability to perform the required function without non-scheduled interruption during the intended operation.
- Accuracy – the degree of conformance between a platform's true parameter and its estimated value, etc.

Substantial part of the system parameters' analysis is represented by a decomposition of system parameters into individual sub-systems of the telematic chain. Part of the analysis is the establishment

of requirements on individual functions and information linkage so that the whole telematic chain should comply with the above defined system parameters.

The completed decomposition of system parameters will enable the development of methodology for the follow-up analysis of telematic chains according to the various criteria (optimisation of the information transfer between a mobile unit and processing centre, maximum use of the existing information and telecommunication infrastructure, etc).

3. MOBILE LOCATION

Mobile Location is fundamentally characterised by two aspects: mobility and location information.

Mobile Location Services are the services that exploit knowledge about as follows – where a mobile terminal capable of wireless data transfers is located. The end user or another person may carry the terminal, or it may be attached to the object. The wireless data connection is typically based on cellular technologies or wireless. Network-based positioning, satellite positioning or indoor positioning technologies can define the location of the terminal. The most suitable technology depends on an application, the environment and the terminal capabilities. As the mobile location services sector is still in its early phases, the terminology varies and they are also called location based services, location enhanced services and location dependent services.

Typical professional applications include, for instance, fleet and mobile workforce management as well as routing and navigation. Location information is very important in various fields and for various purposes.

4. LOCATION SYSTEM STANDARDS

Now and in the near future we will have the opportunity to use the advanced ITS systems based on the standard Location Systems.

The emergence of road transport means is supported by telematic solutions like:

- Traffic monitoring equipment (sensors, detectors, steering equipment, video detectors), television supervision devices (supervising cameras);
- Systems of satellite navigation (GPS, GLONASS, EGNOS, GALILEO);
- Derivative systems used in navigation;
- Systems of radio communication;
- Geographical data bases (GIS);
- Bases of road data;
- Electronic cards;
- Weather monitoring and measuring systems and other.

The GPS is well known as a global navigation satellite system. The analogous systems are the Russian GLONASS and GALILEO system prepared by European Commission and European Space Agency. GPS is the foundation of the present navigation systems. Actually, the GPS is the only one fully applicable global satellite position determination system in the world.

GALILEO will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. It will be inter-operable with GPS and GLONASS, the two other global satellite navigation systems. A user will be able to take a position with the same receiver from any of the satellites in any combination. By offering dual frequencies as a standard, however, GALILEO will deliver real-time positioning accuracy down to the metre range, which is unprecedented for a publicly available system. It will guarantee availability of the service under all but the most extreme circumstances and will inform users within seconds of a failure of any satellite. This will make it suitable for applications where safety is crucial, such as running trains, guiding cars and landing aircraft.

With the help of the GALILEO, SBAS, EGNOS, THALES NAVIGATION, etc. systems with the needed precision objects position may be estimated. It is very important when we have to watch a truck whose position is always changing in the digital map [1].

These systems are the instrumentality to managing land transport in Europe, whether they are by road, rail or inland waterways. They increase both the capacity and the safety of land transport. Not

only airlines but also companies, which operate transport services, need to know where their vehicles are at any times.

As well as improving safety, world satellite navigation and positioning systems are an invaluable aid to managing transport operations. Managers will be able to know exactly when a consignment has been held up and its exact location. This will also improve customer services as clients can be notified of delays and the reason for them and when necessary breakdown crews can be sent out immediately.

5. DOCUMENTS AND MOVING OBJECTS TRACKING SYSTEM

Documents and Moving Objects Tracking System is supplemented by possibilities to control not only cargo documents movements, but also present cargo carrier physical movements, using tracing possibilities, supplied by Global Positioning System (GPS) and Geographical Information Systems (GIS). In addition, several communication channels are used (GSM, Radio Channels or Satellite).

Moving Object Tracking System consists of two main components (Fig.1):

1. Objects Tracing Subsystem;
2. Tracking Communication Subsystem [4].

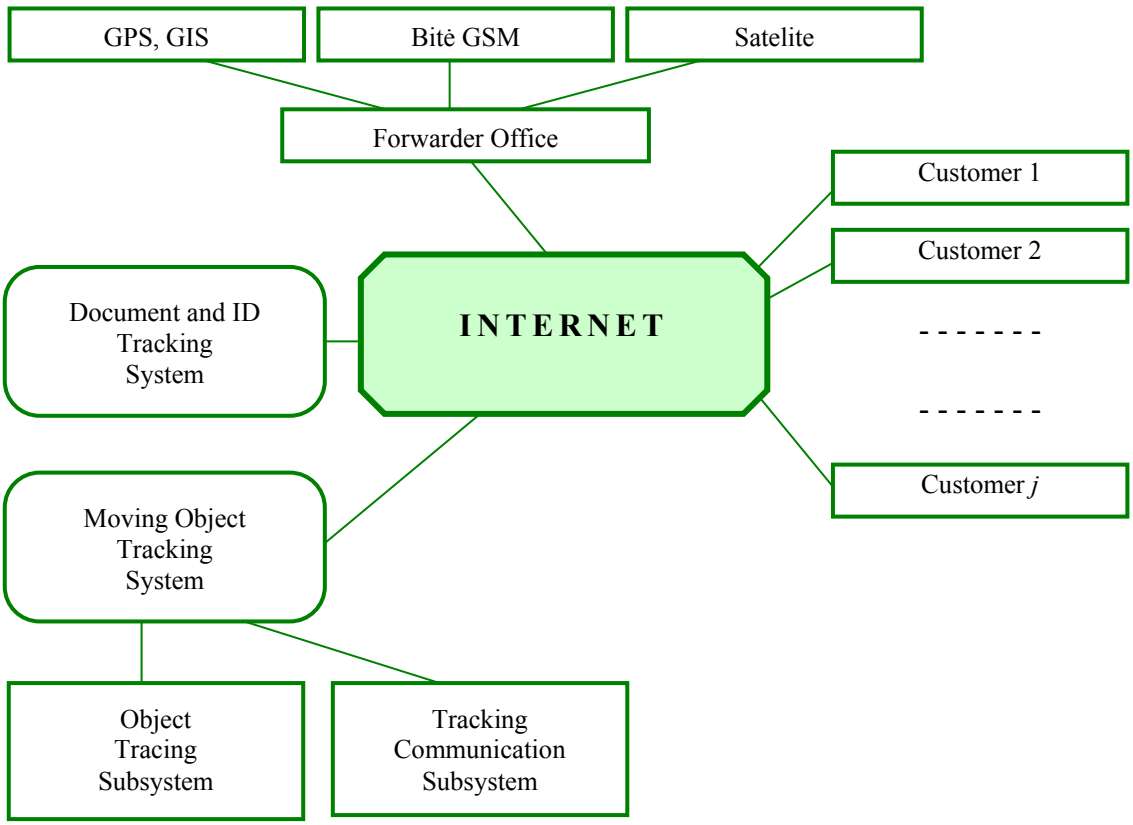


Figure 1. *Documents and Moving Objects Tracking System*

Object Tracing Subsystem serves for driver of a truck to know his transport movement route. There are two constituent parts in the heart of tracing subsystem: GIS module and GPS engine module.

GIS module stores area chart image, which is shown by driver request on the monitor in the cabin. GPS engine ensures truck coordinates calculation by getting signals from GPS satellites. As a result on the display screen we can observe truck movement area chart. This kind of tracing or navigation system should be presented as a part of equipment in any car.

Tracking Communication Subsystem is created of different communication channels, which ensure on-line transmission of information about truck and freight movements to Moving Object Tracking System. In this case satellite communication channels are used.

Tracking Communication Subsystem is presented in Figure 2.

As a result, Operator of the Moving Objects Tracking System at central office can see and control several cargo movement routes.

There are the following benefits for using of this system:

- Transport driver's working quality control (whether he does not spend more than allowed time on a parking and whether fuel consumption corresponds to reported route);
- Cargo movement forecasting (client is able to get ready for cargo receiving);
- Route corrections possibilities (if there are delays on one part of a route, it is possible to change object movement direction);
- Movement safety rising (it is possible to identify a driver, block vehicles engine; it is possible to press alert button in case of unlawful interference).

Documents and ID tracking system is such a cargo tracking system, where movements of documents and identification numbers are controlled using total routes database.

If we know Tracking Number, which is printed on cargo documents, then using Internet it is possible to follow cargo movements among UPS hubs.

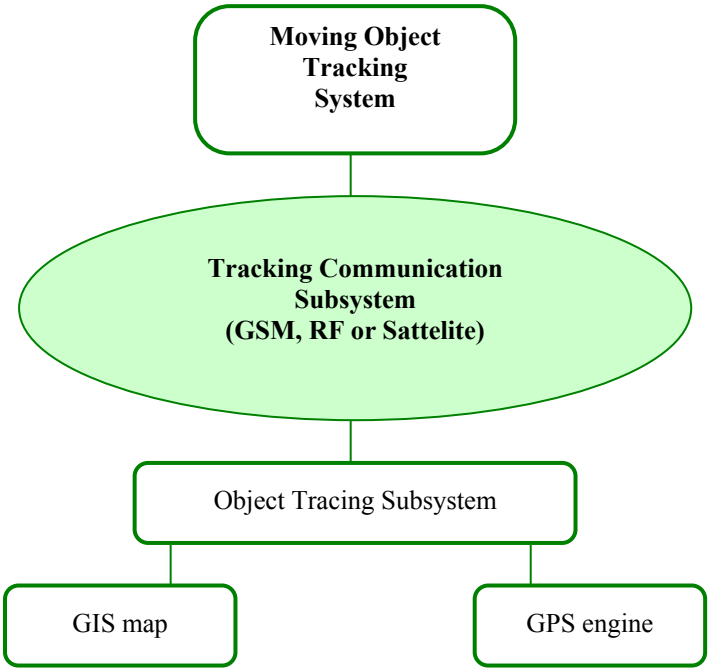


Figure 2. *Moving Object Tracking System*

Tracking and location systems play an important role in transportation of dangerous loads because dangerous loads bring big danger for the environment and the society.

6. SOFTWARE APPLICATION

The catalogue of telematic system has the client-server structure. All data are stored in separate place (computer) named the server. Access to its data is possible by a client applications installed on the user's computer. Clients are connected via, for instance, a local area network (LAN) or wide area network (WAN) [5]. The solution gives many advantages for future users. The central bank of data (server) gives certainly that all users have an access to the same updated data. Any change of the infrastructure telematic system may be input to the catalogue system directly by the service that change made. It causes that the update data will be available for all users soon after updated. Access to the server's data is restricting depending on the service need. It protects against free access to the data for the unprivileged persons.

The local database contains all necessary information about the saved telematic systems, their items, remarks, etc. The digital map server stores a graphic representation of spatial locations a system's item may be found. The external databases module allows users to access to an external temporary databases to improve the knowledge about the telematic system. The graphic user interface combines all data that comes from different module into the one comprehensible view easy to interpret by user. The map scanner allows to the preparation of external maps to use with the system. The last module is responsible for the analysis-loaded data from the server as an answer to user's question. Other function the last module has is the reporting. It is the one of main functions of a catalogue program. Particular parts of the software are presented in Figure 3.

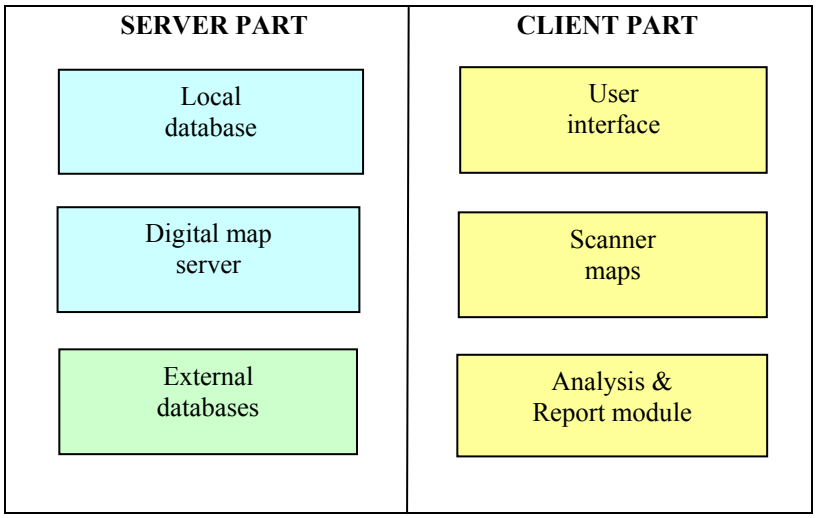


Figure 3. *Main parts and modules of the catalogue of telematic systems*

7. CONCLUSIONS

1. It is important to use decisions of transport mobility in the transportation of road transport.
2. Concerning safety improvement, world satellite navigation and positioning systems are as an invaluable aid to managing transport operations.
3. It is necessary to use vehicle and loads tracking on their trips in the forwarder of road transport.
4. Tracking and location systems play an important role in transportation of dangerous loads.

References

[1] Batarliene N. Vehicles and Loads Mobility Positioning Systems. In: *IV International Conference TRANSPORT SYSTEMS TELEMATICS: Conference Materials. Transport z.51*. Katowice – Ustron, Poland: Faculty of Transport, Silesian University of Technology, 4-5 November 2004.

[2] Baublys A. *Transport System: Models of Development and Forecast.* Vilnius: Technika, 2003. 208 p.

[3] Lewicki W. An Intelligent Vehicle. In: *III International Conference Transport Systems Telematics TST'03*. 2003.

[4] *Logistics Information Systems*. *Part 2*. Riga: Jumi Ltd., 2002.

[5] Sumila M., Tucker M. Catalogue of Telematic Systems. In: *IV International Conference TRANSPORT SYSTEMS TELEMATICS. Transport z.51.* Katowice – Ustron, Poland: Faculty of Transport, Silesian University of Technology, 4-5 November 2004.

INTRODUCTION OF ELECTRONIC CARD SYSTEM IN LITHUANIAN CITY PASSENGER TRANSPORT

Jonas Butkevičius

Vilnius Gediminas Technical University
Dept. of Transport Management
Plytines Str. 27, LT-10105, Vilnius, Lithuania
E-mail: vladas@ti.vtu.lt

Based on the research, the current Lithuanian city passenger transport ticket system has not been changed for already several decades; therefore it has lots of drawbacks (inflexibility of ticket prices, no stored banks of data on carried passengers, no common tickets for all types of transport, etc.). Thus, this system cannot meet the increasing needs of the transport system administrator and the passengers. Consequently, a necessity to improve the city passenger transport ticket system has become inevitable.
In 2006, the electronic card system in the biggest Lithuanian cities, for instance, in Vilnius, Kaunas and Klaipėda it has been planned to install. For this purpose the contact-less electronic cards are foreseen. Implementation of this project will cost about 60 million Litas (i.e., about 17,6 Euro). For the process of implementation of this project, also sources from different European Union funds will be used.

Keywords: *city passenger transport, ticket system, electronic cards*

1. INTRODUCTION

The global city passenger transport has been widely applying electronic ticket systems, made of electronic cards, card-loading machines, electronic ticket scanning technology, control devices, terminals – cash-registers and clearing software. The contact, contact-less, double interface and "hands-free" electronic tickets are used. Electronic ticket systems are considered as the most modern and advanced, as they are multi-functional and ensure a high passenger service level.

2. ANALYSIS OF THE GLOBAL URBAN TRANSPORT TICKET SYSTEMS

Currently, the following major ticket systems are introduced in the global urban transport [1]:

- paper tickets and (or) cards;
- magnetic cards;
- electronic cards.

Paper tickets and (or) cards. Onetime (single) and regular public transportation tickets are discussed. Usually, the fixed ticket prices are established, different discount systems are applied (for pensioners, pupils, etc.). Despite rapidly improving technologies, such tickets are still used in urban transport systems. They are produced of different paper – from a simple thin one up to inflexible cards, which are punched by dynamoelectric facilities. The protection level differs from a more complicate printing up to multiplex graphics, water signs and application of the fibre seen only under ultraviolet rays. For example, currently, the onetime (single) tickets used in Vilnius are covered with double strings, one strings gleam under ultraviolet rays; other ones are visible under simple lighting. Furthermore, each ticket is numbered by a number, which glitters in green under ultraviolet rays. The protection level of a public transportation pass is much higher.

Paper tickets are used in all Lithuanian cities and towns.

Magnetic cards. Magnetic cards are usually produced of thick paper, plastic or their mixture – it depends upon requirements raised on their durability and the printing quality. The difference between magnetic cards and paper tickets lies in one or several magnetic strips covering the cards. Magnetic strips can be pasted in accordance with ISO credit card standards or are simply set in the middle of a ticket. Usually magnetic cards in their size equal to credit cards (such cards are used in London, Dublin, Barcelona, Brussels) or they can be of the so-called Edmonton size (for example, in Paris underground stations, Marseilles).

The data held under the magnetic strip enable to check a tariff, to scan specific card data and save them in a dynamoelectric device. The device can reduce a ticket price (E.G. a number of rides, the rest of time or money), also recognize a magnetic card of other city or town and, if necessary, to scan it.

Most of underground, railway systems and an increasing number of bus carriers successfully use magnetic cards. To summarize, the following conclusion could be made: this ticket technological base is unsophisticated, reliable and safe to use in closed systems when deals of little value are made. Though it has the major drawbacks and shortcomings – it is not protected from falsification and is not comfortable for those passengers who are not frequent travellers and who come from other cities or towns.

Electronic tickets. The public transport electronic ticket system includes [1]:

- electronic cards,
- card loading machines,
- electronic ticket scanning technology,
- control devices,
- terminals – cash-registers,
- clearing software.

Electronic cards. The major component of electronic cards (integral scheme cards) is a microchip installed in a card. This could be a simple memory microchip or a microprocessor, provided with memory and able to process some data. Usually electronic tickets by their size resemble credit cards, however, they can be of any form as their main element – a microchip – is relatively small (e.g. the SIM card used in mobile phones is a sample of the integrated scheme card).

Subject to a way of communication between the integrated scheme card and the scanning device, there are four electronic ticket types: contact, contact-less, double interface and "hands-free" electronic tickets:

Contact electronic cards have a physical contact between ticket microchip plates and analogous microchip plates of a scanning device. Usually cards are inserted into a special gouge. A card receives energy from the scanning device, and then the data are scanned. In order to use a card repeatedly, it should be again inserted into the scanning device. Cards of this type are widely used in telephone, banking, medicine service fields, therefore, their standards and the architecture of open systems are more elaborated than those of other type cards.

Contact-less electronic cards do not need a physical contact with the scanning device to transact a deal. The card transfers data to the scanning device on the airwaves and is usually supplied by the inductive field created by the scanning device. It should be held in at the range of 2–10 cm from the indicated place of the device (e.g. in Helsinki, London, Honk Kong, Manchester). Contact-less cards do not provide such possibilities of data conversion and processing as the contact ones, however, the total time of deals, using them, is much shorter, as there is no need to insert them into gauges. Contact-less cards are usually more expensive, they are not so standardized, no systemic base is created for them, and usually suppliers of non-transport services do not use them. However, great interest for application of this rather new technology in transport sector may increase their popularity and demand.

Double interface electronic cards combine functions of both contact and contact-less cards. This is a combination of contact and contact-less cards created on basis of both technologies.

"Hands-free" electronic cards are still being tested; there are only first attempts to use them (the official name of these cards is not still introduced). The main peculiarity of these cards is an ability to scan data at the range of 1,5–2 m from scanning devices. „Hands-free" electronic cards are provided with their own power supply and the airwaves transmitter. Cards of this type should still be improved with regard to a size and a price, though it could already be stated that their perspectives are greatly promising, especially in such cases when time of passengers' boarding should be minimal.

Electronic ticket systems are considered as the most modern and advanced, therefore, they are installed mostly in bigger cities of the world, as they are multi-functional and ensure a high passenger service level.

The electronic transport ticket technology is most widely applied in the capital of Korea, Seoul. In Seoul even 7,5 million passengers use electronic cards, by means of which about 80 million deals are transacted per month. The project was started in 1996, when the biggest public transport companies in Seoul started to apply the contact-less card technology *Mifare*, instead of tickets.

Some public transport projects supported by electronic (integral scheme) cards are implemented or are being implemented in Great Britain.

Electronic ones in Manchester replace paper tickets as well. In this town multifunctional cards are being implemented. By means of such cards it is possible to pay for public transport services, to participate in programs of regular customers, to settle up for services in small shops, trading machines.

In 1998, electronic tickets were first introduced in London. Electronic ticket scanners will be implemented in 5800 buses and all underground stations in London. Electronic cards, based on an integrated scheme card, will replace the current technology supported with magnetic field-supported cards.

Electronic public transport ticket system is being implemented in Singapore. Five public transport operators, using 3 750 buses, will apply the common electronic card. The system will cover 22 000 card scanners and at the first stage – 5 million electronic cards.

In Trodheym, Norway, 14 carriers issued 100 000 double interface electronic cards up to the year of 2001. By means of these cards it is possible to pay for services in regional buses, trains, taxis and ships. A similar scheme is being implemented in San Francisco *Bay* region, where in 2001 26 trains, buses and road operators joined the electronic card settlement system

Electronic card systems used in public transport service settlement sector are being implemented in the Czech Republic and Slovakia.

Electronic tickets are particularly popular in Finland, which is one of the first countries that had introduced this novelty. Electronic tickets in Finland were introduced in 1988, and the first electronic ticket system started to be functioning in 1991. Up to 2000, in Finland more than 20 electronic ticket systems and several urban card projects were already in use. Popularity of electronic tickets in Finland is illustrated by the fact that within this country with population of 5 million inhabitants about 2 million people use electronic tickets.

Card loading machines. Card loading machines are used on ticket sales points and (or) on loading points for electronic ticket loading into a passenger's card. For transport needs, multifunctional loading electronic cards are used, i.e. a passenger, once having acquired a card with a certain amount of tickets, and having used up them all, does not buy a new card – he will need only to load (to enter) a new number of tickets into the same card on ticket loading points.

Electronic ticket scanning devices (punchers). Electronic ticket scanning devices (further referred to as punchers) are designed for passengers to settle for public transport services. A number of these devices in vehicles is unlimited. All punchers are linked into one system – they exchange information with the central device located in a vehicle. Punchers, subject to a type of devices, may give (or not) a passenger a paper ticket proving the deal. Punchers printing tickets are of more complex construction, therefore, they are more expensive, and their maintenance is more expensive as well.

Control devices. In case a puncher does not give a passenger a paper ticket, the control device scans the card information that shows whether a passenger has paid for his ride.

Terminals-cash registers. Terminals-cash registers perform three functions:

1) calculate settlements in cash,
2) accumulate information from punchers,
3) accept settlements by electronic cards.

These devices are used in cases if it is decided, when implementing the system that it will be possible to pay for a ride in cash in a vehicle, and this money should be calculated.

Clearing software. Clearing software allows the precise and fast collection of data from ticket selling offices and vehicles and the analysis. Based on the detailed driving deal analysis, the income received from card loading device is allocated by actual data to transport companies. Clearing software is localized in three system locations: dispatcher offices, local clearing centres and the central clearing unit.

Currently, electronic tickets are being widely implemented in the world; they are regulated by common standards, so that in future it would be possible to use one electronic ticket, for instance, when travelling through all over the European Union.

Electronic tickets have a huge perspective, as they can be provided with a wide memory and a possibility to process data. A high anti-theft protection level and a possibility to use complex coding algorithms make electronic tickets safe. They can be used to create multimedia, i.e. a ticket may perform different multiple functions, for example, it can be used as a meal ticket or as a card swimming pools, parking lots, etc. One ticket can cover lots of media and they can be adjusted to each consumer. An electronic ticket has multi-fold functions; it can be loaded for a new period or by a new

value [2]. This novelty basically changes an attitude towards ticket selling and distribution. As electronic tickets provide a possibility to create multimedia, they can be a perfect form of settlement for various services and are perfectly suitable to create a such a system in which more emphasis is paid on an individual than on a service (e.g., „Urban card", „Urban guest" or „Tourist card"). Its flexibility, capacity and memory capacity depends upon the ticket microprocessor, and these factors determine what kind of ticket system architecture (a degree of complexity) can be applied. Suppliers of different technologies determine different electronic ticket standards.

3. DRAWBACKS OF LITHUANIAN URBAN PUBLIC TRANSPORT TICKET SYSTEM

Taking into account all aspects of the existing ticket system, the following conclusion could be made – the current Lithuanian urban passenger transport ticket system has not been changed even for several decades, thus, it cannot meet the increasing needs of transport system administrator and passengers, In order to master complicated and precise transport traffic management technologies, to more rationally value passenger transport services, to provide a wider range of services and tariffs, there arises a necessity to modify the existing Lithuanian urban passenger transport ticket system [1].

The major drawbacks of the existing urban ticket system are as follows:

- the equal tariff is applied for different levels of passenger transport services;
- a ticket system is inconvenient for passengers, due to absence of the common ticket for all transport types;
- inflexible ticket price;
- tickets are inadequately protected against falsification;
- huge costs of ticket production, realization and accounting;
- limited possibilities to implement the advanced ticket selling methods, to introduce new forms of settlement;
- without precise data on the passengers carried it is difficult to plan traffic and coordinate routes;
- a ticket system is not proper, as, for a ride of one stop the tariff is the same as for a ride of ten or more stops.

Following the analysis and estimation of all possible ticket system versions, it was finally decided to introduce the electronic ticket system in the biggest Lithuanian cities - Vilnius, Kaunas and Klaipėda.

4. ASPECTS OF ELECTRONIC TICKET SYSTEM INTRODUCTION IN LITHUANIAN URBAN PASSENGER TRANSPORT

The project of introduction of electronic ticket system in Vilnius, Kaunas and Klaipėda passenger transport is being prepared. The author of this article participates in this project as a consultant. In the mentioned cities it will be possible to go by public transport using the common electronic ticket. Electronic tickets will be valid in buses, and Vilnius and Kaunas – in trolleybuses as well (in Klaipėda there are no trolleybuses).

The scheme of electronic ticket system being implemented is covered under the Figure 1.

The major components of the electronic ticket and information system offered for passengers are as follows:

- equipment installed in transport,
- the vehicle positioning system,
- tickets,
- data transfer system (a link between vehicles and servers, between servers and passenger notification locations),
- scoreboards in stops.

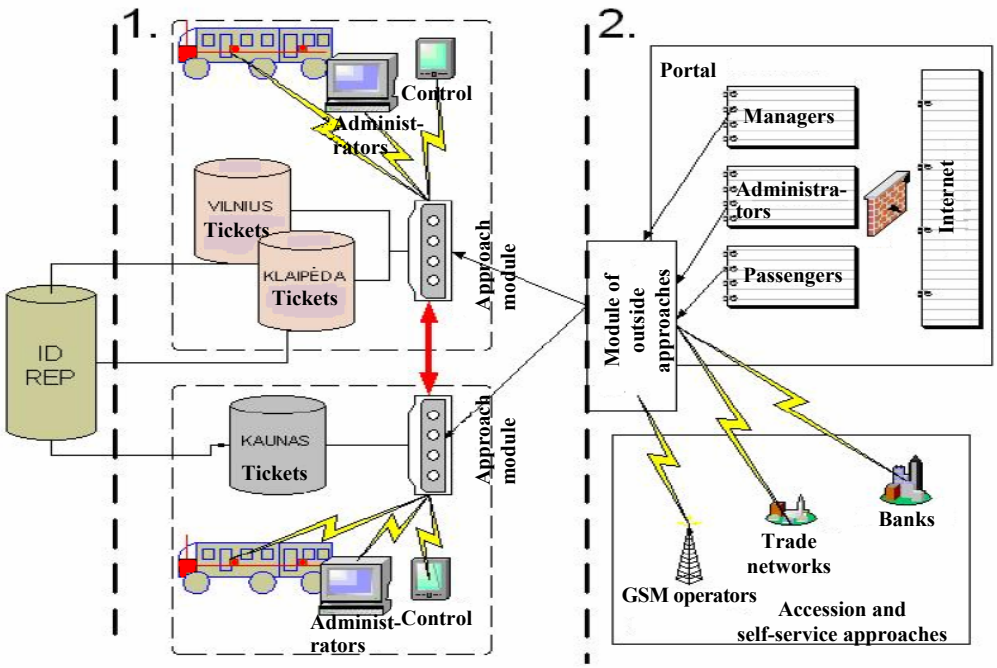


Figure 1. *The electronic ticket system scheme*

Equipment installed in transport

The main equipment installed in vehicles is the board computer and electronic punchers designed for passenger ticket scanning.

Electronic ticket punchers are definitely the most superior devices; they are most frequently used in modern systems. This equipment enables to flexibly apply different tariffs for passengers and price differentiation in time, provides the detailed statistical information on passenger flows, provides passengers with statements on their usage of public transport services, etc.

Vehicle positioning system

The following methods of defining the vehicle location are used in information systems:

1) odometer indication,
2) special "notation" of a vehicle in certain locations,
3) GPS (Global Positioning System).

Tickets

For electronic tickets system the tickets-contact-less cards are recommended. The following advantages of this ticket system are indicated:

- precise information received from electronic ticket database is used for statistics, accounting, planning and administration;
- a high level of passenger throughput due to extremely fast contact-less card scanning;
- cheap service and maintenance of the system;
- a high variety of methods of settlement for services (sales network, internet, mobile telephone, etc.);
- a high level of card protection;
- a possibility of supplementing the card;
- a possible differentiation of tariffs when using the same card.

Drawbacks:

- it calls for huge primary investments;
- a new, unknown system for users, based on the "electronic purse" principle.

Major elements of the electronic ticket system, using a virtual passenger's account, are as follows:

Electronic ticket database, in which information on passenger accounts is accumulated and stored: ID, privileges for passengers, ticket tariffs, the account activation, replenishment and check deals, etc.

Such information is necessary in order to check validity of an electronic ticket and to execute allocation of money and statistic information from trade networks to separate urban public transport companies. The ticket database would be used all over Lithuania; it can be used in all Lithuanian cities.

A personal customer's *electronic card*, with its identification number (outside and inside). The card, at request, would be issued to each client using the public transport system. For occasional customers onetime (single) paper tickets with integrated microchip would be sold.

Selling system is the electronic ticket distribution network. Tickets may be distributed through ATMs (Automatic Telling Machines), trade networks, Internet, mobile telephones, stationary selling machines.

Portable control devices, designed for checking passengers by their ID card number and the number-related information under the electronic ticket database, e.g. is the ticket valid, to which category of benefits or tariffs does a passenger card belong, etc. The control device also enables to watch and monitor checkers' activity by tracing how many invalid tickets were found during checks and how many passengers were fined. The above said measures would allow escaping a probability of checkers' willful actions and increasing efficiency of checking system.

Electronic punchers are installed in vehicles and used to activate the purchased electronic tickets. An user, getting onto a vehicle, attaches an electronic card close to the electronic puncher which, after scanning its number, sends the information through the board computer to the electronic ticket database where certain records are made, for example, records on a passenger's usage of the vehicle.

Board computers, installed in each public transport vehicle, intercommunicate with the electronic ticket database and constantly update information on the tickets purchased (supplemented customers' accounts, also manage other systems.

The major elements of the electronic ticket system based on the electronic purse principle are as follows:

Personal customer's electronic card, with a certain amount of funds. A personal customer's electronic card would be issued at request to each public transport customer. For occasional customers single paper tickets with an integrated microchip and a certain amount of funds in it would be sold.

Card supplement system made of different card filling points, which are to be installed in each selling location. A card may be supplemented through the selling network, stationary checkout selling machines and ATMs.

Card debit devices – electronic punchers, installed in public transport vehicles. A passenger, getting onto a bus or a trolleybus, has to put his or her card close to the contact-less scanning device. At that time a certain amount of funds from the card is scanned and a receipt, a proof of the transaction, may be printed. Information, necessary for accounting and statements, is sent to a certain database after a vehicle returns to depot, or is constantly sent through the board computer to the database.

Control devices are used to control passengers and watch and monitor activity of checkers themselves. A checker scans the passenger card information (its number) and checks data of the last transaction (when and what kind of a ticket was bought). If a ticker is not bought, the control device may deduct a fine directly from the card.

A driver by printers installed in the board computer would print single tickets.

In future, possibilities of a transport card it seems will be expanded – they should be provided with the electronic purse function, also with other additional facilities (settlement for a parking lot, etc.).

Data transfer system

The communications system plays a major role in both implementation of such system and its further maintenance. The data transfer service provided by GSM operators are recommended (GPRS technologies).

This is currently the most developed data transfer technology. Solutions of GPRS data transfer intellectual transport systems are already tested by many producers. A price for data transfer is considered as the main drawback, blocking expansion of this technology abroad. The major advantages are as follows: transport operators do not have to feel concern about transport quality and its technological improvement; aspects of amortization and depreciation of the communication equipment lose any significance. The selected communication operator becomes directly responsible for a quality of communication.

Signboards in stops

In modern information systems passengers are informed about the public transport movement in real time on signboards installed in transport stops. Beside the said boards, other methods of providing the information are used –Internet, information stands, mobile telephones, etc.

Along with introduction of electronic public transport tickets in Lithuanian cities and towns, a legal problem is confronted – a number of legal instruments will have to be replaced. One of the major legal instruments needed to be replaced are as follows: the LR road transport code, Regulations on passenger and luggage transport by roads, Code of Administrative law violations, etc.

Implementation of electronic tickets will cost about 60 million LT (about 17,4 mill. EUR). For the purpose of the said project, financial support from the European Union (EU) funds is received. Municipalities of all three cities also allot funds for this project (1 million Lt, each, per period 2005-2006). Kaunas city bus and trolleybus parks have already invested about 4 million Lt on adjustment of the electronic ticket system equipment.

5. CONCLUSIONS

1. The existing passenger transport ticket system in Lithuanian biggest cities has not been changed for several decades; therefore, it has a number of drawbacks and shortcomings (inflexible ticket price, absence of stored banks of data on carried passengers, no common tickets for all types of transport, etc.). Thus, this system cannot meet the increasing needs of the transport system administrator and the passengers. Consequently, a necessity to improve the city passenger transport ticket system has become inevitable.

2. Electronic ticket systems are considered as the most modern and advanced, as they are multifunctional and ensure a high level of passenger service The contact, contact-less, double interface and "hands-free" electronic tickets are used.

3. The electronic ticket system will be introduced in public transport of the biggest Lithuanian cities, for instance, in Vilnius, Kaunas and Klaipėda. Electronic tickets will be valid in buses and trolleybuses. Contact-less electronic cards will be applied. In future, functions of electronic cards should be extended, so that they could perform the electronic purse functions (settlement for a parking lot, etc.).

4. Implementation of electronic tickets will cost about 60 million LT (about 17,4 mill. EUR). For the purpose of the said project, financial support from the European Union (EU) funds was received. Municipalities of all three cities also allot funds for this project.

5. Along with introduction of electronic public transport tickets in Lithuanian cities and towns, a number of legal instruments will have to be replaced – the LR road transport code, etc

References

[1] Butkevičius J. *Passenger Transport: monograph*. Vilnius: Technika, 2002, pp. 150-162.

[2] Sen S., Pilai R., Joshi S., Rathi A.K. Mean-Variance Model for Route Guidance in Advanced Traveller Information Systems, *Transportation Science,* Vol. 35, 2001, pp.37-49.

MODELLING AS A MEANS OF SOLVING THE PROBLEM OF CITY TRAFFIC OPTIMISATION

Nadezda Kolmakova, Elena Yurshevich, Irina Yatskiv

Transport and Telecommunication Institute
Lomonosov Str. 1, Riga, LV-1019, Latvia
Ph.: (+371)-7100651. Fax: (+731)-7100660. E-mail: ivl@tsi.lv

The article deals with the problem of city traffic modeling at microlevel. The most popular simulation software tools used to solve this problem are being reviewed in the article. The model of complex Riga TN (Transport Node) is used as an example that illustrates the Vissim package potential for traffic modeling. The expediency of the TN reconstruction and the results of the model execution within two different structures are being analyzed in the article.

Keywords: *urban traffic, simulation, microscopic traffic simulators, road network, case studies, vehicle*

INTRODUCTION

Contemporary transport problems are connected first of all with the increase in road traffic and demand for transport services, but not with the restriction on fuel as it used to be before. All mentioned factors lead to delays, accident, traffic jams, environmental problems etc. It is obvious that there is an urgent need to solve these problems and the measures, which can be taken, are different. The simulation modelling is considered as one of the ways to solve the problem of city traffic optimisation. It allows more realistic representation of the hugely varied choice situation that arises in practice [1, 2].

There exist microscopic and macroscopic simulation approaches in simulation of traffic. The main task of microscopic traffic simulation is to support traffic management decisions. At first, it can be used as a part of Intelligent Transport System, which tries to redistribute the flows in the network, re-routing the vehicles according current road conditions. Also it can be used for analysis of traffic scenarios for conflicting situation.

VISSIM 4.0. is the example of microscopic traffic simulators which are simulation tools that realistically emulate the flow of individual objects through a road network. These tools must provide: the ability to accurately represent any road network geometry; detailed modelling of the behaviour of individual vehicles and of course advanced animated possibilities.

1. THE REVIEW OF MICROSCOPIC TRAFFIC SIMULATION TOOLS

The contemporary simulation software market presents the wide spectrum of microscopic traffic simulation tools. So, the source [3] presents more than 30 simulation tools, which are aimed at transport junctions and transport communication modelling. Among the existing professional simulation tools there are such simulation tools as *AIMSUN, PARAMICS, AUTOBAHN, IHSDM, INTEGRATION, PLANSIM-T, FLEXSYT-II, TRANSIMS, SimTraffic 6, VISSIM, MITSIM* etc. The list of traffic simulation tools is constantly being widened, most of them are distinguished by the high level of complexity, the friendly user's interface and the wide spectrum of capabilities provided in transport net simulation, optimisation, design and analysis.

All these packages have many common properties, but there exist some special distinguishing features too. For example, the simulation tool *IHSDM (Interactive Highway Safety Design Model, USA)* involves the modules allowing predicting the traffic accidents. *MITSIM (MITSIMLab, USA)* simulates the transport system with the high level of detailing [5]. The distinguishing feature of the package *TRANSIMS (Los Alamos National Laboratory, Mexico&USA)* is the agent-based simulation principle realized in the package [6].

Let us consider several microscopic simulation tools, which are mostly popular in the world: AIMSUN, PARAMICS and VISSIM. We emphasize the features concerning their application area,

the level of transport system detailed elaboration, description of vehicle behaviour, supporting the interface with other simulation tools and the capability of creating reports and presentation.

AIMSUN (Transport Simulation System, Spain) is a part of the simulation system *GETRAM/AIMSUN* presenting the whole traffic simulation tools complex. The package can deal with different traffic networks: urban networks, freeways, highways, ring roads, arterials and any combinations thereof. It has been designed and implemented as a tool for traffic analysis to help traffic engineers in designing and assessing traffic systems. The package was proved to be very useful for testing new traffic control systems and management policies, either based on traditional technologies or on the implementation of the Intelligent Transport Systems. It supports the telematics capability too.

There does not exist the limitation typical for transport system dimensions. The models of vehicles behaviour are defined by the function of several parameters enabling to simulate different types of vehicles (cars, buses, HGV etc.).

Both constantly defined routes and OD-matrix are widely used for simulation of vehicles movements. In the last case the route is defined by three ways: the itinerary information is defined at the beginning of simulation; according to TS situation and the costs matrix the itinerary is recalculated after predefined time intervals; the itinerary can be defined by the dynamic routings during simulation.

The behaviour of vehicles is redefined at each unit of simulation time taking into account the parameters of vehicles (their size, speed, angle of rotation, weight etc.) and the environmental parameters (the traffic intensity, distance to the nearest vehicles, their speed, size etc.). Gipps model is used for driver's behaviour description.

The AIMSUN package supports the capability of including the macroscopic model of emme/2. The statistic data of any transport system area are collected in special files. If it is necessary, the package supports the capability of storing the data in *.xls format, as well as the capability of storing the data in ODBC database.

PARAMICS (PARAllel MICroscopic Simulation) (Quandstone Ltd., the United Kingdom) – comprises the set of simulation tools. This package is widely spread in the UK and USA. It is aimed at city transport system simulation of any complexity. It supports the capability of analysing the overloaded highway and optimising the work of public transport.

PARAMICS allows realizing any simulation ways for transport system of any complexity optimisation, beginning from simple crossroads and finishing with national transport system. The main limitation of TS model is the computer memory size and processor capacity. The individual behaviour of 200000 vehicles per time unit is suggested. There exists the package of 7 classes for standard vehicles, but if it is necessary, the user can define his vehicle class. The cost matrix defines the route decision. The vehicle behaviour is intelligent and it is regulated by its own physical parameters and current speed.

The capability of collecting statistics and creating reports is successfully realized. The package supports the capability of 2D-3D animation, presentation and video creation.

VISSIM (PTV AG, Germany) – VISSIM is a microscopic, behaviour-based multi-purpose traffic simulation programme. For many engineering disciplines simulation has become the indispensable instrument for optimising the complex technical systems. This is also true for transportation planning and traffic engineering, where simulation is the invaluable and cost-reducing tool. It offers a wide variety of urban and highway applications, integrating public and private transportation. Even complex traffic conditions are visualized on the unprecedented level of details specifications providing realistic traffic models. It supports the capability of comparing junctions with regard to designed alternatives (roundabouts, unsignalized and signal-controlled; grade separated interchanges). The package analyses the traffic management systems such as alternative route control, traffic flow control, toll roads, section control systems, access control and special lanes. It performs a wide range of highly specialized traffic engineering tasks, such as capacity analysis of railroad block section operation and of toll plaza or border control facilities [7].

There does not exist the limitation on transport system size. The vehicles of any type as well as pedestrians are a constituent part of the vehicle flow. There exist realized standard vehicles classes (cars, HGV, buses, trams, trains, motorbikes, bicycles and pedestrians). The user can parameterize all these vehicles types (size, engine power, distribution of acceleration and deceleration, weight etc.) If it is necessary, user can define his one vehicle type. It is possible to support the OD - matrix of VISUM or emme/2.

The driver's behaviour is intelligent and realized by the Widermann model. Such psychophysical capabilities of the person as attention and reaction time diminishing; the decision-making time in environmental conditions should be taken into account.

2. THE COMPARATIVE ANALYSIS OF PACKAGES

Several criteria groups for comparative analysis are taken into consideration:

- The transport telematics indices
- The indices characterizing the capability of simulating special features of TS
- The list of measured indices

The results of the comparative analysis are shown in Table 1 [4].

Taking into account the criteria given in the source [4] we have made the comparative analysis of several packages. The widest spectrum of traffic control and management capabilities belongs to the package PARAMICS. But VISSIM is the only presented package being capable of collecting the information of public transport. In its turn, AIMSUN can adaptively manage the trip during the simulation and change the itinerary if it is necessary.

Table 1. Transport Telematics Capability Analysis [4]

	Coordinated traffic signals	Priority to public transport vehicles	Ramp metering	Motorway flow control	Incident management	Variable message signs	Regional traffic information	Static route guidance	Dynamic route guidance	Parking guidance	Public transport information	Congestion pricing	Adaptive cruise control	Automated highway system	Support for pedestrians and cyclists	Probe vehicles	Vehicle detectors
AIMSUN	●	●		●		●	●		●	●			●				●
PARAMICS	●	●		●	●	●	●	●	●	●		●		●		●	●
VISSIM	●	●	●	●	●						●				●	●	●

The simulation packages differ from each other by the capability to take into account some peculiarities of transport system. In the Table 2 is presented the comparative analysis of the packages capabilities in this field. We can distinguish, that the leader in this field is simulation package *VISSIM*. It has all capabilities without the capabilities to take into account the weather conditions and searching for a parking space which has the package *PARAMICS*.

Table 2. Modelling of Transport System Peculiarities [4]

	Weather conditions	Search for a parking space	Parked vehicles	Commercial vehicles	Bicycles / motorbikes	Pedestrians	Incidents	Public transports	Traffic calming measures	Queue spill back	Weaving	Roundabouts
AIMSUN							●	●		●	●	●
PARAMICS	●	●		●			●	●	●	●	●	●
VISSIM			●	●	●	●	●	●	●	●	●	●

The packages also provide the fixation of the transport network indices (Table 3). VISSIM possesses wide opportunities of collecting the information on the transport network and its environment.

Table 3. Transport Network Characteristics Fixed in Modelling [4]

	Efficiency: modal split	Efficiency: queue length travel time	Efficiency: travel time variability	Efficiency: speed	Efficiency: congestion	Efficiency: public transport regularity	Efficiency: queue length	Safety: headway	Safety: overtaking	Safety: time-to-collision	Safety: accident speed/severity	Environment: exhaust emissions	Environment: noise level	Technical: fuel consumption
AIMSUN	●	●		●			●					●		●
PARAMICS		●	●	●	●	●	●	●	●			●	●	●
VISSIM	●	●	●	●	●	●	●	●	●	●	●	●		●

3. CASE STUDY: THE MODEL OF RIGA TRANSPORT JUNCTION IN VISSIM 4.0

The given model is a part of the project ordered and carried out for Riga Municipal Self-Administration, the purpose of which is to investigate Riga City cargo flows: to analyse an available transport infrastructure, to reveal the "narrow" places, and, consequently, to offer the development and improvement of the transport traffic organization as a whole.

The project's object of research is the transport node (complex junction) with constantly appearing traffic jams. For making decisions concerning the transport flow simulation at micro-level package VISSIM was used. Previously the problem point (one of complex junctions of the city) – crossroads Maskavas – Slavu tilts – Krasta (names of streets and the bridge) has been revealed by means of interrogations and the supervision based on questioning and statistics gathering. In this area (sector) gauging movement intensity, fixing a percentage parity cargo and public transport, phases of signal heads and other necessary data for model construction have been obtained.

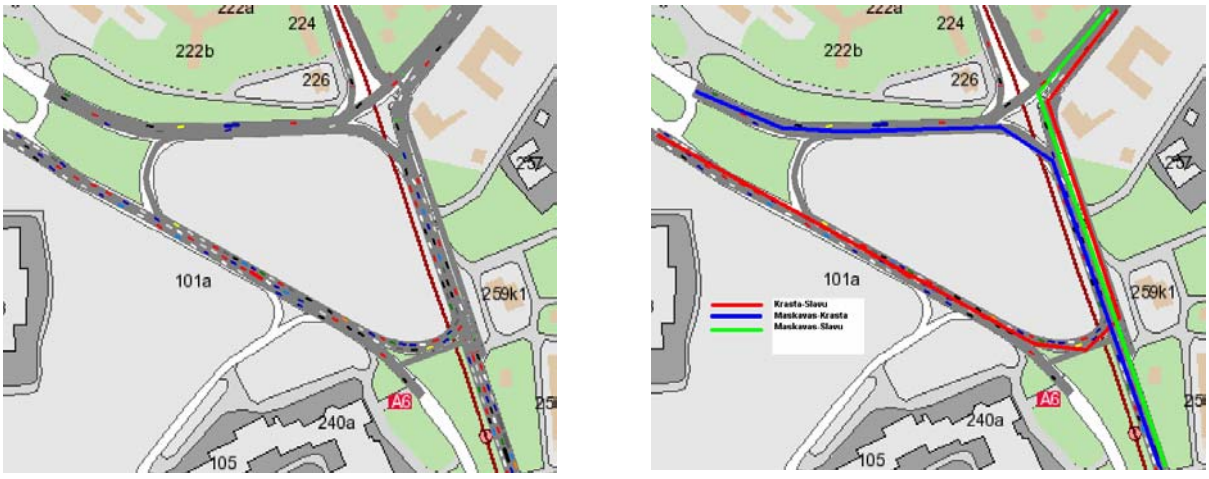


Figure 1. *Modelled junction (Maskavas–Slavu bridge–Krasta) (left-side) and investigated areas (right-side) before reconstruction*

The main tasks of modelling: the choice of the optimal movement organization in the junction and the estimation of capacity for each version of movement; signal heads work optimisation; the actions (measures) analysis on cargo transport traffic simplification.

One of starting conditions of an adequate model creation in VISSIM is the presence, at least of one scaled map, which displays a true network. Due to such opportunity in a package, the model becomes approached to a reality as much as possible. On the basis of the given map, and also of the available statistics the simulation model of a considered area being represented in Fig.1 has been constructed. Transport units' routing has been set in the form of static O/D ways where it has been necessary to set simulation time and a relative flow of vehicles for the chosen network area. The model of transport movement is based on Wiedemann's vehicle movement psychophysical model (1974, 1999). During experiments the model parameters have been varied to make the intensity and structure of transport flows correspond to the observable ones – thus the validation of the model has been made.

It was supposed that a number of offered changes would give a positive effect on the transport traffic organization and will raise the capacity of a considered area. One of the suggestions was: to bring out the roadway directly from Krasta street to Slavu tilts (on the bridge) across the parking place territory that exists now (Fig. 2). Thus two replaces the system of three signal heads. As a result of such re-structuring the large-sized cargo vehicles do not create jams on semi-circle Krasta-Maskavas for exit to Slavu tilts. Also a number of experiments with the model of signal heads phase's change have been made, and the optimum version has been received.

Let's consider the results of experiments with a model before and after reconstruction of the given junction. 30 experiments with each version of a model have been done. In three areas of a model: 1 (Krasta–Slavu), 2 (Maskavas–Krasta), 3 (Maskavas–Slavu) (see Fig.1 and Fig.2) the following characteristics fixing has been made:

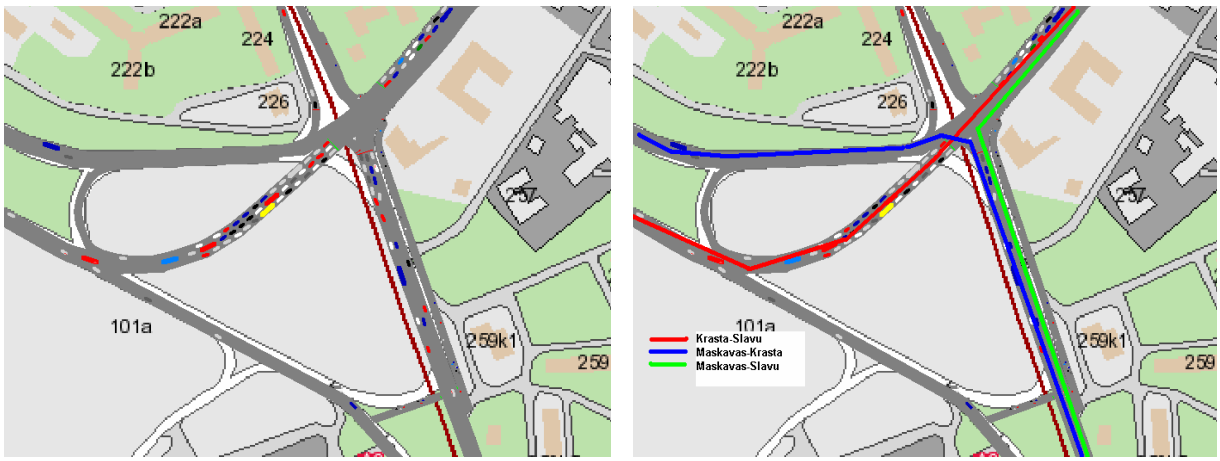


Figure 2. *Modelled junction (Maskavas–Slavu bridge–Krasta) (left-side) and investigated areas (right-side) after reconstruction*

- average time of vehicle going through the area;
- quantity of vehicles crossing the given area.

On the basis of the received data the main empirical characteristics of transport junction parameters before and after reconstruction have been estimated by means of the STATISTICA package. The obtained results are shown in Table 4 and Table 5.

Table 4. Estimations of empirical characteristics of transport junction parameters before reconstruction

Analyzed Indicators		Number of observations	Mean	Confidence limit of mean		Minimum	Maximum	Variance	Standard deviation
				-95,000%	+95,000%				
Krasta-Slāvu	Going through time (sec.)	30	299,27	293,02	305,52	260,70	347,50	280,33	16,74
	Quantity of vehicles (units)	30	523,53	514,14	532,92	475,00	574,00	632,19	25,14
Maskavas-Krasta	Going through time (sec.)	30	184,39	183,06	185,73	175,10	192,40	12,79	3,58
	Quantity of vehicles (units)	30	258,60	253,12	264,08	235,00	289,00	215,56	14,68
Maskavas-Slāvu	Going through time (sec.)	30	194,40	192,89	195,90	183,30	201,70	16,26	4,03
	Quantity of vehicles (units)	30	672,63	662,72	682,55	639,00	722,00	705,27	26,56

It is possible to note that average values of transport junction parameters before and after reconstruction differ.

On the basis of the received results averages of intensity flows in investigated areas before and after reconstruction have been estimated. The obtained values are presented on Fig.3.

Table 5. Estimations of empirical characteristics of transport junction measured parameters after reconstruction

Analyzed Indicators		Number of observations	Mean	Confidence interval for mean		Minimum	Maximum	Variance	Standard deviation
				-95,000%	+95,000%				
Krasta-Slāvu	Going through time (sec.)	30	84,77	81,77	87,78	74,50	103,40	64,81	8,05
	Quantity of vehicles (units)	30	1242,23	1236,03	1248,44	1210,00	1276,00	276,12	16,62
Maskavas-Krasta	Going through time (sec.)	30	87,51	82,68	92,34	68,90	114,90	167,46	12,94
	Quantity of vehicles (units)	30	405,50	400,16	410,84	355,00	421,00	204,88	14,31
Maskavas-Slāvu	Going through time (sec.)	30	93,08	88,38	97,79	78,60	121,70	158,93	12,61
	Quantity of vehicles (units)	30	1066,13	1060,64	1071,63	1046,00	1105,00	216,33	14,71

Analysing the obtained results, it is possible to assume that traffic intensity before and after reconstruction differs: intensity has increased.

In order to be convinced in statistically significant difference of traffic parameters (Average going through time and quantity of vehicles), let's perform the two-sample analysis using the samples of traffic parameters in areas before and after reconstruction. Let the null and alternative hypotheses to be as follows:

- H_0: Both samples belong to the same population (hypotheses about homogeneous);
- H_1: Both samples aren't from the same population (difference is significant).

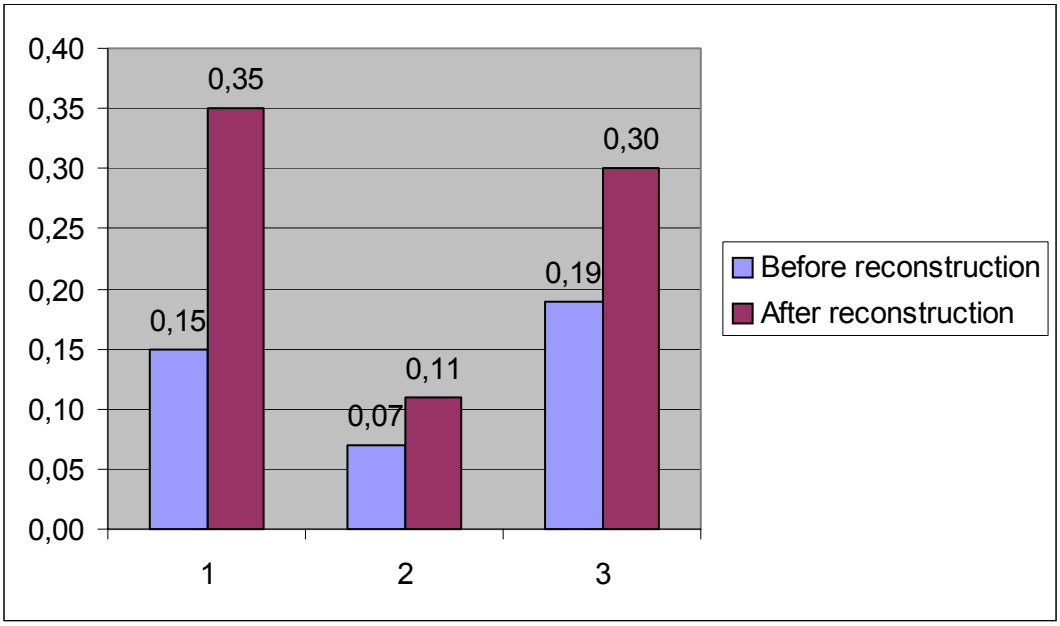


Figure 3. *Traffic intensity before and after reconstruction in three areas of a model*

Let's apply nonparametric rank test - Mann-Whitney two-sample test (Z) for null hypothesis testing. The size of sample is 30. The results of two-sample hypothesis testing are shown in Table 6.

Table 6. The results of two-sample hypothesis testing based on Mann-Whitney test

Area name	Indicators	Z	p-level
Krasta-Slavu	**Going through time (sec.)**	6,6530	2,918E-11
	Quantity of vehicles (units)	-6,6530	2,918E-11
Maskavas-Krasta	**Going through time (sec.)**	6,6530	2,918E-11
	Quantity of vehicles (units)	-6,6530	2,918E-11
Maskavas-Slavu	**Going through time (sec.)**	6,6530	2,918E-11
	Quantity of vehicles (units)	-6,6530	2,918E-11

Analysing the data of Table 6 it is possible to draw a conclusion that samples do not belong to the same distribution, i.e. transport junction characteristics differ significantly before and after reconstruction.

For an illustration we present Box&Whisker diagrams (on the basis average and standard deviation) for the parameters of transport junction crossing time (Fig.4) and quantities of the cars crossing these areas (Fig.5).

From the resulted diagrams Box*Whisker it is possible to see that average values of parameters significantly differ. These diagrams illustrate the obtained results of the two-sample analysis.

Thus, the insignificant financial investments in reconstruction will promote the capacity in the considered area approximately twice. Hence, the suggestion can explain the necessity of including the city roads and streets reconstruction into long-term plans.

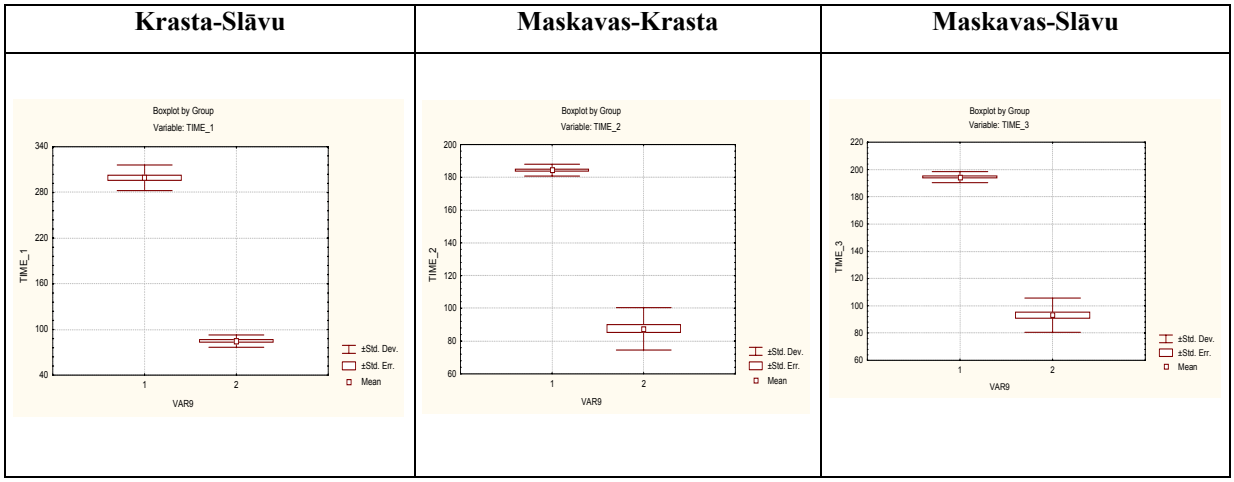


Figure 4. *Box&Whisker diagrams for the parameters of transport junction crossing time*

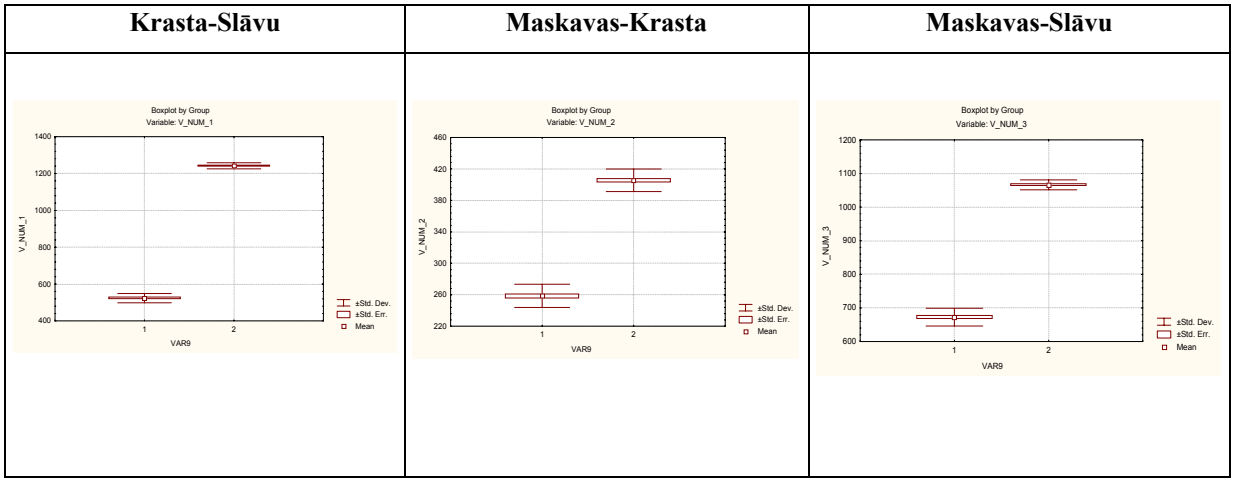


Figure 5. *Box&Whisker diagrams for the parameters of cars quantity crossing these areas*

CONCLUSION

Simulation packages of the traffic at a micro-level are the simulation tools modelling a flow of individual vehicles through a transport network. The features of the given type modern packages are as follows:

- the ability to reproduce precisely any road geometry;
- to model behaviour of individual vehicles in details;
- to realize any traffic control system;
- to expand 2D and 3D animation.

The enumerated opportunities, and also applied behaviour models (including drivers' behaviour), allow considering the given means as elements of Intelligent Transport System (ITS). Complex model of transport flows movement construction based on real traffic rules enables to test all road systems for capacity, to predict fuses; to play any possible road situations, to give an animation picture of transport flows.

In developing model much attention should be paid to creation of adaptive management opportunity on its base both on local crossroads or streets and in a complex area of an integrated system. For this purpose model integration is necessary with ITS and its interaction with general ITS database, in which the information of a city road network current situation operatively acts. The

system obtains data about current transport flows intensities and in appropriate way changes the coordinating management program.

The VISSIM package used for the model development is capable of modelling not only a municipal transportation movement, but also movement of air and sea courts. The complex transport situations with a high detail degree are easily modelled in VISSIM that makes model to be approximated to reality at maximum.

References

[1] Handbook of Transport Modelling, edited by David A.Hensher, Kenneth J.Button, Pergamon, 2000.
[2] Handbook of Simulation edited by Jerry Banks. Jonn Wiley&Sons, 1998.
[3] Review of Traffic Analysis Tools by Category – http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol2/sectapp_e.htm#top
[4] Review of Micro-Simulation Models – http://www.its.leeds.ac.uk/projects/smartest/append3d.html
[5] The simulation package MITSIMLab capabilities specification – http://web.mit.edu/its/mitsimlab.html
[6] The simulation package TRANSIMS capabilities specification – http://www.ccs.lanl.gov/transims/index.shtml
[7] The simulation package VISSIM capabilities specification – http://www.english.ptv.de/cgi-bin/traffic/traf_vissim.pl

SUPPORTING OF FORECASTING MODELS IN INFORMATION-ANALYTICAL SYSTEMS OF RAILWAY TRANSPORTATION

Eugene Kopytov[1], Vasilijs Demidovs[2]

[1]Transport and Telecommunication Institute
Lomonosov Str.1, Riga, LV-1019, Latvia
Fax: +371 7100660. E-mail: kopitov@tsi.lv

[2]State Join-Stock Company "Latvian Railway"
Turgenev Str. 21, Riga, LV-1050, Latvia
Fax: (+371)-7234366. E-mail: dem@ldz.lv

The paper presents the approach of building Informational-Analytical Systems at the railway with the help of modern achievements in the sphere of Data Warehouse. Application of Data Warehouse technologies allows building a lot of system models on the basis of a huge accumulated quantity of data. The suggested conceptual scheme of building virtual models gives opportunity to have several analysed data models concurrently and to create quickly new ones. The offered approach can be applied to forecasting of railway transportation depending on the control action at the system with account of effect of the environment.

Keywords: *forecasting, railway transportation, information system, data warehouse, virtual model*

1. INTRODUCTION

At present time European Union aims to make traffic more flexible in Europe, and the EU White Book on Transport, published in 2001, describes the Union transportation policy until 2010 [1]. It emphasizes the importance of the transportation of loads on railways instead of using the roads. There is a note that community funding should be redirected to shift the focus to the use of railway transport [2].

Railway transport in the Latvian Republic is an important economic field of the country, more than 13 thousand people worked on State Joint-Stock Company "Latvian Railway" in 2003, the asset of the Company made up 195,366 million LVL, its own capital making up 102,056 million LVL [3]. High dynamics of changes of the transport services market and strong competition suggested by other transporters demands a complex analytical research with the account of all data accumulated in different spheres of the railway activities as well as developing multi-variant predictions for different periods of time. It requires, in its turn, developing a sole integrated Dataware system, which should combine in itself data from different Information Systems of the Latvian Railway [4].

Generally, the process of decision-making for the further period of the railway functioning is the analysis of the information (previous, present and future) characterizing objects of management and working out on its basis a certain set of control actions, which provide the achievement of the chosen targets, set (as a rule) by the efficiency criteria. Thus, the task of developing the Decision Support System (DSS) on the railway includes:

- establishing an Information System to provide the completeness and trustworthiness of the stored data;
- developing a system of predicting passenger and cargo flows on the basis of the prediction models;
- working out a system of making reasonable decisions for managing the process of transportation.

Note that in the frame of the given paper the second task is of greatest interest but it cannot be solved in isolation without solving the first task and the third one.

2. PROBLEMS OF DEVELOPING AN INTEGRATED INFORMATION-ANALYTICAL SYSTEM FOR THE LATVIAN RAILWAY

At the present time the Latvian Railway employs Information Systems (IS) responsible for different spheres of its business shown in Figure 1. The information generated by these systems

allows evaluating the efficiency of performance and to execute prospective planning. For solving these tasks in each system there have been worked out specialized local program sets for requirements of any level managers. But these systems are mainly oriented towards performing account-controlling and enquiries functions and the final user doesn't actively interact with them in the course of making optimal managing decisions. Most of these programs have been developed on the basis of outdated technologies, they can work only with small volumes of data, and it is difficult to support this software. As an example we'll give a structure of information support of a passenger transportation system, which combines four Information Systems (Express, Ticket-cash machines #1, Ticket-cash machines #2, Cashiers on site) developed at different times on different program and apparatus basis [5]. These systems generate more than 12 million transactions per year [6]. Under a *transaction* we understand a registered fact of selling a ticket or a group of tickets, which is not equivalent of a trip. Tickets may be single or season, one-way or return. The data received from these systems have different format and degree of aggregation. For example, data from hand sale enter the system being already aggregated according to the type of the ticket, stations of sale, departure and destination. To get information about the number of transported passengers the data should be subjected to additional procession.

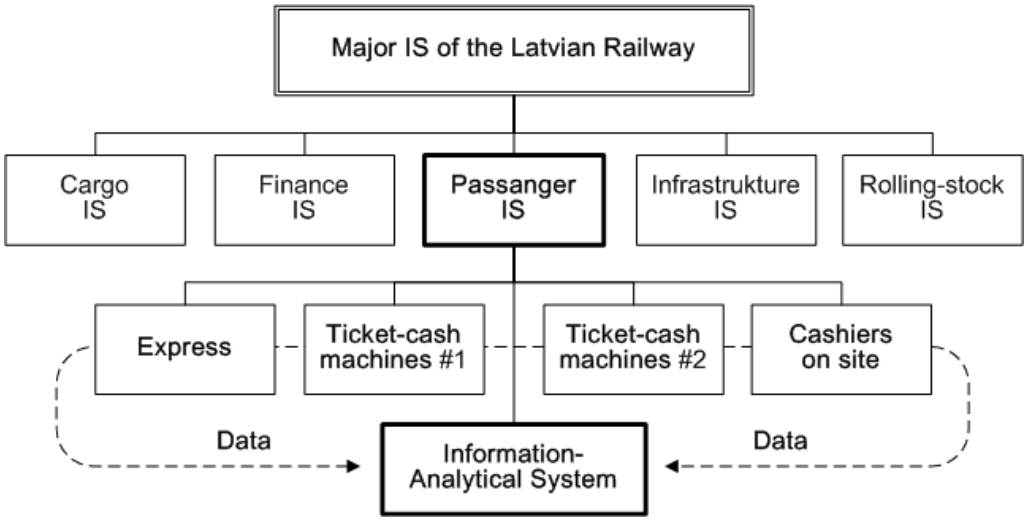


Figure 1. *Information Systems of the Latvian Railway*

The basics of modernizing and developing Information Systems on the Latvian Railway were laid in 1997 when the general conception of developing Latvian Railway IS was worked out and adopted [7]. This conception gave priorities to seven IS and first of all to building a high speed network of data transmission (1GB WAN), a finance system and a single integrated database as a general information resource of the whole enterprise.

Application of new technologies such as Data Warehouse (DW) does not eliminate all existing problems, but allows performing alienation of the existing systems and consolidation of analytical data in DW, thus freeing operative systems from improper functions, and modernizing the systems actually separately [4].

In the sphere of passenger transportation this task was simplified by the fact the four existing systems (see Figure 1) were actually not inter-connected and could function separately. Integration of data from these systems was performed only at the analysis stage [6, 8]. Nevertheless after introducing the analytical system exploitation of the old one continued on for half a year.

Thus in the recent five years there has greatly increased interest to the questions of building Information-Analytical Systems, which allow performing a multilevel analysis, planning and managing the processes of passenger and cargo transportation on railway and other types of transport. These systems enable managers to take prompt, effective decisions in the new, quickly changing economic conditions.

It proves the actuality of carrying out research to improve the dataware system of the decision-making tasks in the Latvian Railway in the sphere of passenger transportation. Recently DSS has stopped being the prerogative of the certain layer of managers and has a form of pyramidal model (see Figure 2), and, therefore, the increased requirements of accessibility and data safety and reliability are laid down to it.

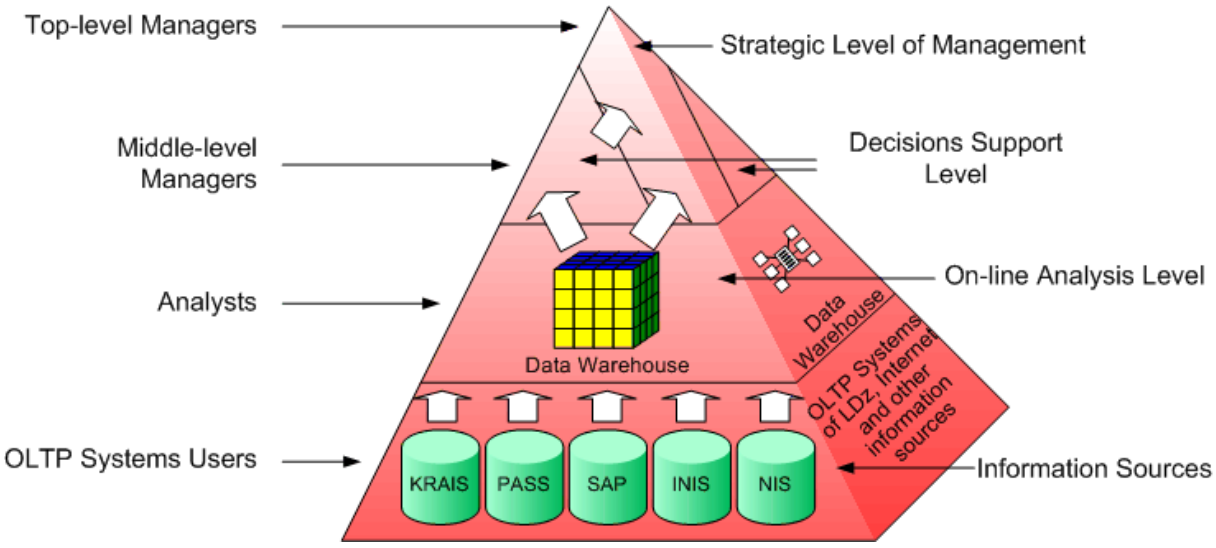


Figure 2. *Pyramidal Model of Decision Support System*

The analysis of the situation in the Latvian Railway has shown that the questions of data trustworthiness are the key questions in building Decision Support Systems. Therefore let's consider them in more detail.

Reliability of prediction depends on the reliability of data stored in Data Warehouses. DW architecture is based on the schemes type "star" and "snowflake". It is peculiar for these schemes to have tables of factors where all transactions and all aggregates of transactions are described, as well as tables of measurements for each entity. Here, the concept of transaction can differ from the similar concept in the initial data obtained from On-Line Analytical Processing (OLAP) systems [7]. One of the obligatory measurements of the given scheme is a measurement of time. Thus, a time indicator is present in the data prepared for analysis. This time indicator is formed periodically once per week, decade, month, quarter or year during the data processing. Forming of data for the certain period is being performed on the basis of Referenced Data System (RDS). Data situated in RDS are the subjects to continual changes, for example, old trains are cancelled and new ones are appointed, schedule and routes of trains are changed. The preparation of data for the long period of time demands registration of all changes in RDS for the processed period. When there is a necessity of the creation of the new physical data model, which is impossible to receive on the basis of the existing ones, we shall need all initial data. Therefore, for the flexibility of the system in Data Warehouse it is necessary to store data received from the initial systems and transformed into one form. Therefore, time factor reflected in temporal model RDS should be taken into account [4, 5].

3. VIRTUAL MODELS IN THE FORECASTING TASKS OF RAILWAY TRANSPORTATION

Forecasting plays an important role in the tasks of managing and planning transportation flows on transport and is the main part of DSS. Prediction in the railway transportation, which is a rather complicated system, is constructed on the experience gained by the system for the prolonged period; at the same time very large volumes of the accumulated historical data are used. In many cases we

assume that behaviour of the data in the past will be a good guide to its behaviour in future. When solving the problem of prediction usually a standard admission is entered: if in the past the system reacted in a certain way on the similar events, then, with higher level of probability it is possible to suppose that it will react in the same way in future as well.

Comprehensive planning of transport company activity demands presence of a certain set of models that adequately describe functioning of the railway and application of various mathematical methods for forecasting of transportation process. During the forecasting we need to develop various decision strategies to deal with future uncertainties.

In general case the considered forecasting task is to anticipate behaviour of railway system in the future taking in account possible control impacts on the system and environment behaviour.

Let vector $Y(t) = \{y_1(t),\ y_2(t),\ ..., y_k(t)\}$ characterizes the status of railway system at the moment of time *t*, where $y_j(t),\ j = \overline{1,k}$ are the system's indicators observed at the moment of time *t*. Let the prehistory of a system is known, i.e. vectors $Y(t_1), Y(t_2), ..., Y(t_n)$ are given, where $t_1, t_2,\ ..., t_m$ are moments of time in the past and present.

As the authors suggest [4-5], we can predict the state of railway system $Y^*(t_e)$ for future moment of time t_e using the prediction model in the following form:

$$Y^*(t_e) = F_1\left[Y(t_i),\ i = \overline{1,m};\ C(t_e); Z^*(t_e)\right], \tag{1}$$

where F_1 is a certain functional;

$C(t_e) = \{c_1(t_e),\ c_2(t_e),\ ..., c_q(t_e)\}$ is the vector of control impacts on the system in the period of time from t_m to t_e;

$Z^*(t_e)$ – the vector of predicted values of random factors, characterizing the impacts of environment on the investigated system in the moment of future time t_e.

So, using model (1) we have to consider a set of possible management strategies $C_1(t_e),\ C_2(t_e),\ ...,\ C_n(t_e)$ for several possible variants of environment behaviour $Z_1^*(t_e),\ Z_2^*(t_e),\ ...,\ Z_n^*(t_e)$ in the period of time from moment t_m to moment t_e. Thus, for *n* versions of environment behaviour we obtain accordingly forecasts $Y_1^*(t_e), Y_2^*(t_e), ..., Y_n^*(t_e)$ that give opportunity to use the situation control in the considered system.

The given approach suggests that some physical models having states $Y_1^*(t_e), Y_2^*(t_e), ..., Y_n^*(t_e)$ are parallel created without changing and locking the initial Real model stored in Data Warehouse (see Figure 3).

Let us note that considered approach has some disadvantages:

- for storage of created Prediction Models it is necessary to have huge amount of free disk space, and amounts of the stored data are increased proportionally to the quantity of models;
- it is necessary to generate a new Prediction Model at any new version of control actions $C_j(t_e)$.

For solution of the given problems the method of the virtual models is offered [5, 8].

Main principles of virtual models are the following:

- in a Data Warehouse are located only metadata of Models Repository, describing a set of virtual models constructed on the basis of real model and vectors of control impacts;
- we can describe all effects at the system in metadata as the functional dependences.

Virtual Models are actually templates of the mathematical prediction models with the calculated values of evaluating unknown parameters and prediction variables are taken from the Data Marts Repository at the time of carrying out the analysis, and it allows exercising prediction for other time intervals. Developing of virtual data models makes it possible to reduce the Data Warehouse size. There is no need of blocking the Real Model of data since each analyst works with its own set of Virtual Models.

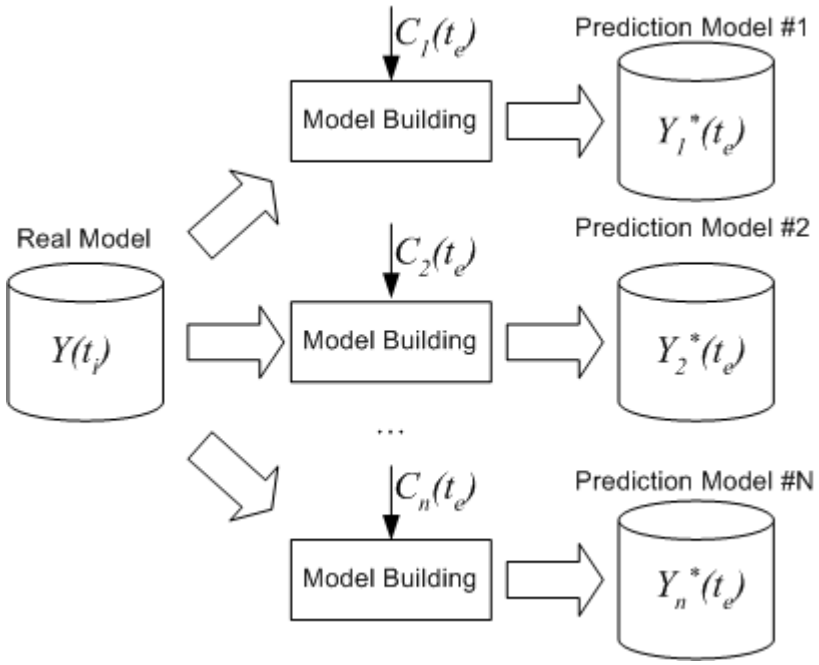


***Figure 3**. Conceptual scheme of Prediction Models building in anticipatory system*

As *an example* that shows an opportunity of the suggested approach let us consider the forecasting task of railway passenger transportation in the regions of Latvia. The search of optimal solutions on the future stages of railway transportation demands the construction of a set of prediction models, on the basis of which various strategies of behaviour of the railway system have to be considered.

To analyse and predict the number of passengers transported by railway in *i*-th region of Latvia during the year it is suggested to employ the multiple linear regression models of the form:

$$y_i^* = \beta_0^* + \beta_1^* \mathrm{x}_{i,1} + \beta_2^* \mathrm{x}_{i,2} + ... + \beta_\mathrm{n}^* \mathrm{x}_{i,n}, \qquad (2)$$

where y_i^* is the predicted value (estimate) of the dependent variable Y (a number of passengers transported by railway in the regions) for the *i*-th observation (region of Latvia);

$\beta_0^*, \beta_1^*, ..., \beta_n^*$ – estimated regression coefficients (evaluations of the unknown parameters);

$x_{i,1}, x_{i,2}, ..., x_{i,n}$ – values of independent (predictor) variables X_1, X_2, ..., X_n (accompanying factors) for the *i*-th observation.

Using formula (2) several Prediction Models, which allow evaluating the influence of the main social-economic factors on the passenger transportation by the railway in the regions of Latvia, have been created [9].

On the basis of the suggested virtual models' approach there appears a flexible possibility of suggested Prediction Models implementation in Data Warehouse, shown in Figure 4. Prediction Models are built using stored in Data Warehouse statistical data about passenger transportation in the regions as well as by the indicators of the regions social-economic development in the observed period. Data Marts Repository is created taking in account the suggested business logics and external factors and consists of two domains:

- Real Data Marts, which data physically exist on hard discs;
- Virtual Data Marts, the data are formed at the access moment.

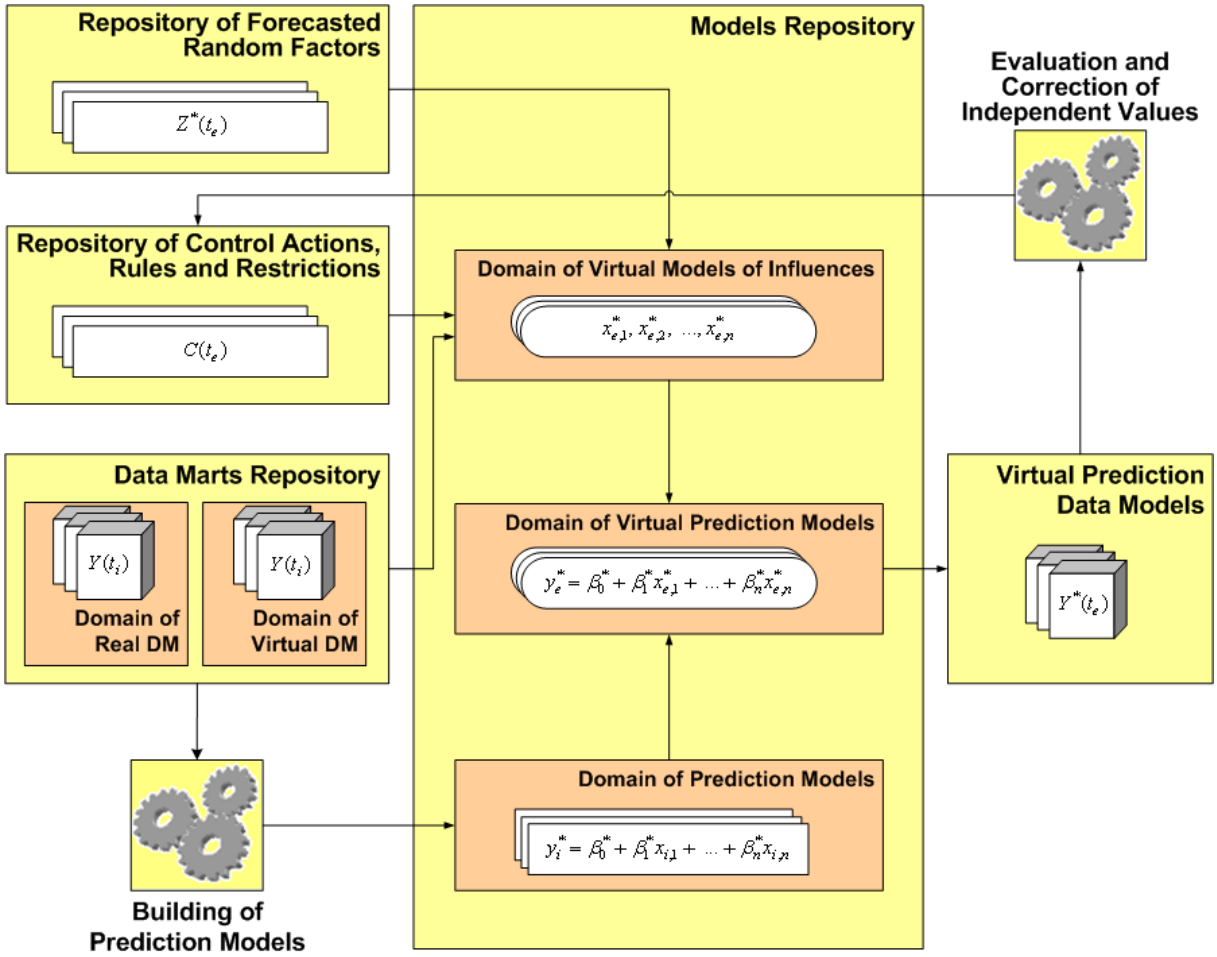


Figure 4. *Conceptual schema of Virtual Prediction Data Models building approach*

Calculated estimates of unknown parameters $\beta_0^*, \beta_1^*, ..., \beta_n^*$ together with corresponding values of predictor variables $x_{i,1}, x_{i,2}, ..., x_{i,n}$ are loaded in the related basic table stored in Domain of Prediction Models. Domain of Virtual Prediction Models consists of a set of views (virtual relations). For each kind of model the corresponding view is created. Views, that realize multiple linear regression models (2), are using evaluations of unknown parameters $\beta_0^*, \beta_1^*, ..., \beta_n^*$ stored in Domain of Prediction Models. Estimates of predictor variables $x_{i,1}^*, x_{i,2}^*, ..., x_{i,n}^*$ are on-line calculated using corresponding data, stored in Data Marts Repository, Repository of Control Actions, Rules and Restrictions and Repository of Forecasted Random Factors, by formula

$$x_{e,n}^* = F_2\left[Y(t_i);\ C(t_e);\ Z^*(t_e)\right], \tag{3}$$

where F_2 is a certain functional;

$Y(t_i)$ is a vector of variables that characterized the passenger transportation stored in Data Marts Repository; for example, train timetable in the prehistory;

$C(t_e)$ is a vector of control impacts on the system in the future period stored in Repository of Control Actions, Rules and Restrictions; for example, the number of railway stations in the region, train timetable, tariff policy, and others;

$Z^*(t_e)$ is a vector of predicted values of factors characterizing the impacts of environment on the investigated system stored in Repository of Forecasted Random Factors; for example, population density in the region, density of the unemployed population in the region, the number of schools per a unit of territory in the region, bus timetable, USD exchange rate, and others.

The considered schema of Virtual Prediction Data Models building allows evaluating the current state of the transportation system, making prediction for future $Y^*(t_e)$, defining necessary correcting impacts $C(t_e)$ and testing them. The correction procedure of management is the following. On the basis of developed recommendation the decision is made, which is evaluated on the developed Virtual Prediction Data Model, and again the prediction is performed taking into account the made decision. Thus, the system allows recognizing operational degradation recursively and in proper time reacts to them [10].

In the process of the receipt of new data a virtual model changes its status reacting to the deviations from the predicted behaviour. Thus, when using self-correction mechanism the correction of the predicted future situation happens as well. A continual testing of the reliability of a prediction is taken place and in case of negative deviations new correction impacts are defined.

Up to the present moment we assumed that the prediction is being performed for the future period, i.e. $t_e > t_n$. But model (2) has practical application for case $t_e < t_n$ as well, i.e. the prediction is being performed for the past period. This allows assessing the efficiency of the undertaken management decisions in comparison with other alternative decisions. The suggested method helps to choose an appropriate strategy to avoid common mistakes in the future. The authors consider in [4] as an illustration of the suggested approach the task of Latvian Railway losses analysis from the sizes of currency corridor.

CONCLUSIONS

The approaches to building Information Analytical Systems suggested by the authors have realized in a number of Decision Support Systems on the Latvian Railway. Employing Virtual Prediction Models makes it possible to change the values of the predictor variables at the time of carrying out the analysis. It allows taking account of any suppositions in predictions or predictions of change of the independent analysed variables, thus realizing the prediction of the type "what will be if …" or "what would be if …".

The experience of realizing virtual models has shown that they can easily set the rules and restrictions managing the process of calculations and make the process of data transformation in Decision Support System transparent and easily controlled. Complex analysis of a number of possible alternatives of the events development in the system of transportation for different variants of managing affects and different behaviour of the external medium and working out the suggestions for optimal system management in different situations – without reiterative increase of the disc space in relation to the basic variant and blocking the data warehouse in the time of carrying out the analysis.

The offered approach can be applied to forecasting of railway transportation depending on the change of charges policy as control action at the system with account of effect of the environment. The external effects which are taken into account during the predicted period of time, for example in a case with freight traffic, can be the registration of activity of other carriers inside the country and in the adjacent states, change of a dollar exchange rate and the prices for transported cargoes etc.

References

[1] Kazatsay Z. The Hungarian Transport policy – Accession to the European Union. http://www.imprint-eu.org/public/Papers/IMPRINT5_Kazatsay.pdf (2005, June 22).

[2] Pohjamo S. Logistics Event. http://www.logisforum.fi/eng/news/pohjamoeng.doc (2005, June 22).

[3] *Annual Report of State Joint-Stock Company "Latvijas Dzelzceļš" for 2003*. Riga: SJSC "Latvijas Dzelzceļš", 2004. 37 p. (In Latvian)

[4] Kopytov E., Demidovs V., Petoukhova N. Principles of Creating Data Warehouses in Decision Support Systems of Railway Transport. In: *Computing Anticipatory Systems. CASYS 2003 - Sixth International Conference: Conference Proceedings 718.* /Edited by D. M. Dubois. Published by The American Institute of Physics, pp. 497-507.

[5] Kopitovs J., Demidovs V., Petoukhova N. Virtual Models in Forecasting Systems of Railway Transportation. In: *Proceedings of the International Conference "Modelling and Simulation of Business System".* /Edited by H. Pranevicius, E. Zavadskas and B. Rapp. May 13-14, 2003, Vilnius, Lithuania. Kaunas: Technologija, 2003, pp. 265-268.

[6] Kopytov E., Petoukhova N., Demidov V. Methodology of Huge Data Volume Processing System Development for Analysis of the Latvian Railway Passengers Transportation. In: *Proceedings of VI International Conference "TransBaltica 2001"*. Riga: RMS Forum, 2001, pp. 201-208. (In Russian)

[7] Korovkin S., Levenets I., Romanov I., and etc. Resolving of Problem of Complex On-Line Analysis of Information in Data Warehouse. – http://www.citforum.ru/database/articles/art_11.shtml (2005, June 22).

[8] Demidovs V. Virtual Models in Decision Support Systems of the Latvian Railway. In: *Transport and Telecommunication,* volume 5(2). Riga: Transport and Telecommunication Institute, 2004, pp. 25-35. (In Russian)

[9] Demidovs V., Bogdanovs J. Regression Models for Forecasting of Traffic Flow in Decision Support System on the Latvian Railway. In: *Abstracts of the International Conference "Reliability and Statistics in Transportation and Communication (RelStat '04)"*. Riga: Transport and Telecommunication Institute, 2004, pp. 37-38.

[10] Allgood G. Mapping Function and Structure for an Anticipatory System: what Impact will it have and is it Computationally Feasible, Today? – http://www.ornl.gov/~webworks/cpr/pres/107928_.pdf (2005, June 22).

INTEGRATED INFORMATION SYSTEMS AS A FACTOR OF RELIABILITY OF LOGISTIC SYSTEMS IN SUPPLY CHAIN ORIENTED BUSINESS

Irina Osobskaya, Vitaly Skaredov

Transport and Telecommunication Institute
Lomonosov Str.1, Riga, LV-1019, Latvia
Ph: (+371)-7100650. Fax: (+371)-7100660. E-mail: iosobskaya@tsi.lv

In the paper methodology is offered to increase reliability of logistic system of enterprise by its integration with statistics analysis systems that is made in cases when ERP system itself do not meet enterprise's logistics goals. This task is reviewed based on case studies of enterprises of Latvia, Lithuania and Estonia, which are using ERP-class information systems (SCALA [3,4,5]), while logistic systems are build on Supply Chain methods. System is analysed in tight connection with strategic and daily logistics tasks. Methodology offered is structured by problems put and level of automation of enterprise internal processes.

Keywords: *ERP, reliability of logistic systems, inter-company integration, statistics in logistics*

In the beginning of the paper authors provide short description of standard functionality of logistic modules in ERP system SCALA. Typical logistic challenges in the Baltic States (Latvia, Lithuania and Estonia), which exceed standard functionality, are reviewed. SCALA is taken as the system for small and middle business, these systems often do not satisfy users from logistics point of view, because it does not allow reaching some of logistics goals. For example, so loyal SCALA users in the Baltic as Schneider Electric, Electrolux, Oriola and others, actively and successfully using this ERP systems for many years, meet the problem of reliability limitation of logistic system based on standard IT solution. On the other hand, system should be more flexible to react faster on customer demand changes. This, for its turn, leads to decrease need of warehouse facilities [1,2]. It could be followed by, i.e. consolidation of warehouses in the Baltic countries into one central.

Authors offer some solutions of the problem. In the paper already implemented and approved solutions are reviewed. Methods offered leads to increased reliability of enterprise logistic system, advantages and disadvantages of each method are described. For example, in case of non-standard logistics indexes and other value calculation different analytics systems in combination with statistical data can be used (like Crystal Reports, Microsoft Access, Microsoft Query, QlikView and others).

Goals achieved are the following:

- Reaching of logistics goals set while saving consistency of enterprise logistics system. Reliability and working results precision are increased in current ERP solution.
- Customer service level is increased up to planned level in current situation. Certain marketing policy implementation becomes possible based as on purely marketing technologies, so as on its integration with logistics system and statistical data.
- More detailed and at the same time more visual (charts, tables) presentation of statistical data made it easier to manage logistics and decreased possibility of mistakes and time needed to make decisions.
- Shortest reaction time of logistics system on changing of marketing situation.
- Stock value optimisation leads to possible decrease of number of warehouses for enterprise in EU countries.

Targets of the Project

- Increasing of systems flexibility to react faster on customer demand changes
- Inter-company Integration of national systems into the Baltic consolidated system

Objectives of the Project

1. Logistics flows optimisation by its redistribution between the Baltic States
2. Order scheduling and monitoring
3. Optimisation of reorder level calculations
   (incl. Creating new categories in stock file)

Successful Result Criteria

1. Decreasing obsolete and overstocked warehouse balances
2. Increasing of customer service level coef=((orders in time)/(total)*100%)>97%
3. Optimising of product availability
   (95% for A&B items, faster delivery for C&D)

Project Milestones

1. Intranet systems implementation – May 2004
2. Concept approval – July 2004
3. Stock file categories – Aug 2004
4. Reorder level calculation – Oct 2004
5. Order Monitor – Nov 2004
6. Intercompany Integration – Nov 2004
7. First results – Q1 2005

Starting Point

- Constant increasing of obsolete and overstocked product warehouse balances
- Unsatisfied customer and management complaints about often unavailability of top sales products
- Unpredictable warehouse work loading

Methods and Tools

- Corporate standard ERP system (SCALA) parameterisation
- Establishing of VPN connection between Baltic country offices
- Inter-connectible Intranet system implementation with monitoring & visualization tools (ERP is ODBC (SQL)-compliant)

Project Scale

- All customer's Financial and Logistics Top Management in every Baltic country involved in the project
- Most parts of the project implemented in all Baltic countries using intranet connections (order monitoring is unique for Latvia)

Stock File Categories

- Monthly updating of stock file categories implemented for detecting concrete item importance for customer service level
  (A=80%, B=15%, C=5% of turnover)

- Additional logistics-related categorization implemented (F=frequent, M=middle, R=rare)

Reorder Levels

- Quarterly formula-based customisable updating of reorder levels implemented
- Formula uses historical or normative delivery terms of each item, ABC category, per-month demand during last 6 month and season factor to calculate exact minimal reorder level per item

Possible reasons of manual changing of Reorder Level:

- Item is used in special projects only
- Item becomes obsolete
- Domestic product – no need to keep on stock
- Developing product type – sales growth expected

etc.

Order Monitor

- Obligatory customer order delivery time entering implemented (24H, 4H, 1.5H, etc)
- Time registration added to standard ERP functionality to control order data flow and its every step: order entry, print-out of picking list, stock withdrawal, print-out of invoices

Intercompany Integration

- Intra-networking connection between concern's companies in all the Baltic States established
- Automated checking of purchase order for possibility to order items from neighbour countries implemented

Current Results

- Automated updating of Reorder Level made quarterly using formula in 80% of cases
- Customer Service Level becomes stable at 97-98% at average
- Obsolete and Overstock balances decreased by redistributing it between Baltic countries

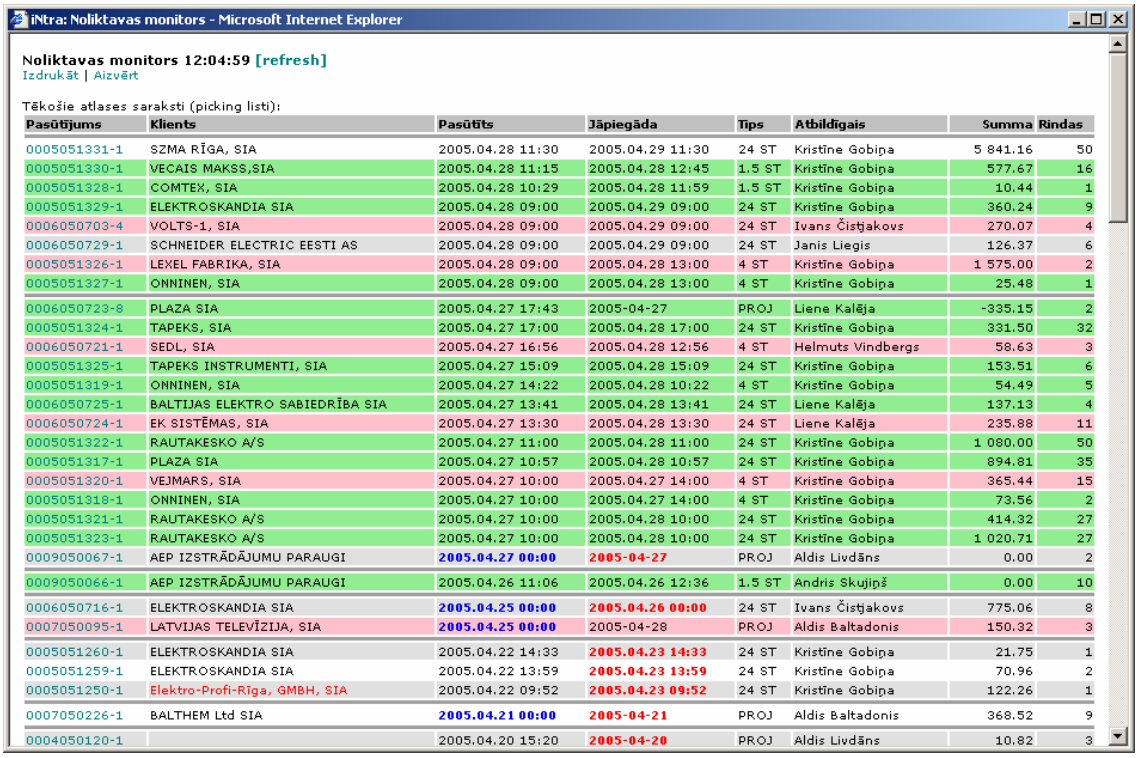
Customer Feedback

Liga Karlsone, Baltic SCM Manager:

"We are truly satisfied with implemented solution, it made it possible to automate decision-making in most of cases. Increased flexibility of this custom solution allowed us to follow corporate standard while suiting our domestic needs."

CONCLUSION

Working experience in the Baltic region shows insufficiency of regular ERP systems for developing integrated logistics system. Using of intranet solution allowed to extend whole system functionality to meet specific logistics needs and make most of decision-making process automatic. Project is still developing, so it's too early to make final conclusion, but first results show positive movement, and further developing can become a theme for future researches.



iNtra: Noliktavas monitors - Microsoft Internet Explorer

Noliktavas monitors 12:04:59 [refresh]
Izdrukāt | Aizvērt

Tēkošie atlases saraksti (picking listi):

Pasūtījums	Klients	Pasūtīts	Jāpiegāda	Tips	Atbildīgais	Summa	Rindas
0005051331-1	SZMA RĪGA, SIA	2005.04.28 11:30	2005.04.29 11:30	24 ST	Kristīne Gobiņa	5 841.16	50
0005051330-1	VECAIS MAKSS,SIA	2005.04.28 11:15	2005.04.28 12:45	1.5 ST	Kristīne Gobiņa	577.67	16
0005051328-1	COMTEX, SIA	2005.04.28 10:29	2005.04.28 11:59	1.5 ST	Kristīne Gobiņa	10.44	1
0005051329-1	ELEKTROSKANDIA SIA	2005.04.28 09:00	2005.04.29 09:00	24 ST	Kristīne Gobiņa	360.24	9
0006050703-4	VOLTS-1, SIA	2005.04.28 09:00	2005.04.29 09:00	24 ST	Ivans Čistjakovs	270.07	4
0006050729-1	SCHNEIDER ELECTRIC EESTI AS	2005.04.28 09:00	2005.04.29 09:00	24 ST	Janis Liegis	126.37	6
0005051326-1	LEXEL FABRIKA, SIA	2005.04.28 09:00	2005.04.28 13:00	4 ST	Kristīne Gobiņa	1 575.00	2
0005051327-1	ONNINEN, SIA	2005.04.28 09:00	2005.04.28 13:00	4 ST	Kristīne Gobiņa	25.48	1
0006050723-8	PLAZA SIA	2005.04.27 17:43	2005-04-27	PROJ	Liene Kalēja	-335.15	2
0005051324-1	TAPEKS, SIA	2005.04.27 17:00	2005.04.28 17:00	24 ST	Kristīne Gobiņa	331.50	32
0006050721-1	SEDL, SIA	2005.04.27 16:56	2005.04.28 12:56	4 ST	Helmuts Vindbergs	58.63	3
0005051325-1	TAPEKS INSTRUMENTI, SIA	2005.04.27 15:09	2005.04.28 15:09	24 ST	Kristīne Gobiņa	153.51	6
0005051319-1	ONNINEN, SIA	2005.04.27 14:22	2005.04.28 10:22	4 ST	Kristīne Gobiņa	54.49	5
0006050725-1	BALTIJAS ELEKTRO SABIEDRĪBA SIA	2005.04.27 13:41	2005.04.28 13:41	24 ST	Liene Kalēja	137.13	4
0006050724-1	EK SISTĒMAS, SIA	2005.04.27 13:30	2005.04.28 13:30	24 ST	Liene Kalēja	235.88	11
0005051322-1	RAUTAKESKO A/S	2005.04.27 11:00	2005.04.28 11:00	24 ST	Kristīne Gobiņa	1 080.00	50
0005051317-1	PLAZA SIA	2005.04.27 10:57	2005.04.28 10:57	24 ST	Kristīne Gobiņa	894.81	35
0005051320-1	VEJMARS, SIA	2005.04.27 10:00	2005.04.27 14:00	4 ST	Kristīne Gobiņa	365.44	15
0005051318-1	ONNINEN, SIA	2005.04.27 10:00	2005.04.27 14:00	4 ST	Kristīne Gobiņa	73.56	2
0005051321-1	RAUTAKESKO A/S	2005.04.27 10:00	2005.04.28 10:00	24 ST	Kristīne Gobiņa	414.32	27
0005051323-1	RAUTAKESKO A/S	2005.04.27 10:00	2005.04.28 10:00	24 ST	Kristīne Gobiņa	1 020.71	27
0009050067-1	AEP IZSTRĀDĀJUMU PARAUGI	**2005.04.27 00:00**	**2005-04-27**	PROJ	Aldis Livdāns	0.00	2
0009050066-1	AEP IZSTRĀDĀJUMU PARAUGI	2005.04.26 11:06	2005.04.26 12:36	1.5 ST	Andris Skujiņš	0.00	10
0006050716-1	ELEKTROSKANDIA SIA	**2005.04.25 00:00**	**2005.04.26 00:00**	24 ST	Ivans Čistjakovs	775.06	8
0007050095-1	LATVIJAS TELEVĪZIJA, SIA	**2005.04.25 00:00**	2005-04-28	PROJ	Aldis Baltadonis	150.32	3
0005051260-1	ELEKTROSKANDIA SIA	2005.04.22 14:33	**2005.04.23 14:33**	24 ST	Kristīne Gobiņa	21.75	1
0005051259-1	ELEKTROSKANDIA SIA	2005.04.22 13:59	**2005.04.23 13:59**	24 ST	Kristīne Gobiņa	70.96	2
0005051250-1	Elektro-Profi-Rīga, GMBH, SIA	2005.04.22 09:52	**2005.04.23 09:52**	24 ST	Kristīne Gobiņa	122.26	1
0007050226-1	BALTHEM Ltd SIA	**2005.04.21 00:00**	**2005-04-21**	PROJ	Aldis Baltadonis	368.52	9
0004050120-1		2005.04.20 15:20	**2005-04-20**	PROJ	Aldis Livdāns	10.82	3

Figure 1. *Order Monitor*

iNtra: PASŪTĪJUMS NR. 0000065184 - Microsoft Internet Explorer

Pasūtījuma Nr.: 0000065184-1
Datums: 2005-04-25
Izdrukāt | Aizvērt

Piegādātājs	Saņemējs/maksātājs	Piegādes adrese
SCHNEIDER ELECTRIC IND., MOIRANS CDI, B.P. 121-Z.I.,Central p220, Rue Du Pommarin 38430-MOIRANS France	**Schneider Electric Latvija SIA** A.Deglava 60 Rīga LV-1035	**Schneider Electric Latvija, SIA** Bikernieku 121, Riga, LV-1021 Latvia

Rinda	Preces kods	Apraksts	Ddz	WH01	Pieg.	Cena	Atlaide %	Summa EUR
000001	48231	[illegible]	3		0	571.10	0.00	1 713.30
000002	48360	[illegible]	3		0	298.14	0.00	894.42
000003	33080	[illegible]	3		0	2.58	0.00	7.74
000004	48392	[illegible]	3		0	302.15	0.00	906.45
000005	48143	[illegible]	3		0	18.26	0.00	54.78
000006	47955	[illegible]	3		0	2.54	0.00	7.62
000007	47994	[illegible]	3		0	0.01	0.00	0.03
000008	48148	[illegible]	3		0	18.26	0.00	54.78
000009	48527	[illegible]	3		0	228.00	0.00	684.00
000010	48484	[illegible]	3		0	41.84	0.00	125.52
000011	48494	[illegible]	3		0	41.84	0.00	125.52
000012	48468	[illegible]	3	3	0	43.16	0.00	129.48
000013	48478	[illegible]	12		0	11.62	0.00	139.44
000014	48545	[illegible]	3		0	16.51	0.00	49.53
000015	48536	[illegible]	3		0	15.38	0.00	46.14
000016	48554	[illegible]	3		0	41.51	0.00	124.53
000017	48587	[illegible]	3		0	38.46	0.00	115.38
000018	48595	[illegible]	3		0	13.01	0.00	39.03
000019	47200	[illegible]	1		0	402.31	0.00	402.31
000020	33532	[illegible]	1		0	298.14	0.00	298.14
000021	33080	[illegible]	1		0	2.58	0.00	2.58
000022	33722	[illegible]	1	3	0	199.73	0.00	199.73
000023	33731	[illegible]	1		0	33.75	0.00	33.75
000024	47107	[illegible]	1		0	2.54	0.00	2.54
000025	33732	[illegible]	1		0	33.75	0.00	33.75
000026	47466	[illegible]	1		0	218.59	0.00	218.59
000027	47443	[illegible]	1		0	41.84	0.00	41.84
000028	33813	[illegible]	1		0	42.53	0.00	42.53
000029	47519	[illegible]	1		0	17.99	0.00	17.99
000030	33897	[illegible]	1		0	14.63	0.00	14.63
000031	33765	[illegible]	1		0	19.69	0.00	19.69
000032	33763	[illegible]	1		0	9.84	0.00	9.84

Figure 2*. Redistribution of logistics flows between countries*

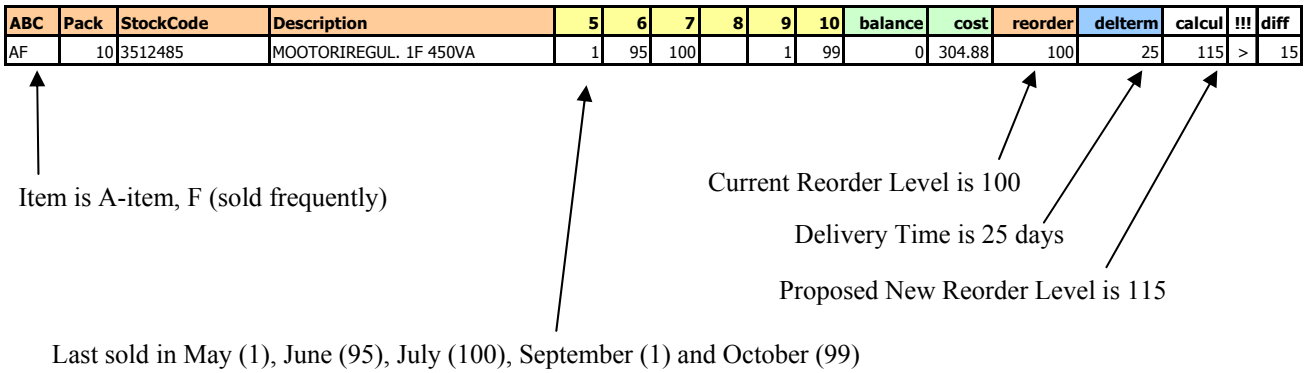


***Figure 3**. Calculation of Reorder Level*

References

[1] Christopher M. *Logistics and Supply Chain Management*. Moscow: Prentice Hall, Peter, 2004, pp. 236-237.
[2] Waters D. *Logistics: An Introduction to Supply Chain Management*. Moscow: Palgrave Macmillan, Unity, 2003, pp. 131-138.
[3] *Scala Stock Control: User's Guide*. Sweden: Scala International AB, Nacka, 1997, pp. 197-227.
[4] *Scala Purchase Control: User's Guide*. Sweden: Scala International AB, Nacka, 1997, pp. 23-56.
[5] *Scala Sales Order/Invoicing: User's Guide*. Sweden: Scala International AB, Nacka, 1997, pp. 127-159.

THE MODELLING OF COMMUNICATION CHANNEL WITH RELAY'S FADING BY USAGE OF ADAPTIVE FILTERS

Marina Konovalenko, Yury Sikerzhitsky

Transport and Telecommunication Institute
Lomonosov Str.1, Riga, LV-1019, Latvia
Ph: (+371)-7100650. Fax: (+371)-7100660
E-mail: marina_konovalenko@yahoo.com

The main idea of this article is modelling of communication channel with Relay's fading by usage of adaptive filters, in order to get characteristics of signal's dependences at channels correspondent exits.
The channel simulation – it is a task for adaptive filter creation with variable weighting coefficients, where experimentally taken data of signal's statistical characteristics was used.
The multi beam channel model should have two equal filters with variable weighting coefficients. One of the filters should work in the regime of adaptation and it should set simultaneously the found value of weighting coefficients to the second filter through which the signal under testing is transferred.

Keywords: *adaptive filtration, communication channel, signal processing, relay's fading*

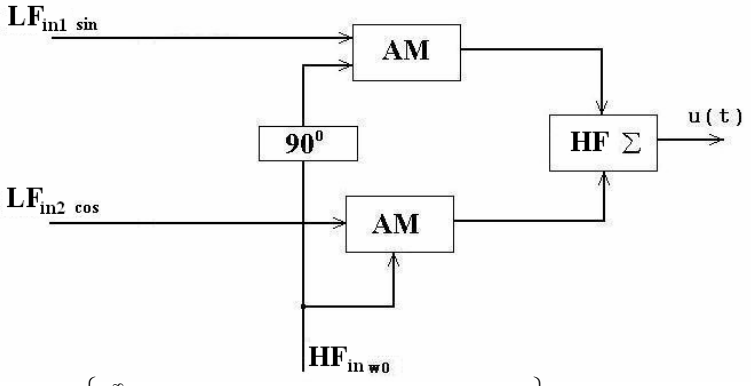
For the multi-beam channel's modelling we need to have a special electronic model (a channel simulator) that could define the output signal when on the input of the channel a signal with any kind of modulation has been received.

Using such a model, different ways of signal's fading control could be investigated, as well as we could compare these methods and then choose the best methods for signals with different kinds of modulation.

At this time in all known methods there are two main ways of channel's modelling. The first one is to make a model of the channel with the help of statistical signal's data without any modulation on the output of the real communication channel. The second way is analytical modelling of multi-path wave propagation [1, 2].

There are structural schemes of signal normalization at the outputs of multi-path channels (see Fig.1 and Fig.2), where statistical characteristics of signals without modulation (on the outputs of real communication channels) have been used.

There is a scheme (Fig.1) that realizes a method of signal's normalization with the help of quadrature modulation [1] at the multi-path channel's output.



$$u(t)=\left\{\sum_{m=-\infty}^{\infty}(-1)^m u(2m\Delta t)\sin c[\pi\Delta F(t-2m\Delta t)]\right\}\cos 2\pi f_0 t -$$

$$-\left\{\sum_{m=-\infty}^{\infty}(-1)^{m+i+1} u(2m\Delta t+\Delta t)\sin c[\pi\Delta F(t-2m\Delta t-\Delta t)]\right\}\sin 2\pi f_0 t$$

Figure 1. *Method of signal's normalization with the help of quadrature modulation at the multi-path channel's output*

To realize this scheme we need to have statistical characteristics of sine and cosine amplitude's envelope of the signal at multi-path channel's output that has been taken experimentally.

There is a scheme (Fig.2) that realizes a method of signal's normalization with the help of modulation of tire carrier by envelope's and phase's readings of the signal at multi-path channel's output [1].

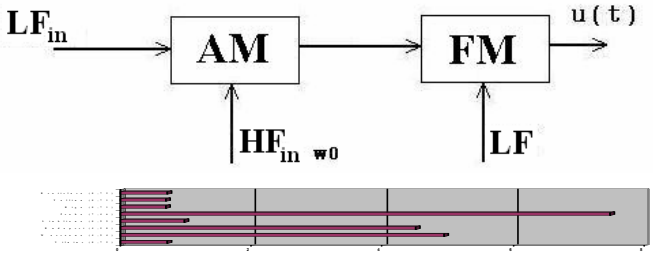


***Figure 2**. Method of signal's normalization with the help of modulation of tire carrier by envelope's and phase's readings of the signal at multi-path channel's output*

It is needed to have statistical characteristics of signal's envelope and phase at multi-path channel's output that has been taken experimentally for the realization of that scheme.

There is a scheme (Fig.3) where analytical modelling of multi-path wave propagation has been shown.

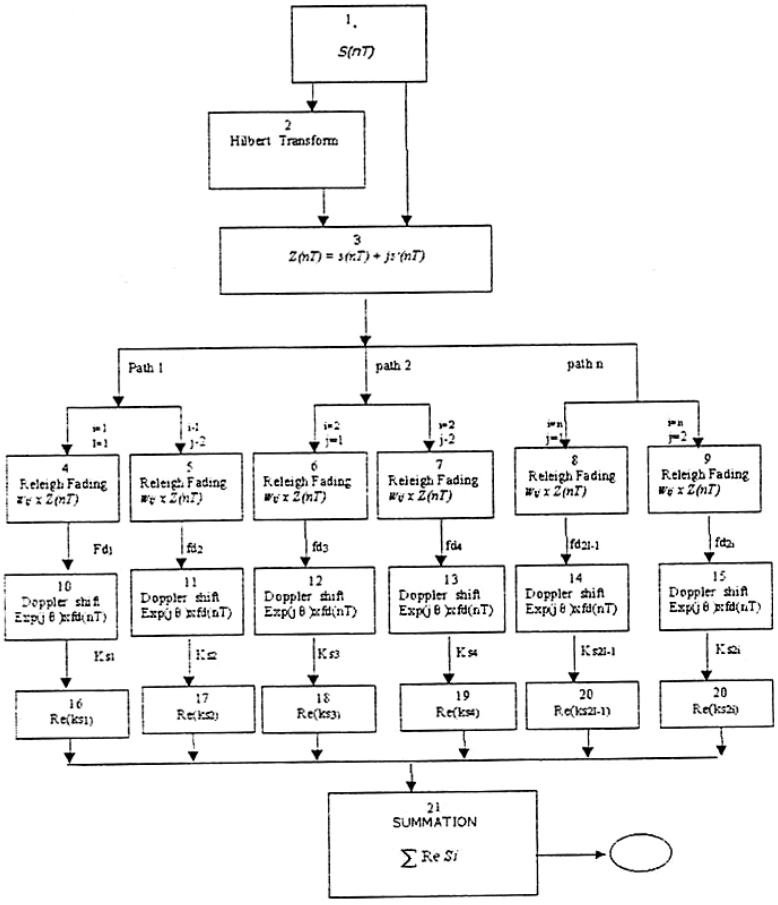


***Figure 3.** Analytical modelling of multi-path wave propagation*

It is needed to model separate beams (with the help of Hilbert transform, Relay's delay, Doppler shift) for realizing this scheme. Then the real part of every complex signal has been allocated and added to each other in consecutive order.

From all the methods mentioned above, only the last one has a possibility to get a response when signals with any kind of modulation are sends on the input of the system.

But the most important disadvantage of the last method is that the result depends on the amount of signal's copies that was added to each other. And, because of this, it is very difficult to identify such a model with real communication channel.

The identification of the model to a real communication channel needs to have additional experimental researches.

Nowadays, adaptive methods of system's identification are developed. Those methods could be also used in multi-path channel's modelling as well [3, 4].

The basic element of systems with adaptive identification is a linear adaptive adder [3, 4]. This is a transversal filter with variable weighting coefficients that is shown on Fig.4.

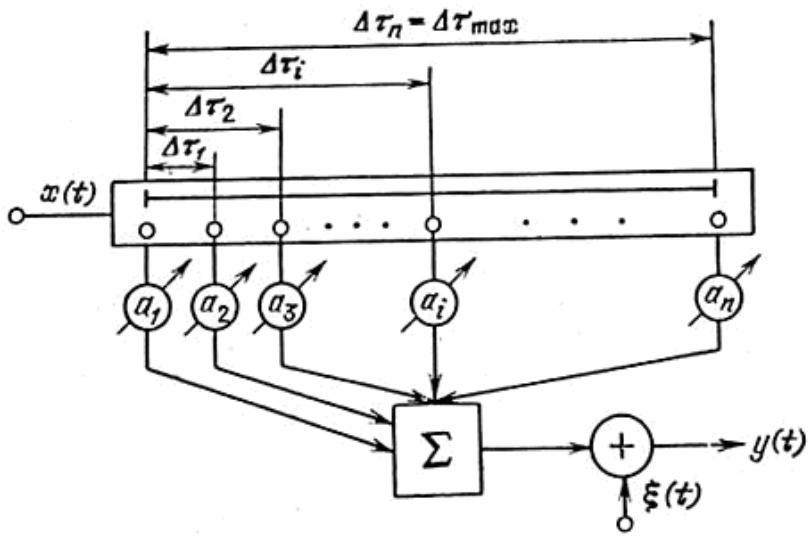


Figure 4. *Linear adaptive filter*

So, going on this way, for multi-path channel modelling it is needed to create an adaptive filter with variable weighting coefficients that are selected in real time and are used in the system. For separating two operations that are made simultaneously (the selection of coefficients and passing signal through the system) we should make those operations in two parallel ways.

The scheme of adaptive model for multi-path radio waves propagation (Fig. 5) is shown.

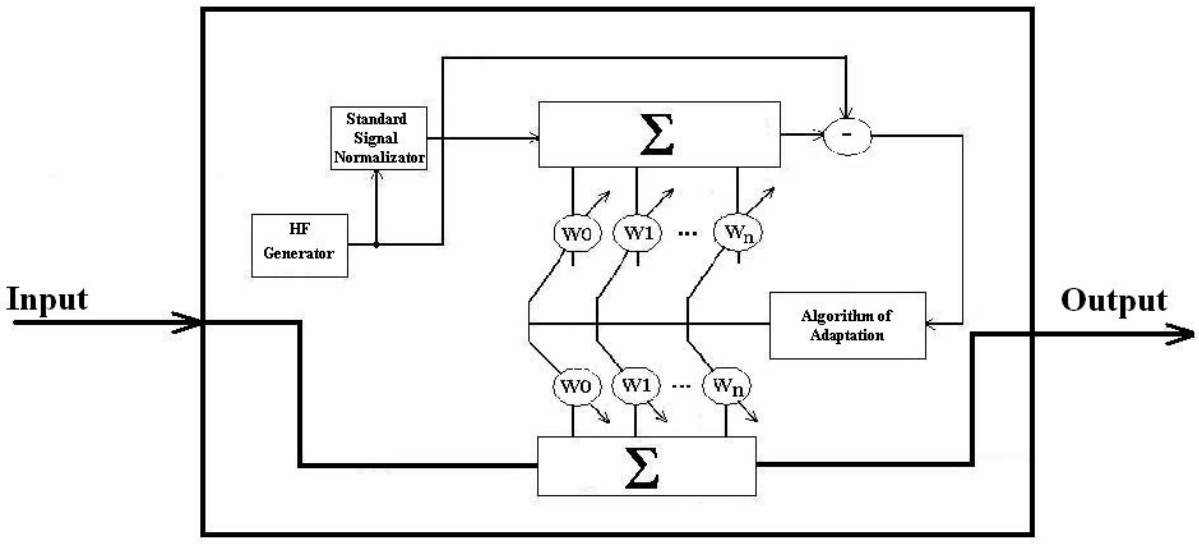


Figure 5. *Scheme of adaptive model for multi-path radio waves propagation*

This multi-path channel has two identical filters with variable weighting coefficients. One of those filters operates in adaptation mode to the test signal. The test signal is formed with the help of method that is shown on Fig.2. This exact method of the test signal forming has been chosen because we had real statistical characteristics of signal's envelope and phase at the output of multi-path channel that was received experimentally [5]. As the algorithm of adaptation a method of least square estimator has been taken. The value of weighting coefficients from the first filter are given to the second one, which is intended to pass through it signals with any kind of modulation.

This modelling was made in application Matlab. But because of manuscript volume's limits it is not possible to present the body of this program there.

The testing results of model for passing through the system signals with amplitude modulation when depth of fading has been changed (Fig. 6) are shown.

When the amplitude on channel's output is normalized, the time scale estimates the depth of fading when the amplitude of the signal is lower than a threshold value to a length of signal's sample at the channel's output.

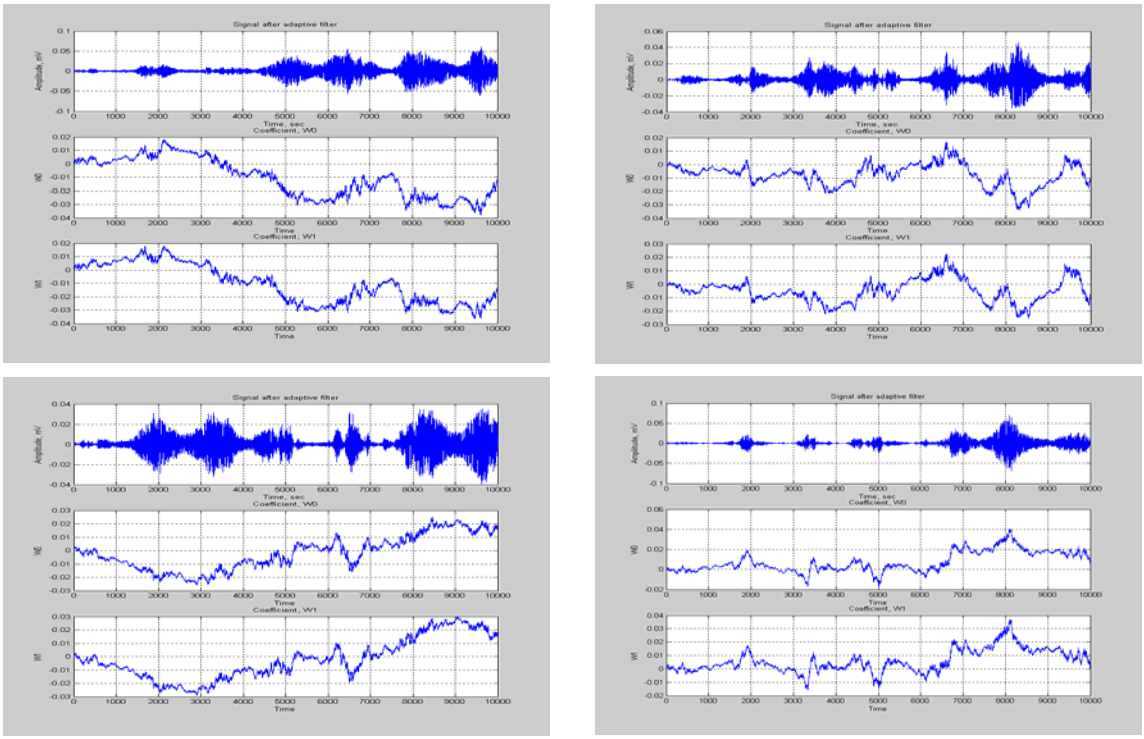


Figure 6. *Testing results of model for passing through the system signals with amplitude modulation when depth of fading has been changed*

The results after model testing are shown in three diagrams. The signal at the channel's output and behaviour of two weighting coefficients in the model are shown. These coefficients correspond to a process of signal normalization. At the diagrams presented above we could see that this model could help us in modelling multi-path channels with changeable depth of fading.

References

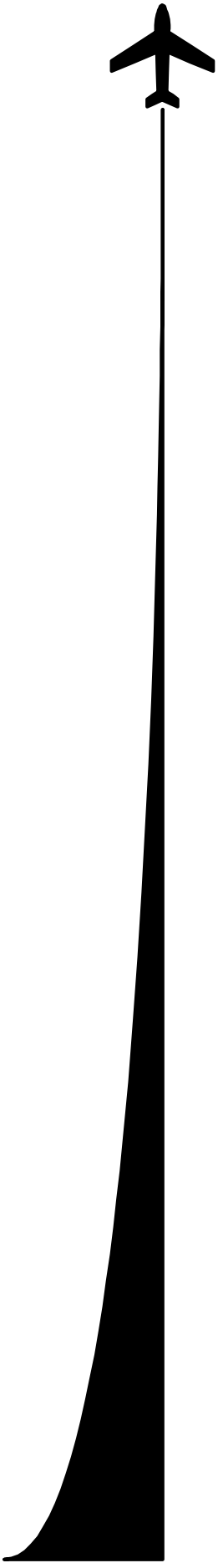
[1] Левин Б.Р. *Теоретические основы статистической радиотехники*. 3-е изд., перераб. и доп. М.: Радио и связь, 1989. 656 с.: ил. - ISBN 5-256-00264-3

[2] Stein S. Fading Channel Issue in System Engineering, *Trans. IEEE Journal in Selected Area in Communication*, Vol. SAC-5, No2, February 1987.

[3] Уидроу Б., Стирнз С. *Адаптивная обработка сигналов* /Пер. англ. М.: «Радио и связь», 1989. 140 с.

[4] Коуэн К.Ф.Н., Грант П.М. *Адаптивные фильтры* /Пер. англ. М.: «Мир», 1988.

[5] Сикержицкий Ю.М., Моргунов А.Д., Шелковников В.А.. *Экспериментальные исследования статистических характеристик сигналов и помех декаметрового диапазона.* Рига: РКИИГА, 1981 г. Рукопись депонирована в ВИНИТИ 27.07.81 г. No 3780-81 Деп.



Session 4

Modern Technologies in Aviation

AIRLINE REVENUE MANAGEMENT IN A CHANGING BUSINESS ENVIRONMENT

Richard Klophaus

Trier University of Applied Sciences and Centre of Aviation Law and Business (ZFL)
Umwelt-Campus Birkenfeld, D-55768 Neubrücke, Germany
Ph: + 49 67 82 17 - 12 20. Fax: + 49 67 82 17 - 14 54
E-mail: klophaus@umwelt-campus.de

The paper first gives an overview on principles of traditional RM. The author outlines a RM approach suited to the pricing policy of low-cost airlines, where each flight only has one fare available at any point of time. In this context, effective RM boils down to a flight-by-flight dynamic price optimization. The paper emphasizes that some traditional RM principles remain valid. However, fare mix optimization and more sophisticated inventory control techniques do not apply for leg-based low-cost operations selling a single fare product at any one time during the booking period of a flight.

Keywords: *transport economics, pricing and revenue management, low-cost airlines*

1. INTRODUCTION

Revenue Management (RM) represents a mainstream business practice in daily airline operation. It is concerned with the optimization of total revenue through the use of tools and techniques. Until very recently, the focus from both the airline industry and academia has been on origin and destination (O&D) multi-leg seat inventory control. However, the changing business environment caused by the strong growth of low-fare, low-cost airlines in short-haul markets such as Europe has raised interest among researchers and airlines alike, how to adjust revenue management techniques and systems given a low-fare pricing model with non-differentiated and less restricted fare products.

The paper deals with a brief overview on principles of traditional RM. This is done in Section 2. In Section 3 it describes pricing and booking procedures currently applied by leading European low-cost airlines like Ryanair and Easyjet, where each flight only has one fare available at any point of time. Section 4 outlines a RM approach suited to this pricing approach.

However, RM for low-cost airlines differs from the one for network airlines with regard to fare mix optimization and more sophisticated inventory control techniques like O&D control. The author concludes with directions for further research on RM forecasting and optimization methods for low-cost airlines and supporting systems solutions. These are also relevant for network airlines facing low-fare competition and downward pressure on yields.

More comprehensive reviews dealing with RM can be found in McGill and Van Ryzin (1999) and Talluri and Van Ryzin (2004). The simple pricing structure that Europe's low-cost airlines apply using Easyjet for their research Koenigsberg, Muller and Vilcassim (2004) have described. The impact of these pricing and booking procedures at low-cost airlines on RM has recently attracted increasing interest of airline consultants like Rubicon Group and RM systems provider like Lufthansa Systems. To the author's knowledge, Fletcher (2003) has provided the first paper with an alternative view on RM given a low-fare airline business model.

2. PRINCIPLES OF REVENUE MANAGEMENT (RM)

There are several characteristics of industries that make the application of RM most effective (Klophaus 1998):

- The product is perishable, which means that it is expensive or impossible to store excess inventory;
- Future demand is uncertain;
- The capacity to offer the product is limited and it is expensive or impossible to increase capacity quickly;

- The market can be segmented (i.e., customers are willing to pay different prices for the same product;
- The fixed cost for offering the product is high, while the marginal cost is low.

All of these characteristics hold for the airline industry. So it is no surprise that airlines have been the inventors and first users of revenue management.

Major US carriers first introduced RM after airline deregulation in 1978. American Airlines is acknowledged for the first capacity controlled discounted fares in the airline market. The principle of placing booking limits on discounted fares allowed the major network carriers to protect their high-yield market segments while simultaneously competing with the new low-cost carriers in the low-yield segment. In the meanwhile, RM has become an industry standard. Lufthansa credits RM techniques for an increase in revenue amounting to more than € 700 million per year (Klophaus 1998). Other industries like car rentals, broadcasting, hotels, cruise lines and so forth followed and adopted the RM principles to their needs.

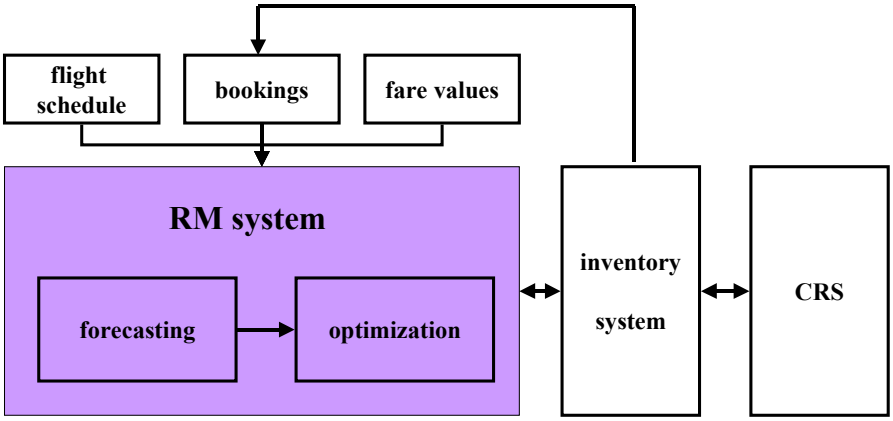


Figure 1. *RM system*

Figure 1 shows the main modules of a RM system. A state-of-the-art system merges two forecasting models to achieve a high degree of quality in this important RM function. These are the seasonal forecast and the bookings-based forecast. The former is ideal for producing a first estimate and for adjusting to seasonal changes, while the latter method performs better in the reservation period closer to departure. Generally, the weighting of the seasonal forecast decreases during the booking period, while the weighting of the bookings-based forecast increases. Hence, both forecasts are used in the optimization. The resulting control parameters are passed to the computer reservation system (CRS) in order to control availability and booking requests.

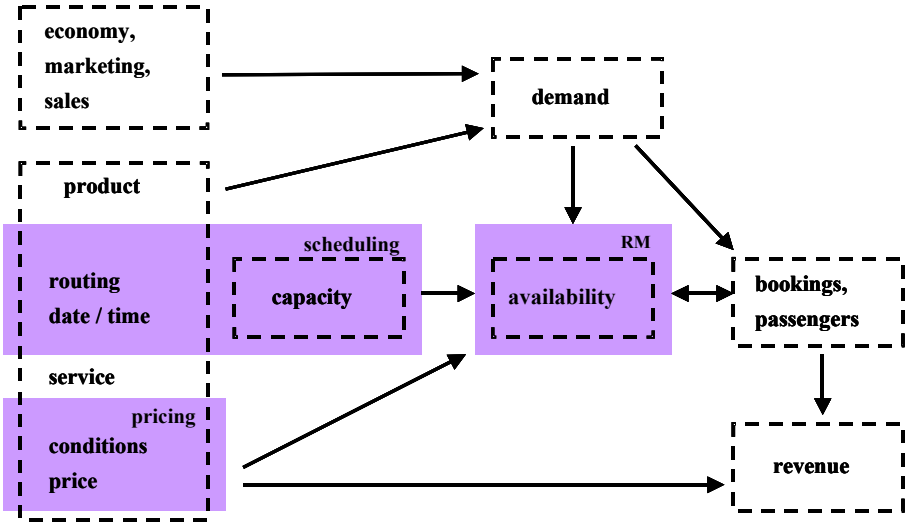


Figure 2. *Interactions of scheduling, pricing and revenue management (Pölt 2002)*

Figure 2 depicts the interactions of scheduling, pricing and RM that determine total airline revenue. The product an airline offers is to a great extent defined by scheduling and pricing. Scheduling specifies the routing, the frequency, the departure time, whether it is a non-stop or a connection. Pricing sets the price and the conditions. Other product features like service, seat pitch, lounges and so on that are defined by product management and frequent flyer programs are not considered here. The quality of the product affects the demand for it. The demand is also influenced by factors like the state of the economy, marketing and sales efforts and so forth. The role of RM is to match the demand with the offered capacity by determining the product availability. This leads to the basic airline seat inventory control problem if a seat should be sold at a current booking request, or if it should be saved for a more profitable customer. For this purpose, RM needs information about the value of the booking request. As information either the fares from pricing can be used or historical average revenues from revenue accounting. The availability together with the demand defines how many bookings the airline has for each product. This translates to revenue. The central message of Figure 2 is that the interactions of scheduling, pricing and RM determine to a large extent the total airline revenue. To maximize revenue the decisions within scheduling, pricing and RM are to be aligned (Pölt 2002).

Common wisdom in airline RM holds that selling more seats than the capacity on a given flight is the only way to compensate for passengers failing to show up at departure, causing loss of revenue due to empty seats. On flights operated by Lufthansa more than 5.5 million passengers did not show up in 2004. This corresponds to 14,000 full Boeing 747. Overbooking allowed Lufthansa to carry more than 640,000 additional passengers. Lufthansa credits the practice of selling a number of tickets for a flight that is greater than the flight capacity for a revenue increase of € 126 million in 2004 (denied boarding costs already deducted) making overbooking not only one of the oldest RM techniques applied by Lufthansa but also one of the most powerful. Like Lufthansa most major American and European airlines overbook their flights above the physical capacity of the aircraft. However, leading low-cost airlines like Ryanair do not overbook their flights and therefore eliminate the possibility of passengers being involuntarily denied boarding as a result of overbooking (Klophaus/Pölt 2005).

There are several ways to calculate and display availabilities in the computer reservation systems. In the beginning, every booking class had its own seat allocation and if the number of bookings had reached this limit, the booking class was sold out. This seat allocation method leads to situations where a high booking class is sold out while a lower booking class is still available. Nesting of booking classes eliminates such illogical situations. In linear nesting there is a linear order of the booking classes and higher nested booking classes have access to the allocations of lower nested booking classes.

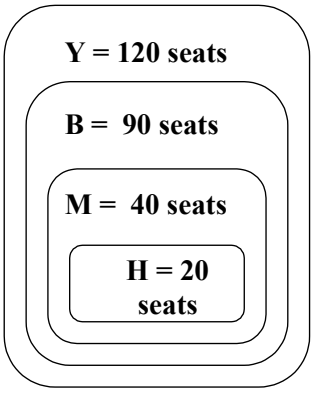


Figure 3. *Nested seat allocation*

In this example, the allocation of highest Y-class contains the allocation of the lower nested B-class. Simulations have shown that with realistic errors in the demand forecasts, linear nesting is the better method and results in revenue gains of 10 per cent and more.

In fare-mix optimization the booking limits are calculated. A popular and robust heuristics to allocate inventory among fare products to maximize profits in the face of uncertain level of demand is expected marginal seat revenue (EMSR) first published in the late eighties.

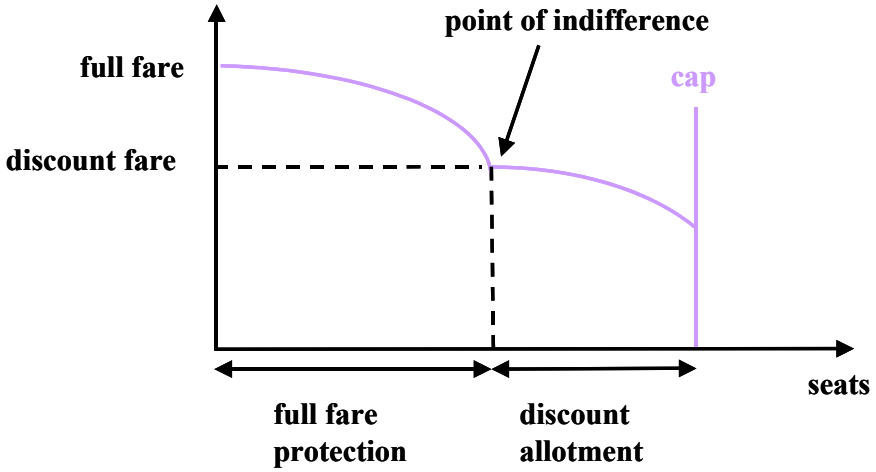


Figure 4. Expected marginal seat revenue (*EMSR)*

For the EMSR heuristic, the probability of each passenger's arrival is calculated from the forecast. The fare level or the average revenue of the booking class leading to the expected marginal seat revenue multiplies the probability. EMSR takes into account the revenue potential of a passenger and the probability of his or her arrival. Figure 4 depicts the basic idea of the EMSR concept. Units of capacity (e.g. seats) are reserved incrementally for customers paying full fare, one at a time, until the expected marginal revenue for the next unit, if protected for a customer in this fare class, is equal to or less than the discount rate.

Leg-based RM methods like EMSR have a disadvantage – they cannot distinguish between one-leg and connecting demand. A connecting passenger gets availability for a booking class if and only if the class is open at both legs. And the optimization of booking class limits is done at both legs independently and separately. Because of the fare structure of airlines two one-leg passengers, one travelling leg 1 and the other travelling leg 2, usually give more revenue than one connecting passenger, while in both cases the same number of seats on the same flights is used. If there is low demand on both legs, the independent optimization of legs does not hurt since every booking request - regardless of one-leg or connecting - should be accepted. If there is low demand at one leg but high demand at the other, connecting passengers should be preferred to one-leg passengers on the bottleneck leg. But, a leg-based RM system cannot distinguish between them. If there is high demand at both legs, two one-leg passengers should be preferred to one connecting passenger of the same booking class. Again, leg-optimization cannot distinguish and accepts within a booking class in a first-come-first-serve order. Another advantage of origin and destination (O&D) inventory control is that it can distinguish different points of sales. For some countries it makes a big difference for the airline at which place the booking was made and in which currency the ticket is paid.

3. PRICING AND BOOKING PROCEDURES AT LOW-COST AIRLINES

The low-cost pricing model radically differs from the pricing approach of network airlines (Fletcher 2003). Traditional pricing includes fences like the fare restriction of a Saturday night or minimum stay to segment travellers according to their willingness to pay different prices for the same product. In addition, each flight is segmented into booking classes, each of which has fare products associated with. The higher fares have fewer restrictions. Further, the fare products may be combined with certain distribution channels to effectively segment the market. The traditional approach to pricing and inventory control is to protect enough seats for higher yielding demand. The resultant seat availabilities are set to get the best mix from a portfolio of fares.

By contrast, in the pure low-cost pricing model, there is no explicit market segmentation. Price versus demand is a continuum although in practice airlines increase fares in steps e.g. € 29, € 39, € 49 etc. The simple pricing problem is how much should the selling price of each flight be at a particular point in the booking period. If the price is too low, the flight will fill up too early meaning higher yielding later booking demand will be turned away. If the price is too high, the flight risks departing with empty seats that otherwise could have been sold.

The low-cost pricing model can be summarized as follows:

- Each flight only has one price available at any point in time;
- One-way pricing, no Saturday night or minimum restriction;
- During the booking period of a flight, prices most likely go up;
- Flights have only one cabin compartment but several booking classes as 'virtual' compartments;
- Removal of advance purchase restriction (Apex rules);
- Bookings are non-refundable but changeable for a fee;
- Most bookings are made through the Internet leading to an increased price transparency.

In consequence, traditional pricing fences of network airlines to segment market are removed. Low-fare pricing can be considered as a synonym for one-way, restriction-free pricing. The only remaining effective segmentation possible is through time of booking and choice of flight. Once the contingent of seats in a lower booking class is sold, the booking class is closed and the one higher booking class becomes available for sales. The basic RM problem is recast from a portfolio mix problem to a price optimization problem.

4. CONSEQUENCES FOR RM

Although pre-conditions to apply RM still hold for low-cost airlines, some of the traditional RM forecasting and optimization techniques are no longer valid under such a pricing model. It becomes difficult to forecast demand. A basic question with regard to demand forecasting is how to derive price elasticity information where only one price is available at any given time. The classic fare mix optimization is also no longer appropriate. The RM problem is now one of how to calculate the optimum fare to charge at any point before flight departure. Network airlines facing low-cost competition which continue to apply traditional RM control techniques may encounter a spiral down effect, i.e., lower demand for higher fare products leads to greater availability of low-fare products resulting in a further decrease in high-fare demand.

Traditional RM assumes market segmentation and fares, which have rules and regulations. Even without RM, there is a mix of passengers owing to fare rules. RM of unrestricted fares is a different issue. The passenger will always buy the lowest fare in the cabin. On off-peak flights with lower seat load factor, demand will always shift to the lowest available booking class. Traditionally, RM controlled only peak flights, as the fare rules ensured some mix of passengers. Now, off-peak flights also need to be controlled at a detailed level. The dilution risk on off-peak flights must be assessed against the potential for volume growth on off-peak flights (Donelly/James/Binnion 2004). The role of RM has been re-defined; the question becomes when to close the current available booking class – after x number of bookings or y days before departure (Donelly/James/Binnion 2004). Calculating when to close a booking class should reflect the level of price elasticity for that flight.

Low-fare RM has to consider that low fares must be visible in the market (e.g. during promotions). Hence, RM assigns a minimal capacity to these fares even on high demand flights. To optimize average revenue, RM needs to find the best time to increase fares on each flight and to force late booking business travellers into high fares (up-selling) even on low demand flights. Further, no nesting of fare classes is required when only one booking class with one fare is available at any point in time and also no origin and destination (O&D) multi-leg seat inventory control due to the point-to-point traffic pattern at low-cost airlines. Optimization boils down to dynamic price optimization instead of getting the best mix from a portfolio of fares. By looking at low-cost airlines and their relatively low no-show rates, network airlines like Lufthansa are prompted to review underlying principles of their own overbooking policy. First, network airlines should pursue ways to better control seat inventory even when travel agents remain the most important sales channel. Second, fare conditions for lower and medium fares are to be reviewed.

5. CONCLUSIONS

In the new business environment revenue gains for airlines from applying RM remain substantial. In addition, pricing, scheduling and RM are still deeply interconnected and a high forecasting accuracy still translates to revenue increases. However, forecasting methods and some basic RM principles like overbooking and the EMSR heuristic need to adapt to the changing airline marketplace. Other inventory control techniques like nested seat allocations or origin and destination (O&D) multi-leg seat inventory control are no longer relevant within the point-to-point traffic pattern of low-cost airlines offering only one booking class with only one available fare at any point during the booking period of a flight.

The low-fare environment asks for new supporting RM forecasting and optimization methods. These are also relevant for network airlines facing low-fare competition and downward pressure on yields.

References

[1] Fletcher S. *Why Revenue Management Is Solving the Wrong Problem in a "Low cost" World*. Mimeo, 2003.

[2] Donelly S., James A., Binnion C. Bmi's Response to the Changing European Airline Marketplace, *Journal of Revenue and Pricing Management*, Vol. 3, 2004, pp. 10-17.

[3] Klophaus R., Pölt S. Overbooking: A sacred cow ripe for slaughter? In: *9th Annual Air Transport Research Society Conference Papers (ATRS, Rio de Janeiro, 3-7 July, 2005). /Air Transport Research Society (ed.).* Rio de Janeiro, 2005.

[4] Klophaus R. Revenue Management: Wie die Airline Ertragswachstum schafft, *absatzwirtschaft - Zeitschrift für Marketing*, Vol. 41, 1998, pp. 146-155.

[5] Koenigsberg O., Muller E., Vilcassim M. J. *EasyJet Airlines: Small, Lean and with Prices that Increase over Time*. Mimeo, 2004.

[6] Pölt S. Revenue Management Tutorial. In: *Presentation at AGIFORS Reservations & Yield Management Study Group.* Berlin, 16-19 April 2002.

[7] Talluri K.T., Van Ryzin G.J. Revenue Management: Research Overview and Prospects, *Transportation Science*, Vol. 33, 1999, pp. 233-256.

[8] Talluri K.T., Van Ryzin G.J. *The Theory and Practice of Revenue Management.* Boston/Dordrecht/ London, 2004.

CREW READINESS INFLUENCE ON NAVIGATION COMPLEX USING EFFICIENCY

Andrey Troyanovsky, Boris Tsilker

Transport and Telecommunication Institute
Lomonosov Str. 1, Riga, LV-1019, Latvia
E-mail: troja@junik.lv; tsilker@tsi.lv

Crew activity at overland flights is coupled to necessity of estimation and compensation of compass system error constant component. Usually this problem is solved by means of positional correction with usage of ground radio means and complex information handling mode (CIH), provided in a base navigational complex (NC). At flight above ocean where corresponding corrective action is impossible, the "residual" constant error in a heading causes linear growth in time of airplane crosses track deviation from the preset path (track). At insufficient efficiency of the CIH mode in NC, CIH functions a qualified operator (navigator) should undertake. Teaching of crews to ways of estimation and compensation of the constant component of compass system error is one of the major elements of navigational training for flights in Northern Atlantic entrusted on flight simulators (FS). Heading error constant component influence on cross-track deviation statistical performances are observed based on assumption that distribution of the heading "residual" errors is DE-distribution. Expressions for a variance of a cross track error are brought. The correction interval relationship with an availability factor of a positional corrector is observed. Requirements to NC modelling in flight simulators are formulated.

Keywords: *navigational complex, complex information handling, flight simulator, cross-track deviation*

As it is known, flight from the Europe through Northern Atlantic assumes air navigation within several hours above the European territory on radials of short-range radio navigation system (VOR radials).

Hard work of crew at overland flights is coupled, in particular, with necessity of estimation and compensation of a constant component of compass system error - for the lack of positional corrections at flight above ocean the constant error in a heading calls linear growth in a time of airplane cross-track deviation from the preset path (rack) [1].

Basically, the problem of an estimation and compensation of compass system error constant component is solved by means of complex information handling mode (CIH), provided in base navigational complex (NC). However at insufficient effectiveness of this mode, the skilled operator (navigator) should undertake CIH function. From here it is clear, that accuracy of this problem solution becomes essentially dependent on preparedness of operator. Teaching of crews to ways of estimation and compensation of compass system error constant component is one of the major elements of navigational preparation for flights in Northern Atlantic entrusted on flight simulators (FS).

As the estimation of the constant component of compass system error is carried out on a background of VOR systematic and random errors, it is clear, that these errors are to be modelled in FS.

At a different degree of crew readiness for compass system error constant component detection different crews will "put out" to Northern Atlantic with different mean square values of "residual" errors $\Delta\psi_0$. Within the limits of one group of crew preparedness we shall pass the normal law of distribution of a residual error, but on the great number of groups with different levels of readiness it is good to think that mean-square values are distributed in accordance with Rayleigh distribution. Then in accordance with Hsu result [2] for universe of crews, including all groups of preparedness, distribution of the heading "residual" errors $\Delta\psi_0$ will be DE distribution. We shall take this distribution for the further calculation.

Reviewing of heading variable component error influence on statistical performances of a cross track error [3] shows, that at an interval of positional correction t, which is essential greater of heading error variable component correlation window τ_κ, there is a normalization (by virtue of integration of lateral velocity) of the corresponding component of a cross track error. At a constant heading error component $\Delta\psi_0$ such normalization has no place ($\tau_\kappa = \infty$) and the distribution law of cross track error at fixed interval of positional correction "repeats" the law of distribution of cross track deviation $y(t)$:

$$y(t) = ct\,, \tag{1}$$

$$c = W\Delta\psi_0 . \quad (2)$$

For a random interval of positional correction t, we shall take the exponential distribution law with parameter λ ($T = \lambda^{-1}$ – mean value of an interval, λ – intensity of positional corrective actions). Considering dominating (at equality of variances of a constant and a variable error components) influence of a heading error constant component on cross track error forming, we shall discover probability density $f(y)$ and variance of a cross track error.

According to (1), for y value, being product of two variates c and t, the probability density $f(y)$ is equal:

$$f(y) = \int_0^\infty \frac{1}{t} f_1(t) f_2\left(\frac{y}{t}\right) dt , \quad (3)$$

where, according to a condition of a problem $\left(\frac{y}{t} = c\right)$, probability densities of c and t variates are equal accordingly:

$$f_1(t) = \lambda e^{-\lambda t} = \frac{1}{T} e^{-\frac{t}{T}} , \quad (4)$$

$$f_2(c) = \frac{1}{2m_c} e^{-\frac{|c|}{m_c}} . \quad (5)$$

In an entry (5) it is considered, that the distribution law of c value at non-random W value (in accordance with (2)) coincides with the distribution law of $\Delta\psi_0$ value (for last the DE distribution was above accepted),

$$m_c = \frac{\sigma_c}{\sqrt{2}} = \frac{W\sigma_\psi}{\sqrt{2}} , \quad (6)$$

where σ_c – mean-square value of c, σ_ψ - root-mean-square value of the "residual" heading error.

Let's substitute (4) and (5) in (3) and we shall calculate an integral

$$f(y) = \frac{1}{2m_c T} \int_0^\infty t^{-1} e^{-\frac{t}{T} - \frac{|y|}{m_c t}} dt , \quad (7)$$

Taking into account, that this integral is a special case of integral [4]

$$\int_0^\infty x^{\alpha-1} e^{-px - \frac{q}{x}} dx = 2\left(\frac{q}{p}\right)^{\frac{\alpha}{2}} K_\alpha(2\sqrt{pq}) \quad (8)$$

at $p = \frac{1}{T}$, $q = \frac{|y|}{m_c}$, $\alpha = 0$, we shall receive

$$f(y) = \frac{1}{m_c T} K_0\left(2\sqrt{\frac{|y|}{m_c T}}\right), \quad (9)$$

where $K_0(x)$ – McDonald's function of a zero order (the modified Bessel's function of 3-rd kind).

Now we shall discover a variance of a cross track error:

$$\sigma_y^2 = \int_{-\infty}^{\infty} y^2 f(y) dy \,. \tag{10}$$

In view of parity of $f(y)$ function:

$$\sigma_y^2 = \frac{2}{m_c T} \int_0^{\infty} y^2 K_0 \left(2 \cdot \sqrt{\frac{|y|}{m_c T}} \right) dy \,. \tag{11}$$

Let's calculate the σ_y^2 value in view of that the integral in (11) is a special case of an integral [4]:

$$\int_0^{\infty} x^{\alpha-1} K_0(bx) dx = 2^{\alpha-2} b^{-\alpha} \Gamma\left(\frac{\alpha+\nu}{2} \right) \Gamma\left(\frac{\alpha-\nu}{2} \right), \tag{12}$$

where $\Gamma(u)$ – gamma function, $b = \frac{2}{\sqrt{m_c T}}$, $x = \sqrt{y}$, $\alpha = 6$, $\nu = 0$.

We shall get:

$$\sigma_y^2 = \left(\frac{\sigma_c T}{\sqrt{2}} \right)^2 \Gamma^2(3) = 2\sigma_c^2 T^2 \,. \tag{13}$$

Let's check up the received outcome by elementary calculations. After squaring of expression (1) and smoothing have:

$$\overline{y^2} = \overline{c^2}\,\overline{t^2} \,.$$

Considering equality $\overline{c^2} = \sigma_c^2$ (the mean of distribution of value c is equal to zero as the mean of distribution of the "residual" heading error is equal to zero), we gain

$$\overline{t^2} = T^2 + \sigma_t^2 = 2T^2 \,. \tag{14}$$

Really, we shall receive (13) – at an entry of equality (14) it is considered that for the exponential distribution low of the variate t its mean of distribution T and root-mean-square deviation σ_t are equal among themselves.

Root-mean-square value of a cross track error according to (13), is equal:

$$\sigma_y = \sqrt{2}\sigma_c T \,. \tag{15}$$

Considering (15) and (6), we shall rewrite outcome (9) in the form of:

$$f(y) = \frac{2}{\sigma_y} K_0 \left(2 \cdot \sqrt{\frac{8|y|}{\sigma_y}} \right). \tag{16}$$

For "tail" areas of distribution (at $\frac{|y|}{\sigma_y} > 2$) we shall take advantage of asymptotic presentation of McDonald function [4]:

$$K_0(x) = \sqrt{\frac{\pi}{2x}} e^{-x} \left[1 - \frac{1}{8x} + \frac{9}{2!(8x)^2} - \frac{9 \bullet 25}{3!(8x)^3} + \ldots \right]. \tag{17}$$

Saving in this representation the first term of a series, we shall receive:

$$f(y) = \frac{2}{\sigma_y}\sqrt{\frac{\pi}{2x}}e^{-x}, \quad x = \sqrt{\frac{8|y|}{\sigma_y}}. \tag{18}$$

Let's consider an example. Let ground speed W = 900 km/h, root-mean-square value of a "residual" heading error σ_ψ = 0,5°, a mean interval of positional correction T = 1 h. Then

$$\sigma_y = \sigma_c T = W\sigma_\psi T = \frac{900 \cdot 0,5 \cdot 1}{57,3} = 7,8 \text{ km}.$$

Such result meets the ICAO minimum navigational requirements (MNR) for accuracy of navigation ($\sigma_y^{\text{MNR}} = 10$ km).

Let's check, whether it is satisfied thus the requirements to reliability of navigation (safety of flight). Considering, that the separation standard in Northern Atlantic S_y = 55,6 km (30 n.m), and assuming in the formula (18) $y = S_y$, we shall gain:

$$x = \sqrt{\frac{8 \cdot 55,6}{7,8}} = 7,55, \quad f(S_y) = \frac{2}{7,8}\sqrt{\frac{\pi}{2 \cdot 7,55}}e^{-7,55} = 2,8 \cdot 10^{-5} \text{ км}^{-1}, \tag{19}$$

while according to MNR

$$f^{\text{MHT}}(S_y) = 1,75 \cdot 10^{-6} \text{ км}^{-1} \tag{20}$$

Now we shall appreciate $f(S_y)$ value at same σ_y (7,8 km) value, when a heading error is variable (is noise-type)). In this case, as it has been pointed above, the cross track error is characterized by a probability density $f(y)$ of DE-distributions. At $y = S_y$ we shall receive:

$$f(S_y) = \frac{1}{\sqrt{2}\sigma_y}e^{-\frac{\sqrt{2}S_y}{\sigma_y}} = \frac{1}{\sqrt{2} \cdot 7,8}e^{-\frac{\sqrt{2} \cdot 55,6}{7,8}} = \frac{1}{\sqrt{2} \cdot 7,8}e^{-10} \approx 0.$$

A similar result turns out at a constant heading error, but non-random value of a correction interval (at same σ_y numerical value). It is clear, that the non-random ("rigid") interval of correction can be ensured only at an availability factor of a positional corrector, equal to one (i.e. at impossibility of temporary failures in activity).

Thus, the constant heading error of a σ_ψ = 0,5°, despite of comprehensible accuracy of navigation (σ_y = 7,8 km), at an exponential distribution low of a random correction interval results in inadmissible safety of flight. Under the same accuracy of a navigation (σ_y = 7,8 km) noise-type heading error practically does not influence upon safety of flight. It means that for tall safety of flight above an ocean solely big importance has teaching of crew to methods of detection and compensation of compass system error constant component at overland flights. From here follows also, that for diminution of a high-tension work of navigator it is necessary to continue activities on improvement of CIH mode in base NC of airplanes, flying above Northern Atlantic (so that the solution of a problem of an estimation and compensation of a constant component heading error to lay to this mode).

References

[1] Молоканов Г.Ф. *Точность и надежность навигации летательных аппаратов*. М.: Машиностроение, 1967. 216 с.

[2] Hsu D.A. Long-Tailed Distribution for Position Errors in Navigation, *Appl. Statist*., Vol. 28, No 1, pp. 62-72.

[3] Рессин А.А., Трояновский А.Д., Цилькер Б.Я. К оценке точности и надежности навигации с учетом коррекций курса и координат, *Изв. Вузов СССР. Приборостроение,* No 5, 1988.

[4] *Справочник по специальным функциям* /Под ред. М. Абрамовица и И. Стиган. М.: Наука, 1979.

INVESTIGATION OF NAVIGATOR'S ACTIVITY ALGORITHMS AS AN INSTRUMENT FOR TEST FLIGHTS NUMBER REDUCING AT THE ESTIMATION OF RELIABILITY OF NAVIGATION

Andrey Troyanovsky, Boris Tsilker

Transport and Telecommunication Institute
Lomonosov Str. 1, Riga, LV-1019, Latvia
E-mail: troja@junik.lv; tsilker@tsi.lv

At sufficient accuracy of modelling, flight simulators allow investigating algorithms of activity of skilled navigator. Knowledge of these algorithms gives a chance to reduce number of the test flights necessary to estimate the reliability of navigation. The aprioristic estimation of navigational complex (NC) conformity to the minimum navigation requirements of the ICAO is usually made by means of analytical methods with use of experimental data. These methods can be effective only at presence of qualitative models of NC functioning, including the navigator, i.e. NC models as ergatic systems of air navigation. Basing on inclusion of the pattern of navigator into flight management system, modelled in flight simulator, the basic algorithms of navigator activity are investigated. It is shown, that the simulator should be such that lacks of navigator could not be «compensated» by lacks of NC modelling. It means that the mandatory condition for replacing a part of the real test flights by simulated flights is modelled of possible refusals and failures in work of radio correction means, and also correct reproduction of workings coverage of radio aids used for correction.

Keywords: *navigation complex, flight simulator, minimum navigation requirements, reliability of navigation, correction*

Flight simulators at sufficient accuracy of flight modelling allow investigating algorithms of activity of skilled navigator. Knowledge of these algorithms enables to reduce number of test flights for estimation of reliability of navigation [1]. To confirm it we shall examine the scheme of inclusion of navigator in an air simulator modelled flight management system (FMS) (Fig. 1).

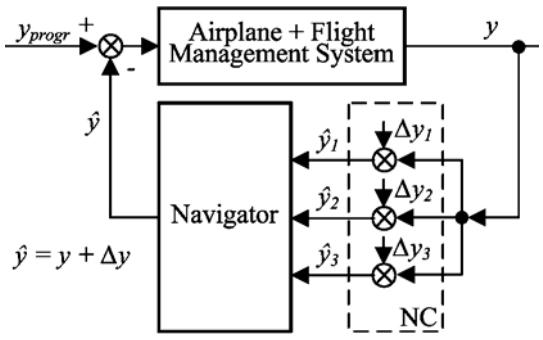


Figure 1. *Scheme of actuation of the navigator in trajectory control system*

Navigator, observing indications $\hat{y}_1$, $\hat{y}_2$, ..., $\hat{y}_N$ of navigation systems included in navigation complex (NC), produces an estimation $\hat{y}$ of the navigation parameter y.

If $\hat{y}_1$, $\hat{y}_2$, $\hat{y}_3$ are cross track deviations from the route axis calculated under indications of various systems of NC, then $\hat{y}$ is an estimation of cross track deviation according to these systems, made by the navigator and entered by him in flight management system.

Notation Δy_i on a Fig. 1 (the case of three navigation systems is examined: i = 1, 2, 3) is used for errors of estimations of cross track deviation, obtained by means of NC, but Δy – an error of estimation by the navigator of real airplane evasion on y_1, y_2, y_3 signals.

Let the probability of that cross track error of an airplane from the axis of route exceeds prescribed value y_0, is equal $P_{OUT} = P(|\Delta y| > \Delta y_0)$, but the probability of that cross track error, calculated from data of the i^{th} system of navigation complex, exceeds Δy_0 value, is equal $P_{INi} = P_i(|\Delta y| > \Delta y_0)$. The skilled navigator acts in such a manner that $P_{OUT} < P_{INi}$.

On the majority of airways maximum permissible value P_{OUT} is 0,05, i.e. is required, that airplanes with probability 0,95 did not evade from the axis of a route on distance, greater, than Δy_0, which depends on that, is provided (or not) the constant radar monitoring over flight of an airplane. At flights on parallel tracks over the North Atlantic all turbojet airplanes should meet the minimum navigation requirements (MNR) [2], [3] of the International Civil Aviation Organization (ICAO). According to modern MNR the maximum permissible value of the standard deviation from the axis of a route should be no more value σ_{MNR} = 5,8 km (first criterion of MNR). Maximum permissible value of probability of flight outside ±27,7 km from axes of tracks of North Atlantic should be no more value $P_{MNR} = 2{,}6 \cdot 10^{-4}$ (second criterion of MNR). In practice of air navigation monitoring of frequency of greater navigational errors is conducted with application of a method of sequential analysis [4].

At designing of new NC the compressed terms of tests do not allow certifying NC on probabilistic criteria because of trifle of P_{MNR} values (it must be confirmed that actual values of the estimated probabilities at confidence probability 0,95 will not exceed the values *of* P_{MNR} twice [4], therefore at aprioristic estimation of conformity of navigation complexes to the minimum navigation requirements are applied analytical methods with the use of experimental data [5]). Analytical methods can be effective only at presence of qualitative models of NC functioning, including the navigator, i.e. NC models as air navigation ergatic systems [1], [4]. Earlier it was noted that skilled navigator acts in such a manner that $P_{OUT} < P_{INi}$. It means, that the probability of big "output" errors of navigator Δy is less then the probability of greater "input" errors Δy_i (Fig. 1).

It is clear, that sufficiently accurate estimation of P_{OUT} value with high (0,95) confidence probability at P_{OUT} values about 10^{-4} requires too big number of test flights. At the same time, the P_{INi} probability, being greater (often on two orders), demands smaller number of expensive test flights. However, knowledge of P_{INi} values does not allow predicting the P_{OUT} value without knowledge of algorithm of navigator activity.

In [6], [7], it becomes firmly established that an experienced navigator at measuring of one navigation parameter by three systems widely uses algorithm of a secondary median. In this case

$$P_{OUT} = \frac{1}{2}(P_{IN1}P_{IN2} + P_{IN2}P_{IN3} + P_{IN1}P_{IN3} - P_{IN1}P_{IN2}P_{IN3}) \quad (1)$$

If all three systems are identical, for example, triplex inertial navigation system (INS), then $P_{IN1} = P_{IN2} = P_{IN3}$, and as these probabilities considerably less than 1, we can consider that approximately

$$P_{OUT} = 1{,}5P_{IN1}^2 . \quad (2)$$

At P_{IN1} = 0,01 from (2) we have $P_{OUT} = 1{,}5 \cdot 10^{-4}$. It is obvious, that estimation of value of the order 0,01 will demand considerably smaller number of test flights, that value of size of $P_{OUT} = 1{,}5 \cdot 10^{-4}$.

Another way of activity of the navigator, providing small value of P_{OUT} also is possible. It is INS or on the base of compass system and Doppler radar built dead reckoning system (DRS) correction according to data of the radio navigation systems.

Let's consider the case of radio correction of the DRS system. It will allow analysing some features of the statistical situation, related to the radio correction and on the basis of this analysis to formulate one of important principles of construction of imitators.

As it is known, navigational training of the operator intends mastering of methods of both recognition of constant components of instrumental errors during the flight, and of inputting of corresponding correction in navigation systems. In the case of the DRS navigator should be able to reveal a constant component of directional gyroscope drift and compensate its influence by inputting of necessary amendment via latitudinal correction desk of compass system.

Suppose that uncompensated component of care rate on great number of flights is random value, having the two-sided exponential distribution with zero average of distribution and mean square value, equal to σ_ω. Then at correction of cross track error through intervals of time, not greater than T, probability of flight outside $\pm\Delta y_0$ from an axis of route will not exceed

$$P_{вых} = e^{-\frac{\sqrt{2}\Delta y_0}{\sigma_y}}, \quad (3)$$

$$\sigma_y = \sigma_\omega W \frac{T^2}{2}, \quad (4)$$

where W – cruising speed, σ_y – mean square value of cross track error.

At σ_ω = 0,4 °/h; W = 900 km/h; T = 1 h we shall receive: σ_y = 3,15 km; P_{OUT} = 6,210^{-7}, i.e. airplane overrun of ±27,7 km from the route base line at such frequent correction of cross track error is practically impossible.

The received result is trivial enough: absolute reliability of the radio correction, allowed to conduct corrections of cross track error with an interval of time less than T, has "compensated" insufficient qualification of the navigator. Now we shall change conditions concerning capabilities of cross error correction. Let now assume that T is a mean interval of correction, i.e. are possible both smaller and larger intervals of correction, the last – due to possible failures of correction at an unfavourable navigation situation or because of refusals of corrector.

Now let's suppose that the random interval of correction is the Rayleigh random value with the mean of distribution, equal to T. We shall get:

$$P_{OUT} = dK_1(d), \tag{5}$$

$$\text{where } \sigma_y = \frac{\sqrt{8}}{\pi}\sigma_\omega W T^2; \quad d = \sqrt{\frac{8\Delta y_0}{\sigma_y}}, \tag{6}$$

$K1(d)$ – McDonald's function of the first order.

In view of the known asymptotic representation of function $K1(d)$ for great values of d (at $d > 4$) from (5) approximately follows:

$$P_{OUT} = \sqrt{\frac{\pi d}{2}}e^{-d}. \tag{7}$$

At the same, as earlier values of parameters, entering in (6), we shall receive: σ_y = 5,65 km; P_{OUT} = 6·10^{-3}. Apparently, results on accuracy in both cases satisfy MNR (σ_{MNR} = 5,8 km). On reliability results are absolutely various: in the first case *of* $P_{OUT} \approx 0$, i.e. not taking into account the unreliability of correction has led to practically absolute reliability of navigation. In the second case reliability of navigation has appeared as inadmissible low – probability P_{OUT} is on the order below minimum requirements (P_{OUT} = 2,6·10^{-4}).

From this it is clear – an air simulator should be such that lacks of navigator could not be "compensated" by lacks of NC modelling [8]. With reference to the case considered above it means that in flight simulator it is necessary to model possible refusals and failures in radio correction as well as correct workings areas of radio means. At observance of these conditions flight simulators will allow to investigate ways of skilled navigator actions and to form a databank, describing the "group portrait" of the navigator.

References

[1] Козарук В.В., Ребо Я.Ю. *Навигационные эргатические комплексы самолетов.* М.: Машиностроение, 1986. 286 с.

[2] *Guidance and Information Material Concerning Air Navigation in the North Atlantic Region*. ICAO European and North Atlantic Office, 7th ed., 2002.

[3] *North Atlantic International General Aviation Operations Manual* – 3rd edition, V 2.1, 2004.

[4] Hazelrig G.A., Bush A.C. Setting Navigational Performance Standards for Aircraft Flying Over the Oceans, *Transp Rev – A,* Vol. 20A, No5, 1986, pp. 373-383.

[5] Белевцев В.П., Введенский А.В., Стулов А.В. Применение средств дальней навигации для обеспечения полетов в регионе Северной Атлантики. В кн.: *Безопасность полетов и профилактика авиационных происшествий: Тезисы докладов 5-ой Всесоюзной научно-практической конференции по безопасности полетов*, 1988.

[6] *Воздушная навигация: справочник* /Белкин А.М., Миронов Н.Ф., Рублев Ю.И., Сарайский. М.: Транспорт, 1988. 303 с.

[7] Сарайский Ю.Н. Алгоритмы устойчивого оценивания для контроля пути экипажем. В кн.: *Безопасность полетов и профилактика авиационных происшествий. Тезисы докладов 5-ой Всесоюзной научно-практической конференции по безопасности полетов,* 1988.

[8] Dillard A.E. Validation of Advanced Flight Simulators for Operational Evaluation and Training Programs, *FAA, Simulation Engineering,* AFS 408, 2002.

THE ANALYSIS OF THE COMMERCIAL SECTOR OF LITHUANIA AVIATION

Jonas Lazauskas

Vilnius Gediminas Technical University,
Department of Transport Management
Plytinės Str. 27, LT-2016, Vilnius, Lithuania
Ph: (+370) 52744780. E-mail: jonlaz@ti.vtu.lt

The article deals with the commercial sector of Lithuanian aviation. It is a constituent part of Lithuanian economy that is open to novelties in the spheres of science and technologies; it does not require much stock and has qualified specialists.
This article examines the particularities of the companies that provide transportation service, their interrelationship, the division of traffic flows according to the airlines companies, the routes of the airlines companies and parks for their planes. The data is compared with Latvian national airlines "Air Baltic" and Estonian State Airlines "Estonian Air". Attention is paid to the situation of Lithuanian airports and landing-fields, moreover the rates of Lithuanian, Middle and Eastern Europe airports are being analysed, as well as the demand for aviation specialists in Lithuania in the years 2004-2009.

Keywords: *air transport, airlines companies, carriers of passengers, freight carriers, traffic flows, airport*

INTRODUCTION

Lithuanian civil aviation sector is an integral part of the Lithuanian economy, which is open to scientific and technical innovations, is rather cost-effective, and has qualified specialists. One of the best aviation infrastructures in the Baltic States is founded in Lithuania with considerable experience in aircraft construction and production.

The major aim of the civil aviation sector is providing passenger carrying and cargo transportation services. The production is directly influenced by the following factors: 1) industrial enterprises producing mechanical systems, engines, computers, electronics, software, materials, and chemicals for aviation; 2) state regulatory institutions issuing laws and regulatory acts, aviation administration, customs, borders; 3) services covering insurance, leasing, telecommunications, technical maintenance of airplanes, supply of fuel and oils, passenger catering; 4) infrastructure covering international airports, other airports, aerodromes, air space control; 5) air transport covering the largest airlines, regional airlines, low cost airlines, charter airlines, cargo airlines and small aviation.

The buyers of air transport sector products, i.e. passengers and cargo senders, also have impact on the activity of other economic sectors. Passengers in their turn are using trains, car rent, parking lots, hotels, restaurants, retail trade, travel agencies, financial services and cargo senders/consignees are using forwarding, carrying, storage, travel agencies, and posting services.

PASSENGER AND CARGO CARRIERS

As at 1 January 2004, ten airlines were registered in Lithuania providing regular and irregular commercial passenger carrying services. These were: the airline AB Lietuvos Avialinijos (Lithuanian Airlines LAL), AB Aviakompanija Lietuva, UAB Aptatas, UAB Aviavilsa, UAB Klaipėdos Avialinijos, UAB Transviabaltika, UAB Aurela, UAB Aviapaslauga, UAB Gintarinės Avialinijos, and UAB Danų Oro Transportas (Danish Air). These air carriers were providing flights by 31 aircrafts. For better understanding of the current situation, each of the companies should be reviewed individually.

The Lithuanian Airlines (LAL) is a national air carrier of the Republic of Lithuania. 100% of the company's authorised capital is owned by the Republic of Lithuania represented by the State Property Fund The Lithuanian Airlines was established in September 1991. The airline is being a member of the International Air Transport Association (IATA) since 1992 and of the European Regions Airline Association (ERA) since 1995. Its core activity is focused on regular air transport services. In 2003, the company had four subsidiaries:

- Airline Lietuva (LAL holds 100 % shares);
- Cargo terminal Lithuanian Airlines CARGO (LAL holds 100 % shares);
- Joint Lithuanian-Danish Company Aero-Chef-LAL (LAL holds 50.8 % shares);
- Travel organisers Aviaturas ir Partneriai (LAL holds 52 % shares).

The airline LAL has signed agreements on common routes with KLM, SN- Brussels Airlines, Finnair, Iberia, CSA Czech Airlines, and LOT Polish Airlines for flights to Amsterdam, Brussels, Helsinki, Prague, and Warsaw.

In 2003, the fleet of the airline LAL consisted of 7 airplanes of two types: Boeing 737 and SAAB-2000. The 5-year rent agreement was signed for two airplanes Boeing 737-500. These airplanes changed the before used Boeing 737-300, which belong to 2nd noise category, therefore their exploitation is forbidden in Lithuania since 2005.

In 2000, the airline LAL changed its business strategy and at the moment is developing routes with business passengers dominating and is refusing the routes taking less than 5 flights per week. In 2004, LAL was offering regular flights to the following cities: Kiev, Amsterdam, London, Frankfurt, Moscow, Helsinki, Copenhagen, Stockholm, Paris, Brussels, Berlin, and Tallinn. In 2003, the flight to Paris was cancelled due to the low number of passengers. In 2003 the number of flights to Amsterdam was increased from 10 to 13 and to London from 7 to 10. In London LAL changed Heathrow airport for Gatwick since the airport service costs are lower than those in Heathrow.

The increasing number of passengers for flights to Amsterdam was conditioned by the common code agreement signed between LAL and KLM airlines, which ensured convenient junctions, coordinated prices and schedules. Similar reasons influenced the increase in number of passengers flying to London. LAL refused flights "from point to point" and is focusing on the routes offering good junctions from the largest European airports. In flights to Amsterdam and London, unlike in flights to e.g. Frankfurt and Copenhagen, LAL is the only airline to tale flights to these cities from Vilnius.

The Technical Department of Lietuvos Avialinijos is certified according to JAR-145 standards. In 2003, LAL signed an agreement with the French airline Regionai on periodical C-check of airplanes Saab 2000 and with Air Botnia, a subsidiary of SAS, on periodical C-check of airplanes Saab 340a. These agreements enable efficient and periodical C0checks of airplanes registered in EU and open the possibilities for air transport development and higher profit seeking.

In 2003, LAL held 42% of flights in Vilnius airport passenger market. Compared to 2002, LAL market share reduced by 4%. The market share changes resulted from the following factors:

- New carriers on the market (Czech Airlines, flying to Vilnius since 2001);
- Change of the airlines flights frequency and volumes;
- External factors: global economic and political tendencies;
- Communication between the airlines.

LAL holds about 46 % of the market share in Lithuania.

The main LAL competitors in the Lithuanian market are the following: SAS, Lufthansa, Austrian Airlines, Finnair, Estonian Air, Air Baltic, Czech Airlines. Most of these airlines are members of large alliances. SAS, Lufthansa, Austrian Airlines belong to Star alliance, Finnair belongs to One-world alliance, Czech Airlines to Skyteam, LOT to Qualiflyer (however this alliance collapsed due to financial problems of its main members and LOT are negotiating for partnership with Star alliance).

Traffic flows distribution by airlines in 2004 is shown in Figure 1 below.

As of 1997, the shareholder of Aviakompanija Lietuva is the national AB Lietuvos Avialinijos, whose shares are owned by the republic of Lithuania represented by the Ministry of Transport and Communications and the State Property Fund.

The aircraft fleet of the company Aviakompanija Lietuva consists of two planes: ATR 42-300 of 1986 make and Lear-jet 55.

Following the agreement with TNT UAB Apatas, the company Aviakompanija Lietuva daily carries cargos by the route Kaunas–Malmė and Kaunas–Ryga. The company also carries UPS cargos UPS to Warsaw and Minsk five times per week. The fleet of UAB Apatas consists of one airplane L410 UVP, four airplanes L410 UVPE, one – CESSNA-421 and one – Lear-jet 55.

UAB Aviavilsa has two Antonov type airplanes AN-26. The company carries DHL consignments under the agreement with UAB DHL International Lietuva.

UAB Aurela offers charter flights by airplanes Jak-42. The main clients are the Lithuanian travel agencies Omnituras and Tez Tours. In 2004, the company started exploiting the airplane Boeing 737-500.

UAB Klaipėdos Avialinijos has a fleet of eight AN-2, one KA-26 and one Pipe140-28 type airplanes. UAB Klaipėdos Avialinijos offers charter flights to Gdansk, Stockholm, Gothland, Bornholm Islands, and Southern Sweden. Nearly fifty per cent of the company's income is received from airplanes repairs and technical maintenance. The company is also engaged in specific aviation: sea and shore intelligence, forest spray by bacteriological preparations. In 2003, the company rented the airplane Panteravią P-68 and is offering air-taxi services. In 2002, the turnover amounted to about one million litas.

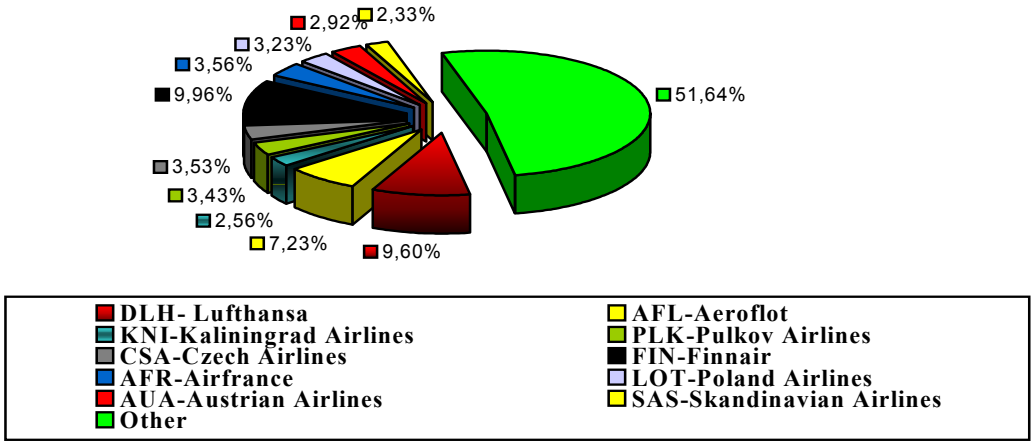


Figure 1. *Traffic flows distribution by airlines in 2004*

Foreign airlines offer flights to Vilnius and Palanga airports. In 2003, regular flights to Vilnius airports were organised by 9 foreign airlines: SAS, Lufthansa, Austrian Airlines, Finnair, Estonian Air, Air Baltic, CSA Czech Airlines, LOT, and Aeroflot. The Swedish Swedline and Direktflyg were flying to Palanga airport on a regular basis.

In order to better understand the situation of the Lithuanian national airline in the European context we must compare the economic ratios of the company with those of other countries' airlines. It would be advisable to make a comparison with airlines of the nearest neighbours of the Republic of Lithuania in Latvia and Estonia since the geographic and economic situation in these countries is similar.

The national Latvian airline Air Baltic was established in 1995. At the moment the Latvian government holds 52.6% of the company's shares, and 47.2% shares are controlled by Scandinavian Airlines/SAS. Air Baltic is flying from Riga to 15 cities: Amsterdam, Berlin, Copenhagen, Brussels, Hamburg, Helsinki, Kiev, Minsk, Moscow, Stockholm, Tallinn, Vienna, Vilnius, Warsaw, and Prague. Air Baltic together with the strategic partner SAS offers common-code flights. This allows offering a big number of junctions and optimising the passenger flows in the routes. In 2003, the company carried 347,966 passengers. The fleet consisted of one Boeing 737-500, three AVRO RJ 70, and five FOKKER 50 airplanes. The airline is based in Riga airport. In 2002, the company's income stood at 28.6 million lats (163.02 million litas).

The national Estonian company Estijos Air was established in 1991, and in 1996 it was privatised. The state kept 34% shares, while Maers Air together with Cresco Ltd subscribed for 66% shares. In September 2003, SAS announced about purchasing of 49% shares from Maers Air. In 2002, the company carried 297,900 passengers and its income amounted to 854,387 Estonian krones (187,965 litas). In 2003, Estijos Air offered direct flights to twelve cities: Stockholm, Copenhagen, London, Frankfurt, Hamburg, Kiev, Moscow, Vilnius, Paris, Oslo, Berlin, and Amsterdam. The company's fleet has four Boeing 737-500 airplanes.

AIRPORTS AND AERODROMES

In Lithuania there are 25 civil airports. At the moment four international airports are operating in the country: Vilnius, Kaunas, Palanga and Šiauliai airports. Vilniuus, Kaunas, Palanga airports are state-owned companies, while Šiauliai airport is operating as a joint-stock company whose shareholders

Šiauliai City Municipality and the Ministry of Transport and Communications of the Republic of Lithuania. There are also five state aerodromes and 14 aerodromes belonging to aero clubs as well as one municipality owned aerodrome and five private aerodromes.

The annual capacity of Vilnius airport is 1,500,000 passengers and 20,000 tons of cargo. It is a member of the Airports Council International (ACI) and since 1993 – member of the European Airports Association. The airport is granted ICAO category.

Vilnius airport is the largest airport in Lithuania and the Baltic States, however compared to other Middle and East European states the passenger turnover is one of the lowest among the airports of capital cities.

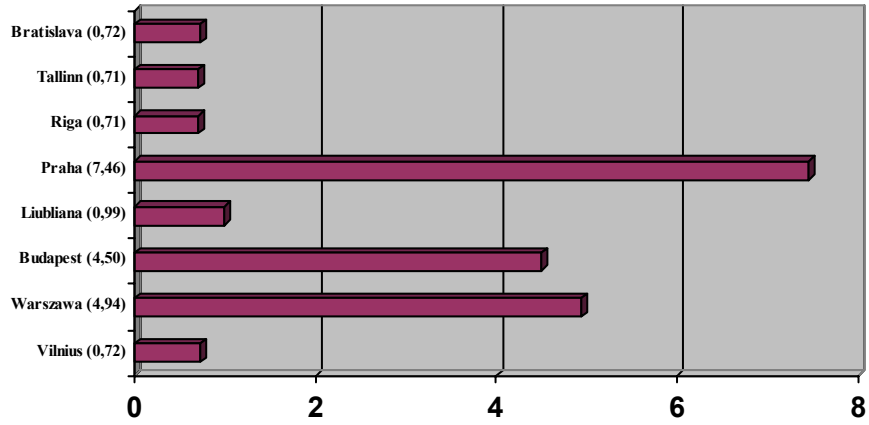


Figure 2. *Number of passengers serviced in Middle and East European airports in 2003 (in million passengers)*

The fleet of AB Lietuvos Avialinijos is based in Vilnius airport as well as the representative offices of twelve foreign airlines. Vilnius airport is constantly reconstructed and renewed to enable higher throughput of passengers and cargo, accept all types of aircrafts without any weight limitations. At the moment the following reconstruction works are in process and planned: extending and renewing of the arrival hall which is to be completed by 2005; prolonging of the current 2.5 km runway up to 3 km; reconstruction of the passenger terminal and the ground.

Kaunas international airport started operating in 1988. Kaunas is capable to serve 500,000 passengers and carry 20,000 tons of cargo per year. Kaunas international airport is located near the transport corridor junction. Two international highways intersect Kaunas: Via Baltica (Helsinki–Tallinn–Kaunas–Warsaw–Athenes) and highway Klaipėda–Kaunas–Minsk–Moscow. Two important railway lines also cross near Kaunas: St. Petersburg–Tallinn–Riga–Kaunas–Šeštokai–Warsaw and Kaliningrad–Kaunas–Vilnius–Minsk–Moscow. The Lithuanian General Territory Plan approved by the Parliament on 29 October 2002 provides that Rail Baltica of the European standard railway (ESG) must cross Kaunas HES, Palemonas and Karmėlava. The Rail Baltica is on the list of EU priority projects. The construction should be completed by 2016, and the segment to Kaunas – by 2010. The construction of inter-modal terminal is planned in eastern Kaunas (Palemonas), while Kaunas airport is planning a second runway.

Kaunas airport receives most of its income from cargo servicing. According to the preliminary data, in 2003 the turnover of Kaunas airport was 5.5 million litas. Kaunas airport has invested 4.5 million litas in the nearly constructed emergency service and the new fire station. In 2006, reconstruction of the passenger terminal and aerodrome perimeter fencing is planned. In 2006-2007 the alarm light system will be installed, the perimeter will be extended, and in 2004-2020 the noise control system will be installed. By 1 January 2005, the airport is still permitted to accept airplanes non-complying with the EU noise standards.

Palanga international airport is located near the sea, 7 km off Palanga resort, 28 km off Klaipėda seaport and is not far from the international highway Kaliningrad–Liepoja. The annual capacity of Palanga airport is 200,000 passengers and 2,000 tons of cargo.

The main passenger flow in Palanga airport comes from Scandinavia and Northern Germany; in winter season 27 regular flights are organised, while in summer season – 45 flights. Palanga airport is

included in the Transport Investment Needs Assessment Programme (TINA). In 1997, the passenger terminal was reconstructed as well as the flight control centre, and the runway cover was renewed. The runway, passengers' terminal and equipment will be modernised. During the Soviet occupation period a maintenance and repairs company servicing military force airplanes and Zokniai military aerodrome were established in Šiauliai international airport. In 1993, the last Soviet fighter aircrafts left Šiauliai airport. For reconstruction of the airport a loan of 29 million US dollars was taken from England's Midland Bank under the state guarantee. After Philips carried out technical reconstruction, the airport was granted ICAO first category. The plan was to establish Šiaulių Free Economic Zone but the idea failed; therefore the perspectives of Šiauliai airport became complicated. Companies like Lufthansa, Wiggins Group and Swedish entrepreneurs were interested in the airport but there were no investors. The main advantage of the airport located 12 km off the city of Šiauliai is the longest runway in Lithuania, which allows accepting all types of aircraft without any weight limitations. The runway is 45 m wide and the airport has the annual capacity for 100,000 passengers and 20,000 tons of cargo. However, since 1 January 2004, the airport is not permitted to accept airplanes of Russian non-complying with the EU noise standards. This way Šiauliai airport lost its major customers: airlines exploiting airplanes non-complying with the noise standards. Upon accession of Lithuania in NATO, the military force airplanes and servicing officers of the organisation were dislocated in Šiauliai airport. Unlike in other Baltic States, a unique airport structure was formed in Lithuania consisting of four international airports. Investments in the airport development are divided, although it would be most rational to target them in one direction. However, such situation in Lithuania remains from the Soviet times when Estonians and Latvians managed to transfer airports from their capital cities but Lithuania did the opposite thing. Airports are one of the main factors for attracting new investments. Industrial and commercial companies prefer regions with well-developed air transport system in coordination with efficient passenger and railway transport infrastructure. The research in the EU states showed that the airport itself, besides secondary investment attracting, has a direct positive impact on the local economy development. Each million of passengers serviced in the airport during a year creates about 1,500 additional jobs.

AIR NAVIGATION AND TRAINING ESTABLISHMENTS

Every country provides air navigation services in the air space over its own territory, i.e. different air traffic control technologies are used, flight routes are inconvenient, and problems arise in crossing the state borders.

With intensifying air traffic, the European air traffic service system is starting to strand. Due to delayed flights, airlines annually incur losses of about 1.5 million euro. Besides, dividing it in separate segments does not efficiently use the current air space. Therefore, the airlines and other air space users together need a totally changed attitude towards providing of air navigation services. The Eurocontrol (European Organisation for the Safety of Air Navigation) and other international organisations took the initiative to solve the problem. This way the idea of "Common European Sky" started providing for developing of the common air space, uniform flight control standards and procedures. The number of flights carried out in the Lithuanian air space in 1999-2004 is shown in Figure 3.

Upon accession of Lithuania to the European Union, the legal acts related with air navigation became binding to our country. Lithuania is preparing for implementation of the "uniform sky" project, which is developed generally by the specialists of Civil Aviation Administration, State Enterprise Air Navigation as well as other companies and institutions. According to the preliminary calculations, the future reform will require considerable investments. We will have to reorganise the country's air traffic service system, modernise the control, communications and surveillance devices, implement the air traffic service quality and security management systems, and prepare the flight guidelines following the new European standards.

Aiming to integrate in the common European Union sky, in 2001 Lithuania established a state enterprise Oro Navigacija (Air Navigation) and a budget institution Civil Aviation Administration. In 2003, the sales and services of the company Oro Navigacija amounted to 44.56 million litas, where 98.1% of income was received for the airport and air navigation services, and 86% of all inflows were income from navigation of foreign airlines' planes, 14% – from navigation of Lithuanian airlines' aircrafts.

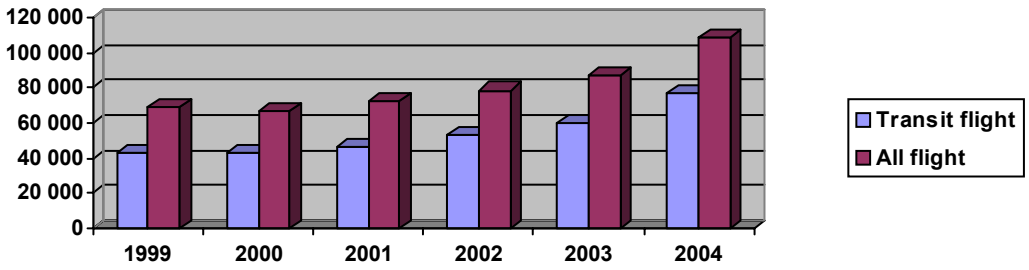


Figure 3. *Number of flights in the Lithuanian air space in 1999–2004*

Aiming to integrate in the common European Union sky, in 2001 Lithuania established a state enterprise Oro Navigacija (Air Navigation) and a budget institution Civil Aviation Administration. In 2003, the sales and services of the company Oro Navigacija amounted to 44.56 million litas, where 98.1% of income was received for the airport and air navigation services, and 86% of all inflows were income from navigation of foreign airlines' planes, 14% - from navigation of Lithuanian airlines' aircrafts.

In 2003, income for the air navigation of foreign airlines' aircrafts (transit) made up 81% of the total income. In 2003, the main transit foreign airlines by income were Lufthansa (Germany), Aeroflot (Russia), Finnair (Finland), Air France (France), SAS (Sweden).

Before membership of Lithuania in the European Union, the specialists of the Lithuanian Civil Aviation Administration and French Civil Aviation together were implementing the Twinning project for a year financed by the European Union. The French experts introduced the implementation practice of the main JAA standards to the Lithuanian aviation specialists basing on this project. Following the approved program, seminars were organised analysing the issues of assessment of civil aviation carriers, personnel, certified designing, production and technical maintenance organisations as well as aircraft compliance and other issues.

It was decided to continue cooperation after the Twinning project was completed. The issues were discussed related with the possibility to prepare specialists in the aviation institute named after A.Gustaitis, air traffic control, assessment procedures for aerodromes and airports, disaster management, preparing of flight managers, and improving of flight security management system in providing air traffic services.

Further cooperation will be continued according to the Twining Light project, which is estimated to cost 250 thousand euro in total. In case the European Commission approves the project, the French General Civil Aviation Direction will also support Lithuania in implementation of other important projects. One of these would be the improvement of standards and procedures for performance assessment of the state enterprise Oro Navigacija following the newly approved directives of the European Parliament.

In Lithuania civil aviation specialists are prepared (re-qualified) in over 20 aviation-training establishments. The largest of them is the Aviation Institute named after Antanas Gustaitis under Vilnius Gedimino Technical University, which prepares flight managers and pilots. The Transport Engineering Department in the Mechanics Faculty of Kaunas Technology University prepares aviation engineers. Other training establishments are operating in airlines, technical service organisations, and aero-clubs. Several independent aviation schools and training centres were established, which are successfully developing their activities.

The Aviation Institute named after Antanas Gustaitis under Vilnius Gedimino Technical University (hereinafter - AGAI) prepares flight managers and pilots. This education institution was established in 1993. At the moment AGAI is preparing specialist according to the following programs: aircraft piloting, aviation mechanics, aviation electronics, aviation electronics devices, and aviation business management. The programs comply with ICAO and JAA standards. The training base of the institute include two flight simulators, 10 training planes CESSNA, one flight control tower simulator, access and air space control trainer as well as other equipment, laboratory premises. AGAI is also using Kyviškių flying base. Since 1993 the institute has prepared 324 specialists, of

which 200 are or were employed in the Lithuanian aviation structures. The training centre at the institute has been operating since 2001, which has organised courses for 350 aviation specialists.

Table 1. The Need for Aviation Specialists in 2004-2009

Training program	Pessimistic variant		Most probable variant		Optimistic variant	
	Need	Need considering wastage	Need	Need considering wastage	Need	Need considering wastage
Flights aircrafts	5	8	10	15	13	20
Piloting management	4	6	7	10	14	28
Aviation mechanics, Electronics, automation	11	23	15	35	18	45

The tariffs of aviation specialists in Lithuania are 2-3 times lower than in West Europe and 3-4 times lower than in Canada and USA.

Vilnius Transport College prepares specialists of aircrafts and engines using and production technology and passenger service in airports. Kaunas Technology University, Mechanics Faculty prepares aviation engineers-mechanics. The training centre of Lietuvos Avialinijos prepares pilots qualifying for Boeing and SAAB type aircrafts; technicians/engineers for servicing of the aforementioned airplanes, flight attendants and other specialists required by the company. The airline Lietuva re-qualifies pilots to fly by plane ATR 42-300. UAB Klaipėdos Avialinijos prepares amateur pilots and re-qualifies pilots to fly by planes AN-2 and AN-28. Technical staff to repair helicopters is re-qualified at UAB Aviabaltika and UAB Helisota. Pilots and technical staff are also re-qualified by UAB Termika, UAB Nerka, and UAB Apatas. Air clubs of Alytus, Biržai, Kaunas, Jurbarkas, Panevėžys, Šiauliai, and Vilnius; Klaipėda gliding club and Flying School of Vytautas Lapėnas prepare amateur pilots. The Aeronautics Centre, Vilnius Aeronautics School prepares aerostat pilots.

CONCLUSIONS

1. The Lithuanian passenger flights leader LAL last year increased the number of passengers by 2.54 per cent up to 312 thousand persons. Seeking to ensure profitability, this year the company is planning to develop important marketing and IT projects aiming at adopting elements characteristic of the so-called low-cost airlines.

2. On the international level the main two national passenger carriers are rather small therefore they were merged. However, the exploitation ratios are still not totally satisfactory. The fleet capacity is not sufficiently used, i.e. the load ratios are low in the sense of both local and international carryings compared to the carriers of West Europe or East and Middle Europe countries. The situation is saved by subsidies.

3. In Lithuania much more aviation specialists are prepared than it is in the country, however the need for aviation specialists in other countries is rather high, therefore high qualification specialists are popular and can easily find employment in foreign airlines. Upon accession of Lithuania in the European Union and harmonising the qualification requirements for aviation specialists, new professional possibilities in the European Union region are opened for Lithuanian aviation graduates.

References

[1] Global airport and airline news, *Airports International „IATA Superdock“*, No8, 2003 October.
[2] Global airport and airline news, *Airports International „Virtual Airports“,* No6, 2003 August.
[3] *White Paper. European Transport Policy for 2010: time to decide*. EU, 2002.
[4] Doganis R. *Flying off Course*. Routledge, 1991.
[5] www.caa.lt
[6] http://www.std.lt
[7] http://www.lal.lt
[8] http://www.riga-airport.com
[9] www.transp.lt

CONFERENCE AUTHORS INDEX

Batarliene N.	144	Krasts Ju.	66
Baublys A.	254	Kundler J.	125
Bazaras D.	232, 390	Labendik V.	287, 304
Berezhnoy A. V.	484	Labeyev V.	520
Berzins G.	60	Latkov A.	442
Bogdevicius M.	110, 342	Lazauskas J.	196
Butkevičius J.	149	Lingaitienė O.	92, 267
Demidovs V.	165	Lingaitis V.	92, 267
Dziubiński M.	318	Litvinenko M.	240
Feofanov V.	515	Lvovich D.	428
Gertsbakh I.	21	Lyumkis V.	428
Grabarnik G.	295	Medvedev A.	386, 515
Grakovski A.	350	Meidute I.	271, 364
Greenglaz L.	28	Michlin Y. H.	295
Greenstein B.	309	Misnevs B.	70
Griskeviciene D.	375	Nechval K. N.	11, 16, 44
Griskevicius A.	375	Nechval N. A.	11, 44, 60, 66
Iscenko A.	529	Niewczas A.	312
Isoraite M.	245	Nikolsky V.	529
Jarasuniene A.	276, 382	Nowak M.	85
Jaržemskis A.	227	Odnakish N.	350
Jonaitis J.	106	Olejnik K.	118
Junevičius R.	110	Osis A.	287
Kapski D.	473, 479, 496	Osobskaya I.	173
Kleinhof M.	50	Ostrovsky E.	309
Klophaus R.	183	Ozolinsh E.	334
Kolmakova N.	156	Ozolinsh I.	334
Konovalenko M.	178	Pabedinskaite A.	434, 448
Kopytov E.	28, 165, 287, 304	Palsaitis R.	262, 360, 390
Kopytov R.	520	Paramonov Yu.	50
Kordos P.	312	Paramonova A.	50
Koszałka G.	312	Pavelko I.	334
Kot Y.	496	Pavelko V.	327, 334

Petukhova N.	504	Tissen F.	28
Platonov R.	442	Titarenko D.	76
Rozite K.	66	Troyanovsky A.	189, 193
Šarkienė E.	97	Tsilker B.	189, 193
Savchenko A.	442	Turskis Z.	459
Sedzukevich V.	473	Ustinovichius L.	97, 459
Senbergs Ju.	70	Vaidogas E. R.	34
Shevchenko G.	459	Vakriniene S.	448
Sikerzhitsky Yu.	178	Vasermanis E. K.	60
Sirota L.	309	Vasiliauskas A. V.	232, 271
Skaredov V.	173	Vorobeu E.	473, 479
Smirnov I. N.	484	Vrubel J.	479
Suslavicius V.	342	Yatskiv I.	21, 156
Svirchenkov A.	422	Yunusov S.	304
Svirchenkov J.	442	Yurshevich E.	156
Tarasov A.	287	Zolova N.	66
Timoshtchenko J.	327	Zvonarev V.	386

CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, Volume 7, No 1, 2006 (Abstracts)

Konstantin N. Nechval, Nicholas A. Nechval. Testing for Crack Initiation in Fatigue-Sensitive Aircraft Structures with Repair under Type I Censored Sampling, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 11–15.

Inferences concerning the location and scale parameters of a two-parameter exponential distribution of time to crack initiation due to fatigue, when crack is repaired, are discussed for samples censored at a fixed value. The procedures considered are uniformly most powerful unbiased if the tests are performed with repair. An example is given.

Keywords: fatigue crack, repair, two-parameter exponential distribution, censored sampling

Konstantin N. Nechval. Approximation Technique for Finding a Probabilistic Assessment of the Fatigue Reliability, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 16–20.

Probabilistic assessments are a useful supplement to deterministic analyses and can also be used as an aid to decision making in areas such as safety analyses, design studies and deployment of resources on maintenance, inspection and repair. Because the initial crack size, the stress, the material properties and other factors that may affect the fatigue crack growth are statistically distributed, the first-order second-moment technique is often adopted to calculate the fatigue reliability of industrial structures. In this paper, a second-order third-moment technique is presented and a three-parameter Weibull distribution is adopted to reflect the influences of skewness of the probability density function. The proposed method that has more characteristics of those random variables that are concerned in reliability analysis is obviously more accurate than the traditional first-order second-moment technique.

Keywords: Paris–Erdogan law, fatigue reliability, Weibull distribution

Ilya Gertsbakh, Irina Yatskiv. Dynamic Classification of Multidimensional Objects, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 21–27.

The goal of this paper is to develop the dynamic classification algorithm. This algorithm might be applied to any object whose state is described by a vector parameter with coordinates changing in time. This algorithm combines from standard clustering algorithms and Fisher discriminant analysis. The application of this algorithm allows transforming the vector process to scalar process. In article this algorithm is demonstrated in application to the economic development of EU countries and an Economic Welfare Growth Index to the EU countries is worked out in the research.

Keywords: Economic Welfare Growth Index, cluster analysis, Fisher discriminant function

Eugene Kopytov, Fedor Tissen, Leonid Greenglaz. Multi-Product Inventory Control Model with Constraints, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 28–33.

Purpose of the offered work is the construction of a multi-product inventory control model with random demand for goods, random lead-time and random deviation of prices and structural constraints on the resources (stock capacity, capital and others). It is proposed, that distributions of these random variables are known. Considered task has been solved as the problem of stochastic programming in E-statement.

Keywords: inventory control, multi-product order, demand, lead-time, optimisation, constraints on resources

Egidijus R. Vaidogas. Bayesian Approach to Forecasting Damage to Buildings from Accidental Explosions on Railway, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 34–43.

A procedure for estimating potential damage to buildings induced by accidental explosions on railway is developed. By the damage are meant failures of nearby structures due to actions generated by the accidental explosions. This damage is measured in terms of probabilities of potential failures caused by the explosions. The estimation of the damage probabilities is based on a stochastic simulation of railway accident involving an explosion. The proposed simulation-based procedure quantifies epistemic (state-of-knowledge) uncertainties in the damage probabilities. These uncertainties are expressed in terms of Bayesian prior and posterior distributions. A foundation of the procedure is a computer intensive method known as a Bayesian bootstrap. It is used for approximating the posterior distributions of damage probabilities. An application of the Bayesian bootstrap makes the proposed procedure highly automatic and convenient for assessing structures subjected to the hazard of the accidental actions. In addition, it can be used for specifying safe distances between the railway and nearby buildings. Structures of these buildings can be designed for tolerable probabilities of failures induced by the accidental explosions.

Keywords: railway, accident, damage, explosion, Monte Carlo simulation, Bayesian bootstrap

Konstantin N. Nechval, Nicholas A. Nechval. Prediction Limits for Future Samples from a Weibull Distribution, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 44–49.

Based on a random sample from the Weibull distribution with unknown shape and scale parameters, lower and upper prediction limits on a set of m future observations from the same distribution are constructed. The procedures, which arise from considering the distribution of future observations given the observed value of an ancillary statistic, do not require the construction of any tables, and are applicable whether the data are complete or Type II censored. The results have direct application in reliability theory, where the time until the first failure in a group of m items in service provides a measure regarding the operation of the items, as well as in service of fatigue-sensitive structures to construct strategies of inspection of these structures.

Keywords: likelihood, conditioning, Weibull distribution

A. Paramonova, M. Kleinhof, Yu. Paramonov. Normal, Lognormal, Weibull or P-Sev Distribution of Ultimate Strength of Strands And Composite Specimens, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 50–59.

Analysis of ultimate strength of strands (bundles) and specimens of composite material is considered with the use of simple goodness-of-fit test for cumulative distribution function (cdf) with location and scale parameters. The test, offered for preliminary analysis, is based on comparison of ordered statistics with their standard distribution expected values (when location parameter is equal to zero and scale parameter is equal to one). For specific W-L dilemma testing (**W**eibull against **L**ognormal distribution) some approximation of uniformly most powerful invariant test (UMPIT) is offered. The critical boundary of the region of rejection of null-hypothesis and power of the tests can be calculated using modern PC. Numerical examples (processing of ultimate strength dataset) are given. As a subject of further research new p-sev family distribution is offered for ultimate strength distribution description. The weakest link model can be combined in this family with lognormal or some other distribution law.

Keywords: distribution function, composite, static strength

Gundars Berzins, Nicholas A. Nechval, Edgars K. Vasermanis. Multiperiod Project Portfolio Investment Strategy, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 60–65.

This paper considers an analytical optimal solution to the mean-variance formulation of the problem of optimisation of multiperiod investment strategy for project portfolio. Specifically, analytical optimal multiperiod investment strategy for project portfolio is derived. An efficient algorithm is proposed in order to maximize the expected value of the terminal wealth under constraint that the variance of the terminal wealth is not greater than a pre-assigned risk level or to minimize the variance of the terminal wealth under constraint that the expected terminal wealth is not smaller than a pre-assigned level. A numerical example is given.

Keywords: project portfolio, multiperiod investment strategy, optimisation

Jury Krasts, Nicholas A. Nechval, Kristine Rozite, Natalie Zolova. New Information Criterion and It's Applications to Multiple Regression**,** *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 66–69.

In this paper, we propose a new information criterion for variable selection in the classical regression model based on F statistic with an added penalty term for penalizing over fitting (or informational complexity). The penalty function denoted by ϑ depends on the number of independently adjusted parameters and the sample size n. It is chosen to ensure the consistency in the selection of true model.

Keywords: multiple regression, variable selection, change detection, new approach

Jurijs Senbergs, Boriss Misnevs. Research of a Statistical Process Control in Software Engineering Project, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 70–75.

This paper presents some results of the "Research of a Statistical Process Control in Software Engineering Project", which was performed in Transport and Telecommunication Institute. The purpose of the research was evaluation of stability of Software Engineering processes of the Organization.

Keywords: software measurement, process management and improvement, statistical control

Deniss Titarenko. The Influence of Foreign Direct Investment on Domestic Investment Processes in Latvia, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 76–83.

The primary aim of the paper is to estimate the extent of FDI influence on domestic investment processes in Latvia. Author analyses the theoretical issues of FDI effect on capital formation process in the

host economy. The results of econometric analysis of the total investment model presented in this paper show the evidence of crowding out long-term effect of FDI on investment in Latvia.

Keywords: foreign direct investment, econometric analysis of the total investment model, crowding in/out effect

Maciej Nowak. Multicriteria Technique for Project Selection under Risk, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 85–91.

Profitable investments lead to the growth and prosperity of each corporation. Various objectives are usually taken into account when an engineering, construction or R&D projects are analysed, including economic desirability, technical issues, and environmental and social factors. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, so a multicriteria decision problem arises. Criteria, according to which projects are compared, are usually of different nature. While some of them are quantitative ones, others are of qualitative type. When faced with the decision of selecting a project, the decision maker has also to face uncertainty.

The paper proposes a comprehensive methodology for project selection problem, that enables handling both quantitative and qualitative criteria, and takes into account risk associated with each objective. Monte Carlo simulation is used for generating alternatives' evaluations with respect to quantitative measures. Experts' assessments are taken into account when projects are appraised in relation to qualitative criteria. A multicriteria procedure presented in the paper is based on two concepts: stochastic dominance and interactive approach. The first is employed for comparing projects with respect to each criterion separately, the latter in used for generating final solution of the problem. A numerical example is presented to illustrate the applicability of the proposed technique.

Keywords: project selection, Monte Carlo simulation, stochastic dominance, multicriteria analysis

Olga Lingaitienė, Vytautas Lingaitis. Application of a General Model of Multimodal Transportation in Logistics, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 92–96.

The requirements for transport services are exogenous and can be generated by the input-output model if it is available or determined from other sources observed needs or corrected previously observed needs. The choice of a particular transport facility or a group of facilities is exogenous and multimodal transhipments are admissible.

A suggested mathematical model is aimed at optimising multimodal transportation allowing us choose the most suitable transport facilities in each particular case.

Keywords: logistic**,** model, multimodal transportation, optimisation

Leonas Ustinovichius, Edita Šarkienė. The Analysis of Apartment House Construction Investments Efficiency Applying Mathematical Modelling, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 97–105.

In the paper the application of mathematical modelling to evaluating the efficiency and risk of investment projects is discussed.

Keywords: apartment house, construction, investment, mathematical modelling

Jonas Jonaitis. The Operation of the Gauge Changing Facility of the New Railway Line Rail Baltica, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 106–109.

This article describes the operation mode for the trains gauge changing facilities. These facilities enables the trains specially constructed or adapted for the gauge changing to run on the two gauge systems that will coexist in Lithuania, namely European Standard (UIC) gauge 1435mm and Wide (Russian) gauge 1520mm.

Several gauge-changing systems are available in the international market. The description below is based on the Talgo system. This system is state of the art and well proven. It operates on the Spanish – French Border (Irún/Hendaye) as well as on the connections of the Madrid – Seville Highs Speed Line (1435 mm gauge) and Spanish conventional rail network (1668mm) in Cordoba and Seville.

Keywords: gauge changing facility, auxiliary locomotives, draggers

Marijonas Bogdevičius, Raimundas Junevičius. Retrofitted Rear Suspension Efficiency, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 110–116.

It is popular to retrofit cargo van to passenger mini Bus. Such retrofitting is based on cargo vans, gross weight up to 5t andintended for 10 – 22 passenger seats. Usually the retrofitters in order to improve vehicle ride and passenger comfort are upgrading suspensions. The main aim of this investigation is to compare

ride differences of the retrofitted rear vehicle suspension and to evaluate vehicle dynamic characteristic improvement. Three types of a quarter vehicle rear suspensions dynamic models are presented. The first one is a typical cargo van leaf spring suspension, the second most popular retrofitted suspension with additionally mounted air chamber; the third one has modified leaf spring at one end fixed to the vehicle body through an air chamber. As the road disturbance is used speed reduction bump. Mathematical simulation is made with Maple using Runge-Kutta method.

Paper presents variation of the different suspensions natural frequencies; quarter vehicle body accelerations and air spring pressure dependences on natural frequencies of quarter vehicle rear suspension; quarter vehicle vertical body accelerations in respect to time. Dynamic characteristics of all three vehicles rear suspensions are compared and the results are listed.

Keywords: vehicle, rear suspension, dynamics, numerical methods

Krzysztof Olejnik. Modelling of Indirect Visual Transfer Collected by Car Driver, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 118–124.

In the paper the establishment to create mathematical model of indirect visual transfer from car surroundings, transmitting by mirrors the vehicle equipped with is shown. It served to create an analytical program in C++ programming language, using Open GL library, operating under Microsoft Windows system. Research and cognitive possibilities are discussed which elaborated the computer program. Examples of calculations' results together with the graphic illustration of the received results are presented.

Keywords: modelling, visibility, indirect visual transfer

Jörg Kundler. IT-Security Protection and Audit Concept for ATC IT-Systems (SAIFIT), *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 125–143.

We found out that no relevant standard for ATC IT-Security do exist. An own Standard for IT Security Protection and Audit Concept to measure IT-Security for ATC Systems is developed. ATC Safety aspects are clearly defined. The idea of the paper is as follows - to be able to measure IT-Security based on a defined and uniform standard for basic and high level protection.

The goals and benefits of the IT Security Protection and Audit Concept for ATC IT-Systems are as follows:

- Establishing a IT-Security Standard for ATC Systems
- Differentiating between different categories of ATC Systems and Protection Level
- Making IT-Security measurable and performing a regular benchmark process based on the IT Security Standard
- Establishing IT Security Standard into the overall ATC System Life Cycle
- Making IT-Security visible and showing a trend analysis during the life cycle. The ATC IT Security Standard has to satisfy all possible requirements and to guarantee an overall ATC security level and to describe all related subject areas like: Technical Infrastructure, Facility Management and Building, IT-System, Networking, Telecommunication.

The IT Security Protection and Audit Concept for ATC IT-Systems are in operational use since year 2001. Now this process of IT Security Inspection is a strong established process in ATC and we have to collect data and experience over several years. All ATC Centre, Tower Locations, central function and most part of the surveillance and navigation installations are inspected. This database is important to calculate and to derive forecast information and possible trends in IT-Security. The database is also important to perform a risk analysis.

Keywords: ATC security standard, audit concept, measurement method, tool support, reporting

Nijole Batarliene. Location and Control of Cargo and Vehicles with New Technologies, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 144–148.

This paper presents several ideas of effective transport systems technologies, technological solutions in systems for identification objects on the road.

In the article is theoretically shown the coherence of new technologies and new possibilities for location and control of cargo and vehicles with systems of navigation and positioning system. The expansion of Internet connectivity by GSM-GPRS network to transport elements allows using of new possibilities of differential GPS (GNSS) techniques and applications.

Keywords: cargo, technologies, location, vehicle, control

Jonas Butkevičius. Introduction of Electronic Card System in Lithuanian City Passenger Transport, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 149–155.

Based on the research, the current Lithuanian city passenger transport ticket system has not been changed for already several decades; therefore it has lots of drawbacks (inflexibility of ticket prices, no stored banks of data on carried passengers, no common tickets for all types of transport, etc.). Thus, this system cannot meet the increasing needs of the transport system administrator and the passengers. Consequently, a necessity to improve the city passenger transport ticket system has become inevitable.

In 2006, the electronic card system in the biggest Lithuanian cities, for instance, in Vilnius, Kaunas and Klaipėda it has been planned to install. For this purpose the contact-less electronic cards are foreseen. Implementation of this project will cost about 60 million Litas (i.e., about 17,6 Euro). For the process of implementation of this project, also sources from different European Union funds will be used.

Keywords: city passenger transport, ticket system, electronic cards

Nadezda Kolmakova, Elena Yurshevich, Irina Yatskiv. Modelling as a Means of Solving the Problem of City Traffic Optimisation, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 156–164.

The article deals with the problem of city traffic modeling at microlevel. The most popular simulation software tools used to solve this problem are being reviewed in the article. The model of complex Riga TN (Transport Node) is used as an example that illustrates the Vissim package potential for traffic modeling. The expediency of the TN reconstruction and the results of the model execution within two different structures are being analyzed in the article.

Keywords: urban traffic, simulation, microscopic traffic simulators, road network, case studies, vehicle

Eugene Kopytov, Vasilijs Demidovs. Supporting of Forecasting Models in Information-Analytical Systems of Railway Transportation, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 165–172.

The paper presents the approach of building Informational-Analytical Systems at the railway with the help of modern achievements in the sphere of Data Warehouse. Application of Data Warehouse technologies allows building a lot of system models on the basis of a huge accumulated quantity of data. The suggested conceptual scheme of building virtual models gives opportunity to have several analysed data models concurrently and to create quickly new ones. The offered approach can be applied to forecasting of railway transportation depending on the control action at the system with account of effect of the environment.

Keywords: forecasting, railway transportation, information system, data warehouse, virtual model

Irina Osobskaya, Vitaly Skaredov. Integrated Information Systems as a Factor of Reliability of Logistic Systems in Supply Chain Oriented Business, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 173–177.

In the paper methodology is offered to increase reliability of logistic system of enterprise by its integration with statistics analysis systems that is made in cases when ERP system itself do not meet enterprise's logistics goals.

This task is reviewed based on case studies of enterprises of Latvia, Lithuania and Estonia, which are using ERP-class information systems (SCALA [3,4,5]), while logistic systems are build on Supply Chain methods. System is analysed in tight connection with strategic and daily logistics tasks. Methodology offered is structured by problems put and level of automation of enterprise internal processes.

Keywords: ERP, reliability of logistic systems, inter-company integration, statistics in logistics

Marina Konovalenko, Yury Sikerzhitsky. The Modelling of Communication Channel with Relay's Fading by Usage of Adaptive Filters, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 178–181.

The main idea of this article is modelling of communication channel with Relay's fading by usage of adaptive filters, in order to get characteristics of signal's dependences at channels correspondent exits.

The channel simulation – it is a task for adaptive filter creation with variable weighting coefficients, where experimentally taken data of signal's statistical characteristics was used.

The multi beam channel model should have two equal filters with variable weighting coefficients. One of the filters should work in the regime of adaptation and it should set simultaneously the found value of weighting coefficients to the second filter through which the signal under testing is transferred.

Keywords: adaptive filtration, communication channel, signal processing, relay's fading

Richard Klophaus. Airline Revenue Management in a Changing Business Environment, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 183–188.

The paper first gives an overview on principles of traditional RM. The author outlines a RM approach suited to the pricing policy of low-cost airlines, where each flight only has one fare available at any point of time. In this context, effective RM boils down to a flight-by-flight dynamic price optimization. The paper emphasizes that some traditional RM principles remain valid. However, fare mix optimization and more sophisticated inventory control techniques do not apply for leg-based low-cost operations selling a single fare product at any one time during the booking period of a flight.

Keywords: transport economics, pricing and revenue management, low-cost airlines

Andrey Troyanovsky, Boris Tsilker. Crew Readiness Influence on Navigation Complex Using Efficiency, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 189–192.

Crew activity at overland flights is coupled to necessity of estimation and compensation of compass system error constant component. Usually this problem is solved by means of positional correction with usage of ground radio means and complex information handling mode (CIH), provided in a base navigational complex (NC). At flight above ocean where corresponding corrective action is impossible, the "residual" constant error in a heading causes linear growth in time of airplane crosses track deviation from the preset path (track). At insufficient efficiency of the CIH mode in NC, CIH functions a qualified operator (navigator) should undertake. Teaching of crews to ways of estimation and compensation of the constant component of compass system error is one of the major elements of navigational training for flights in Northern Atlantic entrusted on flight simulators (FS). Heading error constant component influence on cross-track deviation statistical performances are observed based on assumption that distribution of the heading "residual" errors is DE-distribution. Expressions for a variance of a cross track error are brought. The correction interval relationship with an availability factor of a positional corrector is observed. Requirements to NC modelling in flight simulators are formulated.

Keywords: navigational complex, complex information handling, flight simulator, cross-track deviation

Andrey Troyanovsky, Boris Tsilker. Investigation of Navigator's Activity Algorithms as an Instrument for Test Flights Number Reducing at the Estimation of Reliability of Navigation, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 193–195.

At sufficient accuracy of modelling, flight simulators allow investigating algorithms of activity of skilled navigator. Knowledge of these algorithms gives a chance to reduce number of the test flights necessary to estimate the reliability of navigation. The aprioristic estimation of navigational complex (NC) conformity to the minimum navigation requirements of the ICAO is usually made by means of analytical methods with use of experimental data. These methods can be effective only at presence of qualitative models of NC functioning, including the navigator, i.e. NC models as ergatic systems of air navigation. Basing on inclusion of the pattern of navigator into flight management system, modelled in flight simulator, the basic algorithms of navigator activity are investigated. It is shown, that the simulator should be such that lacks of navigator could not be «compensated» by lacks of NC modelling. It means that the mandatory condition for replacing a part of the real test flights by simulated flights is modelled of possible refusals and failures in work of radio correction means, and also correct reproduction of workings coverage of radio aids used for correction.

Keywords: navigation complex, flight simulator, minimum navigation requirements, reliability of navigation, correction

Jonas Lazauskas. The Analysis of the Commercial Sector of Lithuania Aviation, *TRANSPORT and TELECOMMUNICATION,* Vol. 7, No 1, 2006, pp. 196–202.

The article deals with the commercial sector of Lithuanian aviation. It is a constituent part of Lithuanian economy that is open to novelties in the spheres of science and technologies; it does not require much stock and has qualified specialists.

This article examines the particularities of the companies that provide transportation service, their interrelationship, the division of traffic flows according to the airlines companies, the routes of the airlines companies and parks for their planes. The data is compared with Latvian national airlines "Air Baltic" and Estonian State Airlines "Estonian Air". Attention is paid to the situation of Lithuanian airports and landing-fields, moreover the rates of Lithuanian, Middle and Eastern Europe airports are being analysed, as well as the demand for aviation specialists in Lithuania in the years 2004-2009.

Keywords: air transport, airlines companies, carriers of passengers, freight carriers, traffic flows, airport

TRANSPORT and TELECOMMUNICATION, 7.sējums, Nr.1, 2006 (Anotācijas)

Konstantin N. Nechval, Nicholas A. Nechval. Plaisas rašanās noguruma jutīgajās lidmašīnu struktūrās ar labošanu pie I tipa cenzētās atlases, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 11.–15. lpp.

Autors rakstā dod secinājumus par divu parametru eksponenciālās distribūcijas plaisas rašanās laiku sakarā ar nogurumu, kad plaisa ir salabota, izvietojumu un mēroga parametriem; secinājumi tiek diskutēti atlasei, kas cenzēti ar fiksēto vērtību. Autors apraksta arī piemēru.

Atslēgvārdi: noguruma plaisa, divu parametru eksponenciālā distribūcija, cenzētā atlase

Konstantin N. Nechval. Aptuvens paņēmiens noguruma ticamības varbūtējās novērtēšanas atrašanai, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 16.–20. lpp.

Varbūtējie novērtējumi ir lietderīgi pielikumi noteicošajai analīzei un arī var tikt lietoti kā līdzeklis tādās lēmumu pieņemšanas jomās kā drošības analīze, dizaina studijas, aprūpes izvietošanas resursi, izpēte un labošana u.c.

Autora piedāvātā metode, kurai ir vairāk nejaušu varbūtību īpašību, kas attiecas uz ticamības analīzi, ir acīmredzami precīzāka nekā tradicionālā pirmās kārtas otrā momenta paņēmiens.

Atslēgvārdi: Parisa-Erdogana likums, noguruma ticamība, Veibula distribūcija

Ilya Gertsbakh, Irina Yatskiv. Multidimensionālo objektu dinamiskā klasifikācija, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 21.–27. lpp.

Šī raksta mērķis ir parādīt dinamiskās klasifikācijas algoritmu. Algoritmu var pielietot jebkuram objektam, kura stāvokli apraksta vektora parametrs ar koordinātēm, kas mainās laikā. Šis algoritms sastāv no standarta klasteru algoritmiem un Fišera diskriminanta analīzes. Algoritma pielietošana atļauj transformēt vektora procesu skalārajā procesā.

Autori diskutē par rakstā piedāvātās pieejas lietojumu ekonomikas attīstības izpētē Eiropas Savienības valstīs pēdējās dekādes laikā. Tiek izveidots dinamiskās klasifikācijas algoritms, kas tiek lietots, lai izstrādātu tā saucamo ekonomiskās labklājības izaugsmes indeksu – *Economic Welfare Growth Index* (EWGI) – katrai no ES valstīm. Izstrādātais indekss dod iespēju katru gadu katrai valstij noteikt un analizēt tās ekonomisko labklājību, salīdzināt labklājības izaugsmi starp dažādām valstīm un līdz ar to izdarīt atbilstošus secinājumus.

Atslēgvārdi: ekonomiskās labklājības izaugsmes indekss, klasteru analīze, Fišera diskriminanta funkcija

Eugene Kopytov, Fedor Tissen, Leonid Greenglaz. Daudzproduktu krājumu vadības modelis ar ierobežojumiem, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 28.–33. lpp.

Šī pētījuma mērķis ir radīt daudzproduktu **krājumu vadības** modeli ar nejaušu preču pieprasījumu, nejaušu piegādes laiku un nejaušām cenu novirzēm un strukturāliem resursu ierobežojumiem (krājumu kapacitāte, kapitāls u.c.). Tiek pieņemts, ka šo nejaušo mainīgo lielumu sadale ir zināma. Uzdevums tiek risināts kā stohastiskās programmēšanas problēma E-uzdevumā.

Atslēgvārdi: krājumu vadība, daudzproduktu pasūtījums, pieprasījums, piegādes laiks, optimizācija, resursu ierobežojumi

Egidijus R. Vaidogas. Ēku bojājumu, ko negadījumos rada eksplozijas uz dzelzceļa, paredzējums pēc Beija metodes, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 34.–43. lpp.

Rakstā autors apraksta procedūru, kurā jāizvērtē potenciālie ēku varbūtējie bojājumi, kas rodas negadījumos eksploziju rezultātā. Bojājumu varbūtību izvērtējums tiek pamatots uz stohastiskās simulācijas metodes. Šīs varbūtības ir izteiktas ar Beija iepriekšējām un turpmākām distribūcijām.

Procedūru pamats ir intensīvā datora metode, kas pazīstama kā *Bayesian bootstrap* jeb Beija sāknēšanas programma. Tā tiek lietota, lai noteiktu vēlākās varbūtējo bojājumu distribūcijas, kā arī ar minēto metodi ir iespējams noteikt drošības distanci starp dzelzceļu un ēku, pasargājoties no iespējamiem negadījumiem.

Atslēgvārdi: dzelzceļš, negadījums, bojājums, eksplozija, *Bayesian bootstrap* jeb Beija sāknēšanas programma

Konstantin N. Nechval, Nicholas A. Nechval. Paredzēšanas ierobežojumi nākotnes atlasei no Veibula distribūcijas, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 44.–49. lpp.

Tiek veidoti apakšējie un augšējie paredzēšanas limiti veselai nākotnes novērojumu no tās pašas distribūcijas *m* rindai, kas pamatojas uz nejaušu atlasi no Veibula distribūcijas ar nezināmiem veidola un mēroga parametriem.

Rezultātiem ir tiešs pielietojums ticamības teorijā, kā arī noguruma jutīgo struktūru servisā, lai veidotu šo struktūru novērojumu stratēģijas.

Atslēgvārdi: varbūtība, kondicionēšanās, Veibula distribūcija

A. Paramonova, M. Kleinhof, Yu. Paramonov. Šķiedras un kompozīta parauga galīgā spēka normālā, *log*-normālā, Veibula vai *p-sev* distribūcija, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 50.–59. lpp.

Rakstā tiek diskutēta šķiedras vai tās saišķa un kompozīto materiālu paraugu galējā spēka analīze, parādot tā lietojumu vienkāršā testā kumulatīvajai distribūcijas funkcijai ar izvietojumu un mēroga parametriem.

Tests, ko autori piedāvā, bāzējas uz kārtējās statistikas salīdzināšanu ar tās standarta distribūcijas sagaidāmām vērtībām (kad izvietojuma parametrs ir vienāds nullei un mēroga parametrs ir vienāds vieniniekam).

Autori rakstā sniedz arī virkni skaitlisku piemēru.

Atslēgvārdi: distribūcijas funkcija, kompozīts, statiskais spēks

Gundars Berzins, Nicholas A. Nechval, Edgars K. Vasermanis. Multiperiodu projekta portfeļa investēšanas stratēģija, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 60.–65. lpp.

Autori rakstā parāda analītisko optimālo risinājumu multiperiodu investēšanas stratēģijas projektu portfeļa optimizācijas problēmas vidējās pretrunas formulējumam. Rakstā diskutēta un iegūta projektu portfeļa analītiskā optimālā multiperiodu investēšanas stratēģija. Tiek doti skaitliskie piemēri.

Atslēgvārdi: projekta portfelis, multiperiodu investēšanas stratēģija, optimizācija

Jury Krasts, Nicholas A. Nechval, Kristine Rozite, Natalie Zolova. Jauns informācijas kritērijs un tā lietojums multiplā regresijā**,** *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 66.–69. lpp.

Šajā rakstā autori parāda jaunu informācijas kritēriju mainīgajai izlasei klasiskajā regresiju modelī, kas bāzējas uz *F* statistiku ar pievienoto soda termiņu.

Soda funkcija, kas apzīmēta ar ϑ , ir atkarīga no neatkarīgi pievienoto parametru skaita un no izlases lieluma *n*. Tas tiek izvēlēts, lai nodrošinātu konsekvenci patiesā modeļa atlasē.

Šī raksta mērķis ir piedāvāt jaunu pieeju minētās problēmas risināšanā, tiek doti skaitliskie piemēri.

Atslēgvārdi: multiplā regresija, mainīgā izlase, izmaiņu atklāšana, jauna pieeja

Jurijs Senbergs, Boriss Misnevs. Procesa statistiskās uzraudzības pētījums programmatūras izstrādēs projektā, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 70.–75. lpp.

Rakstā parādīti pētījuma rezultāti, kas tika veikti Transporta un sakaru institūtā. Tā mērķis ir programmatūras izstrādes procesu stabilitātes izvērtēšana organizācijā.

Atslēgvārdi: procesa vadīšana, procesa uzlabošana, statistiskā izvērtēšana, programmatūra

Deniss Titarenko. Ārvalstu tiešo investīciju ietekme uz iekšējiem investīciju procesiem Latvijā, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 76.–83. lpp.

Raksta primārais mērķis ir novērtēt ārzemju tiešo investīciju (ĀTI) lieluma ietekmi uz investīciju procesiem Latvijā. Autors analizē ĀTI ietekmi uz kapitāla veidošanās procesiem lokālajā ekonomikā. Investīciju modeļa ekonometriskās analīzes rezultāti parāda acīmredzamo ĀTI iespiešanās ilgtermiņa efektu uz vietējām investīcijā Latvijā.

Atslēgvārdi: ārzemju tiešās investīcijas, kopējā investīciju modeļa ekonometriskā analīze, iespiešanās/stimulēšanas efekts

Maciej Nowak. Riska projektu atlases multikritēriju paņēmiens, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 85.–91. lpp.

Ienesīgas investīcijas parasti veicina firmu izaugsmi un labklājību. Analizējot nozaru projektus, dažādi apstākļi tiek ņemti vērā, kas iekļauj sevī gan ekonomiskos, tehniskos, vides, gan arī sociālos faktorus. Lēmumu pieņēmējs projekta atlasē bieži vien sastopas ar nedrošību, šeit arī rodas multikritēriju lēmuma problēma.

Raksta autors piedāvā saprātīgu metodoloģiju projektu atlasē, kas dod iespēju risināt kā kvantitatīvos, tā arī kvalitatīvos kritērijus, ņemt vērā risku, kuru pavada katra objektivitāte. Rakstā tiek lietota *Monte Carlo* simulācijas metode, kā arī tiek doti skaitliskie piemēri, kas pamato piedāvātās metodes lietošanu.

Atslēgvārdi: projektu atlase, *Monte Carlo* simulācijas metode, multikritēriju analīze

Olga Lingaitienė, Vytautas Lingaitis. Multimodālo pārvadājumu vispārējā modeļa pielietošana loģistikā, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 92.–96. lpp.

Pieprasījums pēc transporta pakalpojumiem ir eksogēns, un to var ģenerēt ar ievades-izvades modeļa palīdzību, ja tas ir pieejams, vai arī noteikts no citiem avotiem.

Piedāvātais matemātiskais modelis ir paredzēts multimodālo pārvadājumu optimizēšanai, kas atļauj mums izvēlēties vispiemērotākos transporta līdzekļus katrā noteiktā gadījumā.

Atslēgvārdi: loģistisks, modelis, multimodālie pārvadājumi, optimizācija

Leonas Ustinovichius, Edita Šarkienė. Daudzdzīvokļu mājas būvniecības investīciju analīze, pielietojot matemātisko modelēšanu, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 97.–105. lpp.

Autori rakstā izskata matemātiskās modelēšanas pielietošanu, lai izvērtētu investēto projektu efektivitāti un risku.

Atslēgvārdi: daudzdzīvokļu māja, būvniecība, investēšana, matemātiskā modelēšana

Jonas Jonaitis. Jaunā dzelzceļa *Line Rail Baltica* sliežu platuma izmaiņu viegluma funkcionēšana, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 106.–109. lpp.

Šajā rakstā autors iztirzā funkcionēšanas paņēmienu vilcienu sliežu platuma mainīšanas iespējām. Tas dod iespēju vilcieniem, kas ir speciāli konstruēti sliežu platuma maiņai, ritēt pa divu sistēmu sliedēm, kas drīzumā darbosies Lietuvā, t.i., Eiropas standarta sliežu platums (1435 mm) un platais sliežu platums – Krievijas (1520 mm).

Starptautiskajā tirgū ir iespējamas vairākas sliežu platuma izmaiņu sistēmas. Rakstā lietotais apraksts ir pēc Talgo sistēmas.

Atslēgvārdi: sliežu platuma izmaiņu iespējas, palīglokomotīves, vilcēji

Marijonas Bogdevičius, Raimundas Junevičius. Retropiemērotā aizmugurējā tilta efektivitāte, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 110.–116. lpp.

Mūsdienās bieži vien kravas mazie autobusi tiek pārtaisīti par pasažieru mini autobusiem. Šādu pārtaisīšanu parasti piemēro kravas autobusiņiem ar pilnmasu līdz 5 tonnām, izveidojot 10-22 pasažieru vietas. Parasti, lai uzlabotu transporta līdzekļa gaitu un pasažieru komfortu, tiek sakārtoti tilti.

Autori rakstā izskata trīs transporta līdzekļu piemērus. Matemātiskā simulācijā tiek lietota Runges-Kuta metode. Rakstā visu triju transporta līdzekļu dinamiskie raksturojumi tiek salīdzināti un rezultāti tiek parādīti.

Atslēgvārdi: transporta līdzeklis, pakaļējais tilts, dinamika, skaitliskās metodes

Krzysztof Olejnik. Autovadītāja netiešās vizuālās pārvietošanās modelēšana, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 118.–124. lpp.

Rakstā autors izveido netiešās vizuālās pārvietošanās matemātisko modeli ar spoguļu palīdzību, ar ko automobilis ir apgādāts. Tas kalpoja, lai izveidotu analītisko programmu C++ programmēšanas valodā, pielietojot *Open GL* bibliotēku, darbojoties *Microsoft Windows* sistēmā. Autors rakstā sniedz arī aprēķina rezultātu piemērus ar grafisko ilustrēšanu.

Atslēgvārdi: modelēšana, redzamība, netieša vizuālā pārvietošanās

Jörg Kundler. Informācijas tehnoloģiju drošības aizsardzība un audita koncepts *ATC* IT sistēmām (*SAIFIT*), *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 125.–143. lpp.

Autors konstatē, ka nepastāv ATC IT- drošības standarts. Raksta mērķis ir šāds – izvērtēt IT- drošību, kas bāzējas uz noteikta un vienota standarta vienkāršai un augsta līmeņa aizsardzībai.

Autors rakstā izskata IT drošības aizsardzību un audita konceptu *ATC* Informācijas tehnoloģiju sistēmām. Šīs sistēmas tiek pielietotas jau kopš 2001. gada. Šobrīd mums ir jāsavāc dati un pieredze par šo periodu. Rakstā autors iztirzā drošības aizsardzības aspektus visiem *ATC* centriem un to būvniecību, torņu izvietojumus, centrālās funkcijas un lielāko daļu no pārraudzības un navigācijas instalācijām.

Atslēgvārdi: *ATC* drošības standarts, audita koncepts, vērtējuma metode, līdzekļu atbalsts, ziņojums

Nijole Batarliene. Kravas un satiksmes līdzekļu izvietošana un kontrole ar jaunām tehnoloģijām, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 144.–148. lpp.

Autors šajā rakstā parāda dažas efektīvas transporta sistēmas tehnoloģiju idejas, tehnoloģiskus risinājumus sistēmās, kas paredzētas objektu identifikācijai uz ceļiem.

Teorētiski tiek parādīts jauno tehnoloģiju un jauno iespēju saskaņotību kravas un satiksmes līdzekļu izvietošanai un kontrolei ar navigācijas un pozicionēšanas sistēmām. Internet tīkla lietojums ar GSM-GPRS tīklu transporta elementiem paver jaunas iespējas GPS (GNSS) diferenciāļa tehnikas un pielietojumus.

Atslēgvārdi: krava, tehnoloģijas izvietošana, satiksmes līdzeklis, kontrole

Jonas Butkevičius. Elektronisko karšu sistēmas ieviešana Lietuvas pilsētas pasažieru transportā, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 149.–155. lpp.

Šībrīža Lietuvas pilsētas pasažieru transporta biļešu sistēma nav bijusi mainīta jau daudzas dekādes, līdz ar to tai ir ļoti daudz mīnusu, piem., biļešu cenu neelastīgums, nav pieejami dati par pārvadāto pasažieru skaitu, nav biļešu vienveidības visiem transporta veidiem.

Autors rakstā pievēršas jauno tehnoloģiju ieviešanai minētajā jomā, t.i., elektroniskās biļešu sistēmas pielietojums, elektronisko karšu izgatavošana, karšu ielādēšanas mašīnu izmantošana utt.

Elektronisko karšu sistēmu transportā ir plānots ieviest Lietuvas lielākajās pilsētās, piem., Viļņā, Kauņā, Klaipēdā jau 2006. gadā.

Atslēgvārdi: pilsētas pasažieru transports, biļešu sistēma, elektroniskās kartes

Nadezda Kolmakova, Elena Yurshevich, Irina Yatskiv. Modelēšana kā līdzeklis pilsētas trafika optimizācijas problēmu risināšanai, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 156.–164. lpp.

Rakstā tiek apskatīta pilsētas trafika modelēšanas mikro līmenī problēma. Tiek veikts vispopulārāko imitācijas programmēšanas līdzekļu apskats, kurus izmanto šī uzdevuma risināšanai. Kā piemērs, kas ilustrē trafika modelēšanas pakotnes Vissim iespējas, tiek apskatīts Rīgas pilsētas sarežģītā transporta mezgla modelis. Uz konstruētā modeļa pamata ar eksperimentu palīdzību tiek apskatīta šī mezgla rekonstrukcijas lietderība, modeļa gājienu rezultāti pie divām dažādām mezgla struktūrām tiek analizēti ar *Mann-Whitney Rank* testa palīdzību.

Atslēgvārdi: pilsētas trafiks, modelēšana, trafika modelēšanas līdzekļi mikro līmenī, ceļa tīkls, mācību piemēri, transporta līdzeklis

Eugene Kopytov, Vasilijs Demidovs. Prognozēšanas modeļu atbalsts dzelzceļa pārvadājumu informācijas analītiskajās sistēmās, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 165.–172. lpp.

Rakstā apskatīta dzelzceļa informācijas analītiskās sistēmas uzbūves pieeja, izmantojot mūsdienu sasniegumus datu noliktavu jomā. Datu noliktavu tehnoloģiju pielietošana ļauj uz uzkrātā milzīgā datu apjoma bāzes izveidot lielu skaitu sistēmas modeļu. Piedāvātā konceptuālā virtuālo modeļu radīšanas shēma ļauj analīzes procesā pielietot vairākus alternatīvus datu modeļus un ātri radīt jaunus. Virtuālo modeļu lietošana kopā ar precīzu sistēmas formalizēšanu ļauj saīsināt jaunu pārskatu izstrādāšanas laiku un nodrošināt to garantētu ticamību. Piedāvāto pieeju var izmantot dzelzceļa pārvadājumu prognozēšanā atkarībā no vadības iedarbības uz sistēmu izmaiņām, ņemot vērā ārējās vides iedarbības.

Atslēgvārdi: prognozēšana, dzelzceļa pārvadājumi, informācijas sistēma, datu noliktava, virtuāls modelis

Irina Osobskaya, Vitaly Skaredov. Integrētās informācijas sistēmas kā loģistisko sistēmu drošuma faktors piegāžu biznesā, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 173.–177. lpp.

Autori rakstā izskata un piedāvā metodoloģiju, lai palielinātu uzņēmuma loģistisko sistēmu drošumu, integrējot to statistiskās analīzes sistēmā.

Autori pievēršas vairāku valstu uzņēmumiem, kā Latvijā, tā arī Lietuvā un Igaunijā, kur tiek pielietotas *ERP* klases informācijas sistēmas (*SCALA* [3,4,5]). Sistēma tiek analizēta ciešā saiknē ar stratēģiskiem un ikdienas loģistiskiem uzdevumiem.

Atslēgvārdi: *ERP,* loģistiskās sistēmas drošums, integrētās informācijas sistēmas, statistika loģistikā

Marina Konovalenko, Yury Sikerzhitsky. Komunikāciju kanāla modelēšana ar releju fedingu, lietojot adaptīvos filtrus, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 178.–181. lpp.

Raksta galvenais mērķis ir komunikācijas kanālu modelēšana ar releja fedingu, lietojot adaptīvos filtrus, lai iegūtu signālu raksturlīkņu atkarības uz attiecīgā kanāla izejas.

Kanāla simulācija – tas ir uzdevums adaptīvo filtru radīšanai ar maināmiem svara koeficientiem, kur tiek pielietoti signāla statistiskās raksturlīknes eksperimentāli iegūtie dati.

Daudz staru kanāla modelim ir jābūt diviem vienādiem filtriem ar maināmiem svara koeficientiem. Vienam filtram ir jāstrādā adaptācijas režīmā, un tam ir jāuzstāda vienlaicīgi atrastās svara koeficientu vērtības otrajam filtram, caur ko signāls tiek pārraidīts testēšanas laikā.

Atslēgvārdi: adaptīvā filtrācija, signāla pārraidīšana, releja fedings

Richard Klophaus. Aviolīnijas ieņēmumu pārzināšana mainīgajā biznesa vidē, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 183.–188. lpp.

Ieņēmumu pārzināšana jeb vadība ir saistīta ar kopējo ieņēmumu optimizāciju, pielietojot dažādus līdzekļus un tehnikas.

Autors rakstā sniedz pārskatu par tradicionāliem ieņēmumu vadības principiem. Autors pasvītro ieņēmumu vadības pieeju, kas der lēto aviolīniju cenu politikai, kur katram lidojumam ir tikai viena braukšanas maksa jebkurā laika sprīdī. Šajā sakarā efektīva ieņēmumu vadība samazina no lidojuma uz lidojumu dinamisko cenu optimizāciju. Rakstā tiek pasvītrots, ka daži tradicionālie ieņēmumu pārzināšanas principi ir un paliek vērtīgi.

Atslēgvārdi: transporta ekonomika, cenu veidošanas un ieņēmumu vadība, zemo cenu aviolīnijas

Andrey Troyanovsky, Boris Tsilker. Komandas gatavības ietekme uz navigācijas kompleksa pielietojuma efektivitāti, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 189.–192. lpp.

Ekipāžas darbība virszemes lidojumos tiek papildināta ar nepieciešamību izvērtēt un kompensēt kompasa sistēmas kļūdas konstanto sastāvdaļu. Šī problēma parasti tiek risināta ar pozicionālās korekcijas līdzekļiem, lietojot zemes radio līdzekļus un komplekso informācijas apstrādes režīmu, kas paredzēts bāzes navigācijas kompleksā. Lidojumā virs okeāna, kur atbilstoša korekcija ir neiespējama, nekompensētā konstantā kļūda kursā izsauc lidmašīnas sāna novirzes lineāro pieaugumu laikā no noteiktās trases (treka). Darbā pieņemts, ka nekompensēto kursa kļūdu sadale atbilst DE-sadalei, kas tiek ņemts vērā, izskatot kursa kļūdas konstantās sastāvdaļas ietekmi uz sāna novirzes statistiskajiem raksturojumiem. Autori rakstā parāda izteiksmi sāna novirzes dispersijai. Tiek izskatīta saikne starp korekcijas intervālu un pozicionālā korektora gatavības koeficientu. Rakstā tiek formulētas arī prasības navigācijas kompleksa modelēšanai aviācijas trenažieros.

Atslēgvārdi: navigācijas komplekss, kompleksā informācijas apstrāde, aviācijas trenažieris, sāna novirze

Andrey Troyanovsky, Boris Tsilker. Navigatora aktivitātes algoritmu pētīšana kā līdzeklis testa lidojumu skaita samazināšanai navigācijas drošuma izvērtēšanā, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 193.–195. lpp.

Pietiekamas lidojuma modelēšanas precizitātes gadījumā aviācijas trenažieri pieļauj pētīt pieredzējuša navigatora darbības algoritmus. Šo algoritmu pārzināšana dod iespēju samazināt testa lidojumu skaitu, kas savukārt ir nepieciešami, lai novērtētu navigācijas drošumu. Navigācijas kompleksu (NK) atbilstības ICAO minimālajām navigācijas prasībām *apriori* novērtējums parasti tiek veikts ar analītisko metožu palīdzību, izmantojot eksperimentālos datus. Šīs metodes var būt efektīvas tikai tad, ja pastāv NK funkcionēšanas kvalitatīvi modeļi, kas iekļauj arī navigatoru, t.i., ja modeļi apraksta NK kā lidmašīnas vadības ergatisko sistēmu.

Tiek parādīts, ka trenažierim jābūt tādam, lai navigatora nepietiekamā sagatavotība nevarētu būt kompensēta, pateicoties trūkumiem navigācijas kompleksa modelēšanā.

Atslēgvārdi: navigācijas komplekss, aviācijas trenažieris, minimālās navigācijas prasības, navigācijas drošums, korekcija

Jonas Lazauskas. Lietuvas aviācijas komerciālā sektora analīze, *TRANSPORT and TELECOMMUNICATION*, 7.sēj., Nr.1, 2006, 196.–202. lpp.

Autors rakstā izskata Lietuvas aviācijas komerciālo sektoru. Tā ir Lietuvas ekonomikas svarīga sastāvdaļa, kas savukārt ir atvērta jauninājumiem zinātnes un tehnoloģiju laukā.

Rakstā tiek analizētas kompāniju īpatnības, kas saistītas ar pārvadājumu pakalpojumiem, to savstarpējās attiecības, satiksmes plūsmu sadale atbilstoši aviolīniju kompānijām, aviokompāniju maršruti un lidmašīnu stāvvietas.

Dati tiek salīdzināti ar tādām lielām Baltijas valstu aviolīniju kompānijām kā "Air Baltic" un "Estonian Air".

Atslēgvārdi: gaisa transports, aviolīniju kompānijas, pasažieru pārvadājumi, kravu pārvadājumi, satiksmes plūsmas, lidosta