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CONTENTS

PREDISASTER DESIGN OF TRANSPORTATION NETWORK

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In this paper we consider transportation network optimal reinforcement problem. We mean by that network reliability improvement achieved by reinforcement of a certain number of its most important links (road segments), which are subject to failure (destruction). This reinforcement is made given a budgetary constraint, and its goal is to maximize the global network performance measure, which depends on the source-terminal reliability of a fixed set of origin-destination routes or network all-terminal connectivity.

The central role in the proposed optimization is played by a combinatorial Monte-Carlo algorithm for estimating the network $s-t$ reliability or the probability of all-terminal connectivity, and the gradient vector. The proposed optimization method is tested on an example described in [1] of a road network of Istanbul. The link failures are caused by natural disasters like earthquakes, and link e reinforcement means its replacement for a cost $c(e)$ by a more reliable one. Another example is a 4-terminal 34-link with 25 nodes network in which the reinforcement raises the link reliability up to 0.9 and the problem is stated as find the minimal cost reinforcement policy to guarantee the prescribed value of the probability of all terminal connectivity.

Keywords: network Monte Carlo, reliability gradient vector, network design, link failure, earthquakes, $s-t$ network reliability, all-terminal connectivity

1. Introduction

Optimal transportation network (TN) reliability design is not a well-defined notion. Its formulation demands first of all answering the following principal questions:

1) What are the network components subject to failure.
2) What is the definition of component failure.
3) How network reliability is connected or related to its component failure.
4) What is the whole network performance criterion (NPC) and how is it expressed via its reliability parameters.

After these issues are clarified, it is necessary to define the relevant resources which are at the disposal of the network designers. Then it will become possible to formulate the problem of finding the best policy of using these resources to achieve the maximal possible NPC under given constraints.

Following recently published papers [1, 2], we make the following assumptions:

a) TN components subject to failure are the links (or arcs), i.e. the road segments connecting network nodes.

b) Link failure formally means that the link $e=(a,b)$ connecting nodes (a,b) becomes not operational, i.e. the connection between a and b via this link is completely disrupted. Physically it might be due a natural disaster (earthquake, flood), road accident or, speaking in military terms, an "enemy attack".

c) Each link e has its failure probability $q(e)$, and link failures are viewed as independent events.

d) The TN performance criterion is a function of the network ability to provide a connection between two sets of its nodes – the origins and destinations, or the connection between a special set of so-called terminal nodes. The simplest case of NPC will be a functional depending on the probability to provide connection between a "source" and "terminal", or the so-called probability of $s-t$ connectivity. The model considered in [1], singled out several most important $s-t$ pairs in the TN and assumed that the NPC depends on the set of $s-t$ connection probabilities of these pairs. Another version of the NPC is the value of the probability of all-terminal connectivity.

e) A natural way to formalize network improvement or reinforcement (termed in [1] as predisaster investment) is to carry out link e "repair" to reduce its failure probability from $q(e)$ to $q_{\min}(e) < q(e)$ by investing $c(e)$. In physical terms, this means reconstruction of the road segment and/or reinforcement of its weak elements, like bridges, tunnels, etc. Since there are always budget constraints, the total amount of money invested in the network component reinforcement must be limited by a certain budget D.

The above assumptions a)-e) allow formulating our problem in several ways: find the "best" set of reinforced components (links) in order to maximize the NPC subject to the budget constraint D, or to find the cheapest way to guarantee the desired level of network reliability, which is a formulation dual to the first one.

The paper is organized as follows. In Section 2 we formulate the problem in formal terms and present our principal optimization algorithm. We suggest using a greedy-type semi-heuristic procedure. Its most important and difficult part is the estimation of network reliability and the reliability gradient vector for the selected network reliability criterion. We shortly describe this procedure in Appendix. Section 3 presents an account of our optimization results for an Istanbul network analyzed in [2]. Section 4 is an investigation of a 34-link network for which the problem is stated as achieving the desired level of all-terminal connectivity for minimal price. Section 5 presents a probabilistic description of network disintegration process based on so-called network D-spectrum.

2. Problem Formulation and Algorithm

By transportation network (TN) $N = (V, E, T)$ we denote an undirected graph with a node-set $V, |V| = n$, an edge-set $E, |E| = m$, and a set $T \subseteq V$ of special nodes called *terminals*. Instead of the term *edge* we will often use the word *link* or *arc*. Each network link e is associated with a probability p_e of being *up* and probability $q_e = 1 - p_e$ of being *down*. We postulate that link failures are mutually independent events. Link failure means its elimination (erasing) from E.

A. Let s and t be two distinct terminals, $s, t \in T$. The TN will be called $s-t$ (or source-terminal) connected if there is a path connecting s and t, with all its edges being in the *up* state. Denote by $R(s-t; \vec{p})$ the probability that the TN is $s-t$ connected. Here $\vec{p}$ denotes the vector of link *up* probabilities $: \vec{p} = (p_1, p_2, \ldots, p_m)$. In TN, typically there are several $s-t$ pairs of nodes whose connection is of special importance. We assume that there are k such pairs and denote them as $Z = \{s_1 - t_1, \ldots, s_k - t_k\}$.

Our first formulation of the NPC is *maximizing* the *minimal* reliability of the $s-t$ connectivity over the set of all source-terminal pairs Z:

$$G(\vec{p}) = \min_{i \in Z}[R(s_i - t_i; \vec{p})]. \tag{1}$$

Let us introduce two additional vectors: $p^* = (p_1^*, \ldots, p_k^*)$ and $c^* = (c_1, \ldots, c_k)$, where c_j is the cost of *increasing* link j *up* probability from p_j to p_j^*.

Let $\vec{B} = (b_1, \ldots, b_k)$ be a k-dimensional vector with binary 0/1 components. The set of all 2^k binary vectors we denote by Ω. Suppose we choose a particular vector $\vec{B} \in \Omega$ and decide to reinforce those links whose coordinates in $\vec{B}$ are not zeroes. Then the vector of link *up* probabilities will become

$$\vec{p}(\vec{B}) = (p_1 + (p_1^* - p_1) \cdot b_1, \ldots, p_k + (p_k^* - p_k) \cdot b_k).$$

The cost of this action will be

$$C(\vec{B}) = c_1 \cdot b_1 + \ldots + c_k \cdot b_k.$$

Suppose that the total reinforcement budget must not exceed the given value B.

Now we are ready to formulate our optimization problem in the following compact form: find such $\vec{B} \in \Omega$ which *maximizes*

$$G(\vec{p}(\vec{B})) \quad \text{subject to} \quad C(\vec{B}) \le D. \tag{2}$$

Now let us approach the maximization procedure. It will be based on an efficient Monte Carlo procedure of estimating network reliability gradient function. It does not demand the knowledge of the analytic form of $R(s_i - t_i; \vec{p})$. Let us postpone to the Appendix the details of the gradient estimation procedure and suppose that we have an accurate estimate of

$$\Delta_i R(s-t; \vec{p}) \approx \frac{\partial R(s-t; \vec{p})}{\partial p_i} \cdot (p_i^* - p_i).$$

Now we are ready describe a greedy type semi-heuristic solution algorithm for solving problem (2). Denote by S the set of all indices $\{1, 2, ..., k\}$ and all *pairs* of indices $\{(i, j), 1 \le i < j \le k\}$.

Algorithm MinGradKnapsack

1. Set $X := 0$.

2. $Y := G(\vec{p})$. (This is the initial value of the NPC)

3. For each element $\alpha \in S$, estimate $\Delta_i G(\vec{p})$. [Calculate the increase of the minimal probability of $s-t$ connectivity as a result of the reinforcement of link (or links) α].

4. Calculate $\eta_\alpha = \dfrac{\Delta_i G(\vec{p})}{c_\alpha}$, for each $\alpha \in S$ and arrange them in *decreasing* order. Denote by w the index of the *maximal* η_i. [If α is a pair of indices, e.g $\alpha = (r, s)$, then put $c_\alpha = c_r + c_s$].

5. Put $X := X + c_w; S := S \setminus \alpha$. [Delete α from the set S; if $\alpha = j$, delete j and all pairs containing j. Act similarly if $\alpha = (r, s)$].

6. Recalculate p by replacing p_α by p_α^*. [If α is a pair (r,s), replace the r-th and the s-th component of p by p_r^*, p_s^*].

7. If $X > D$, then Stop. Otherwise GOTO 2. #

In simple words, the algorithm finds on each step the link or a pair of links whose reinforcement provides the maximal performance measure *increase per unit cost*, recalculates the reliabilities of all $s-t$ connections involved and the gradient vector after the links have been reinforced, repeats this procedure in a loop and stops when the budget becomes exhausted.

B. Our second network predisasted design approach is dual to the previous one. It consider the search for the minimal-cost link reinforcement to provide the given level of the reliability criterion, which in our example is defined as the probability of all-terminal connectivity. The optimization algorithm basically copies the above described heuristic Knapsack-type procedure: on each step, it chooses for reinforcent that link which provides the maximal reliability increase per unit cost.

3. Example 1: 30-link Network of Istanbul [1]

We describe in this section a road network of Istanbul, borrowed from the paper [1] by Srinivas Peeta, F.Sibel Salman, Dillek Gunnec, and Kannan Viswanath. The data for this example are summarized in Table 1 and are cited with the kind permission of the authors.

The network has 30 links and 20 nodes. The first and the fourth columns contain data on the links and the nodes they connect. Columns 2 and 5 are the link reinforcement costs; columns 3 and 6 give the link *up* probability. As suggested in [1], five $s-t$ routes are of primary importance: $a = (14,20)$, $b = (14,7), f = (12,18), g = (9,7)$, and $h = (4,8)$.

Our goal is to find the links which are to be reinforced in order to *maximize* the minimal reliability of the $s-t$ connectivity over the routes a, b, f, g, h. As assumed in [1], reinforcement of a link e raises its *up* probability from p_e to $p_e^* = 1$ for all e. We assumed the budget constraint $D = 1700$.

Our algorithm found that the following links have to be reinforced: 10, 17, 20, 21, 22, 23, the total cost of which is 1680. Our algorithm carried out 5 cycles. On each of the first four cycles, one link has been reinforced, and two links were selected on the last, fifth cycle.

The minimal reliability has route h: $R(h)=0.686$; the reliability of other $s-t$ pairs are as follows:

$$R(a) = 0.773, R(b) = 0.723, R(f) = 0.999, R(g) = 0.834.$$

In spite of the fact that [1] considers quite different NPC, a convex combination of functions of paths lengths for 5 selected pairs, our optimization results greatly coincide: [1] recommends the reinforcement of the links 10, 20, 21, 22, 23, 25. The cost of this replacement is smaller – 1640, the minimal $s-t$ probability 0.682 have routes b, h. The average reliability of the above 5 pairs differ only by 0.003 and is 0.800.

Table 1. Links, their repair costs and reliability for Example 1

Link $e=(a,b)$	c_e	p_e	Link $e=(a,b)$	c_e	p_e
1=(1,3)	80	0.80	16=(11,13)	940	0.55
2=(2,4)	80	0.80	17=(12,13)	300	0.70
3=(3,4)	320	0.80	18=(12,16)	520	0.60
4=(3,5)	260	0.70	19=(12,25)	40	0.80
5=(4,6)	160	0.80	20=(13,14)	800	0.55
6=(5,8)	420	0.60	21=(14,15)	40	0.80
7=(5,10)	160	0.80	22=(15,18)	160	0.70
8=(6,7)	620	0.60	23=(16,17)	40	0.80
9=(7,10)	120	0.80	24=(17,21)	620	0.60
10=(7,11)	340	0.70	25=(18,20)	260	0.70
11=(8,9)	940	0.55	26=(18,21)	780	0.60
12=(8,10)	160	0.80	27=(19,20)	800	0.55
13=(9,11)	620	0.60	28=(20,22)	120	0.80
14=(9,12)	180	0.50	29=(21,23)	220	0.70
15=(9,24)	40	0.80	30=(22,23)	500	0.60

4. Example 2: 34-link Network with 25 Nodes, 4 Terminals

Table 2. Links, costs and reliabilities for Example 2

Link $e=(a,b)$	c_e	p_e	Link $e=(a,b)$	c_e	p_e
1=(1,2)	1	0.6	18=(11,13)	2	0.8
2=(1,3)	2	0.7	19=(12,13)	3	0.6
3=(1,23)	3	0.8	20=(12,16)	4	0.7
4=(2,4)	4	0.6	21=(12,25)	1	0.8
5=(2,22)	1	0.7	22=(13,14)	2	0.6
6=(3,4)	2	0.8	23=(14,15)	3	0.7
7=(3,5)	3	0.6	24=(15,18)	4	0.8
8=(4,6)	4	0.7	25=(15,24)	1	0.6
9=(5,8)	1	0.8	26=(16,17)	2	0.7
10=(5,10)	2	0.6	27=(17,21)	3	0.8
11=(6,7)	3	0.7	28=(18,20)	4	0.6
12=(7,10)	4	0.8	29=(18,21)	1	0.7
13=(7,11)	1	0.6	30=(19,20)	2	0.8
14=(8,9)	2	0.7	31=(19,25)	3	0.6
15=(8,10)	3	0.8	32=(20,22)	4	0.7
16=(9,11)	4	0.6	33=(21,23)	1	0.8
17=(9,24)	1	0.7	34=(22,23)	2	0.6

Table 3. First iteration of the solution for Example 2

Link $e=(a,b)$	$\alpha = \dfrac{\partial R}{\partial p(e)}$	$\dfrac{\alpha \cdot (0.9 - p)}{c(e)}$	Link $e=(a,b)$	$\alpha = \dfrac{\partial R}{\partial p(e)}$	$\dfrac{\alpha \cdot (0.9 - p)}{c(e)}$
1=(1,2)	0.0618	0.018	18=(11,13)	0.1534	0.075
2=(1,3)	0.1430	0.0014	19=(12,13)	0.2524	0.0253
3=(1,23)	0.1632	0.0053	20=(12,16)	0.1638	0.0068
4=(2,4)	0.0709	0.0052	21=(12,25)	0.1005	0.010
5=(2,22)	0.0648	0.013	22=(13,14)	0.0868	0.013
6=(3,4)	0.0502	0.0153	23=(14,15)	0.0756	0.005
7=(3,5)	0.1526	0.0153	24=(15,18)	0.1405	0.0035
8=(4,6)	0.0856	0.0042	25=(15,24)	0.0946	**0.028**
9=(5,8)	0.0502	0.005	26=(16,17)	0.1362	0.0135
10=(5,10)	0.0708	0.010	27=(17,21)	0.1192	0.004
11=(6,7)	0.0852	0.0057	28=(18,20)	0.1235	0.0092
12=(7,10)	0.1325	0.0032	29=(18,21)	0.1720	**0.034**
13=(7,11)	0.1113	**0.033**	30=(19,20)	0.1008	0.005
14=(8,9)	0.0843	0.0085	31=(19,25)	0.1334	0.0133
15=(8,10)	0.1055	0.0037	32=(20,22)	0.1010	0.005
16=(9,11)	0.0775	0.0058	33=(21,23)	0.1538	0.015
17=(9,24)	0.0825	0.016	34=(22,23)	0.0528	0.008

The network has 34 links, 25 nodes, 4 of which are terminals (nodes 1, 18, 10, 12). Link reliabilities are presented in the third and sixth columns of Table 2. They range from 0.6 to 0.8. Reinforcement costs are given in the second and fourth column of Table 2. They range from 1 to 4. Contrary to the assumption made in the previous example, in this example we assume that the reinforced links have reliability less than 1, namely p*= 0.9.

Our goal is to reinforce edges to achieve $R^* = 0.85$ for minimal cost. The initial network reliability is $R_0 = 0.471$. Table 3 presents the first iteration of the solution by the Algorithm MinGradKnapsack. Note that in this example on each iteration we choose three "best" links.

The second and fifth columns give the values of the partial derivatives $\alpha = \dfrac{\partial R}{\partial p(e)}$. The third and

sixth columns give the crucial ratio for reinforcement $\dfrac{\alpha \cdot (0.9 - p)}{c(e)}$. We see from the Table 3 that three

links have the largest values of this ratio are 13, 25 and 29. According to the algorithm, we replace these links by more reliable, with the probability 0.9. This reinforcement raises the network reliability to $R_1 = 0.627$.

In the next iteration (not shown in this table) the links 7, 19 and 13 were chosen, and the network reliability becomes $R_2 = 0.719$. The next iteration gives links 1, 10, 17 and $R_3 = 0.783$. The last iteration adds links 2, 18, 22 and the final reliability is $R_4 = 0.848$.

In addition we can do the following remark about the accuracy of the result. The costs are rather approximate. Suppose that each cost c(e) = 1, 2, 3, 4, have possible fluctuations in the range [–0.5, +0.5].

Assuming that they are random, then approximately the sum of twelve such cost values will have fluctuations in the range $[-3.5 \cdot 0.5, +3.5 \cdot 0.5]$, i.e. in the range about [–2, +2]. This justifies our heuristic solution, not speaking about other sources of uncertainty like errors in determining p(e) and p*.

5. D- spectrum and Network Behaviour in the Process of Link Elimination

Imagine that there is an external process of "shocks", which destroy *in random* order, one link of the network after another. Such process may be a sequence of earthquakes, heavy road accidents, or even "enemy attacks". For the purpose of our exposition, the probabilistic description of this process is not essential, since we count "time" in the number of destroyed links.

We are interested in the probabilistic description of the process of gradual network disintegration into isolated components containing network terminals (which we call "clusters"). Theoretically, there are

several stages of this disintegration. On the first, the all-terminal connectivity is violated and the network falls apart into two clusters. When the links continue to fail, sooner or later there will appear three clusters, and finally each terminal will become isolated from all others.

Let us illustrate the first stage of this process on the example of 34-link network described in Section 4.

The central role in this description belongs to the so-called network *D-spectrum* which in our case coincides with so-called *signature* [4], [5]. Definition and some properties of the D-spectra are described in Appendix 2. For our exposition it is important only to mention that the D-spectrum is a discrete cumulative distribution function $H(x)$ of the random variable Y which is the number of sequentially destroyed links which cause network transition from state *UP* (all terminals are connected to each other) to the state *DOWN* defined as the loss of terminal connectivity. It means the following.

Suppose that links fail in random order. Let $h(i)$ be the probability that the network failure took place on the *i-th* step of this process, i.e. after exactly i links have failed, $h(i) = P(Y = i)$ and

$$H(x) = h(1) + h(2) + ... + h(x) = P(Y \le x), x = 1,2,...,n.$$

In the table below we present the D-spectrum $H(x)$ for the 34-link network of Example 2. $H(1) = H(2) = 0$, $H(24) = H(25) = ... = H(34) = 1$, all other $H(x)$ values are shown in Table 3. These values are obtained as a result of a Monte Carlo experiment the detail of which are described in the Appendix 2.

From this table we see that the minimal size cut set of the network is 3. (More exactly, there are 12 such cuts). With probability about 0.93 the network fails after 7 or more links have failed. After 16 links fail, network is *DOWN* with probability close to 1. So, all process of loss of terminal connectivity takes place in rather narrow interval [7, 16] of failed links. On the average, about 10 link failures cause the network to lose its terminal connectivity. In network analysis, the quantities which describe network *resilience* are expressed via the ratio of the number of failed links causing network failure to the total number of links.

In our example, the average resilience is $\frac{10}{34} = 0.31$. This is a rather low number typical for sparse network. Indeed, our network is rather sparse, it has the average node degree $d = 34 \cdot \frac{2}{25} = 2.7$, which means that on the average there are less than 3 links incident to each node.

Table 4. Cumulative D-spectrum of the Network of Example 2

x	3	4	5	6	7	8	9
H(x)	.00216	.00991	.02790	.06464	.12748	.22590	.35821
x	10	11	12	13	14	15	16
H(x)	.51183	.66381	.79200	.88272	.93876	.97106	.98769
x	17	18	19	20	21	22	23
H(x)	.99509	.99816	.99934	.99984	.99996	.99999	1

6. Appendices

Appendix 1. $s - t$ Reliability and Reliability Gradient

To estimate the $s - t$ connectivity reliability we suggest one of the Monte Carlo procedures described in [3], e.g. the turnip algorithm, see Chapter 9. For small networks, it might be even the crude Monte Carlo.

Let us describe an efficient approach to estimating the network reliability gradient vector. It is based on identifying so-called network *border states* [3], Chapter 5.

Definition A1.

Reliability gradient vector ∇R is defined as $\nabla R = (\frac{\partial R}{\partial p_1}, \ldots, \frac{\partial R}{\partial p_k}).\#$

Denote by a binary variable e_i the state of the *i*-th network component: 0 means *down*, 1 means *up*.

Definition A2.

Network state $V = (e_1, \ldots, e_k)$ is called *border state* if:

1. This state is a *DOWN* state;

2. There exists such state $W, W \in UP$, that the states V and W differ in exactly one position (i.e. the Manhattan distance between vectors W and V equals 1). #

The following formula [3] binds together the partial derivative $\dfrac{\partial R}{\partial p_i}$ and the set of such border states that each of them may be transferred into the *UP* state by turning a single *down* element $e_i = 0$ into *up* state $e_i = 1$:

$$\frac{\partial R}{\partial p_i} = q_i^{-1} \{ \sum_{\{v \in BD, v+(0,\ldots,0,1_i,0,\ldots 0) \in UP\}} P(v) \}, \qquad i = 1, \ldots, k. \tag{3}$$

Here *BD* is the set of all border states, and *P(v)* stands for the static probability of the state *v*. In words: to calculate the *i*-th gradient's vector component, it is necessary to find the probability of all border states which become *UP* by "activating" a single component e_i.

The last formula is the key for Monte Carlo algorithm for computing reliability gradient. Note that this algorithm is rather efficient and avoids the so called *rare event phenomenon*. The algorithm works as follows.

Simulate permutation of the network elements. Suppose that initially all elements are *down*, and they are arranged in the order determined by this permutation. Start turning the elements from *down* to *up* from left to right. Suppose that after adding a new *up* element we arrive at a border state. Clearly, from this moment the network remains in border states until the moment it becomes *UP*. Calculate and sum up *P(v)* for all elements which may transfer the border state *v* into an *UP* state.

Appendix 2. Cumulative D-spectrum

Let us number the components of the network subject to failure by numbers $e_1, e_2, \ldots, e_n$, and consider an arbitrary permutation $\pi = (e_{i_1}, e_{i_2}, \ldots, e_{i_n})$ of these numbers. Assume that all components are *up* and we start turning them *down* moving from left to right along π. On each step of this process we check the network state and fix the step number $Y(\pi)$ on which network state becomes *DOWN*. Imagine that all *n*! permutations are equally probable and this procedure is repeated for each of these n! permutations. Let $h(k) = \dfrac{N(k)}{n!}$ be the ratio of permutations for which $Y(\pi) = k$ to all permutations, or the probability that *Y=k*. $\{h(k), k = 1, \ldots, n\}$ is a discrete density of random variable *Y*. This density was first considered in slightly different context by F. Samaniego in 1985 and called *signature*. In 1991 it was independently introduced by M. Lomonosov and termed *Internal Distribution* (*ID*). Later on, we used the term *D-spectrum* [3], with "D" for destruction process. The cumulative distribution of *Y,* $H(x) = h(1) + h(2) + \ldots + h(x)$ is called cumulative D-spectrum (or cumulative signature). It is important to stress that the D-spectrum is a structural parameter of the network which depends only on its topology and failure state, i.e. *DOWN* definition, and not on the random mechanism governing the real process of network component failures.

The D-spectrum has many interesting properties, the central of which is the following formula for network *DOWN* probability if the network components fail independently of each other and have failure probability *q*:

$$P(DOWN; q) = \sum_{x=1}^{n} H(x) q^x (1-q)^{n-x} \cdot \frac{n!}{x!(n-x)!}.$$

It follows from the definition of the D-spectrum that *H(x)* describes the probabilistic mechanism of network transition from *UP* state to *DOWN*, which in our example was defined as the loss of all-terminal

connectivity. Introducing several stages of network disintegration (appearance of two, three and four isolated components containing terminals, so-called clusters), we arrive at the definition of the first, second and third marginal D-spectra. This extension will not be considered here and the interested reader can find the details in [4].

The exact calculation of the D-spectrum is a NP computation problem. We will adopt a Monte Carlo approach to the approximation of D-spectrum. The corresponding Monte Carlo algorithm is based on M replications of the process of generating random permutation and on follow up of the network state in the process of turning *down* network components in accordance to the above described definition. Let $N(k)$ be the number of permutations, out of M generated, in which the network failure take place on the

k-*th* step. Then the estimate of $H(k)$ will be the ratio $\dfrac{N(k)}{M}$. The details of this algorithm can be found

in [3]. For networks of size similar to that considered in Example 2 it is enough to take $M = 10^5$, which takes just a few seconds of calculation on a PC computer.

References

1. Srinivas Peeta, F. Sibel Salman, Dillek Gunnec, Kannan Viswanath. Predisaster Investment Decisions for Strengthening a Highway Network, *Computers & Operations Research,* Vol. 37, 2010, pp. 1708–1719.
2. Sanchez-Silva, M., Daniels, M., Lleras, G., Patino, D. A Transport Network Reliability Model for Efficient Assignment of Resources, *Transportation Research, Part B*, Vol. 39, 2005, pp. 47–63.
3. Gertsbakh, Ilya and Yoseph Shpungin. *Models of Network Reliability: Analysis, Combinatorics, and Monte Carlo*. CRC Press, 2010. 217 p.
4. Gertsbakh, Ilya and Yoseph Shpungin. *Network Reliability and Resilience*. Springer Briefs, Springer, 2011. (In Press)
5. Samaniego, F. *System Signatures and Their Applications in Reliability Engineering*. New York, Berlin: Springer, 2007. 166 p.

UPGRADING THE EFFICIENCY OF AIRSPACE FLIGHT SIMULATORS FOR EMERGENCY-RESPONSE TRAINING OF SPACE CREWMEMBERS

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Both the flight safety and space crew efficiency depend for the most part upon the crewmembers' professional qualities achieved with the aid of different training systems. The inconvenience of such systems consists in their failure to provide an overall simulation of some psycho-physiological sensations experienced by the crewmembers in real space flight conditions, e.g. air sickness, distortion of equilibrium sense, fatigue, apprehension, anxiety, pain sense modality, etc. With regard to the significance of the above component of space crew training a simulator model with improved training efficiency was designed. The multidimensional effects of the simulating system suggested provide facilities for quality improvement in the crewmembers' training and development of the appropriate decision-making, managerial and other skills essential to the crew in both standard and emergency situations.

Key words: Flight simulator system, operator, psycho-physiological sensations, emergency situations

Introduction

Currently, a great number of methods are available for simulating psycho-physiological sensations in training simulators [1] based on which the characteristics of an object's behaviour are calculated on the real-time basis, the psycho-physiological sensations are synthesized in data paths and converted into the sensations of spatial movements, "in-cockpit" and "out-of-cockpit" visual over-reliance, auditory information (noise and voice data), tactile and kinaesthetic information (from the control devices).

The inconvenience common to simulation systems available consists in their failure to simulate some of psycho-physiological sensations of discomfort that are experienced by crewmembers in real-life space flight conditions, e.g. air sickness, blur of vision, fatigue feeling, apprehension, anxious feeling, pain sense modality, euphoria, distortion of equilibrium sense, etc.)

The designers engaged in development of integrated training systems used to be sceptical about possibility of simulating, by using the technical aids available, the complete real-life information environment including the psycho-physiological stress experienced by the aircrew. For this reason, the object's emergency conditions simulated were marked by representative incompleteness, under-coverage, a kind of conventionality and lack of the sensational component. Consequently, it had its impact on the training efficiency and offered no prospect for acquiring the appropriate skills and decision-making abilities essential in both standard and emergency situations.

In the course of the data analysis on the subject it was found that the occupational activity of air crews, including space crews, is a variety of a complex combination of brain work, physical labour, a nervous activity and emotional tension notable for a dramatic psycho-physiological stress. Based on the results of the expert survey [2] four blocks of essential professional qualities were selected:

- disciplinary and occupational qualities (diligence, responsibility, industry, discipline, performance ability, etc.);
- specific professional qualifications (engineering culture, imaginative thinking, clairvoyance, speciality knowledge, practical knowledge and skills, etc.);
- leadership (managerial abilities, exactingness, critical judgement, educational and character building skills, etc.);
- psychological properties (target aiming function, speed of decision and command, emotional stability, initiative, resoluteness, attentive behaviour, personal autonomy, etc.).

It should be noted that development, accumulation and evaluation of the above qualities are carried out directly during operation and service of a system at real-life strategic facility. According to the analysis the first three blocks of the qualities mentioned are integrated with the psychological properties of a trainee and they determine not only the crew behaviour in a relevant area but also have an effect on the crew flight performance.

Additionally, during the research it was found that most of the psycho-physiological sensations experienced by a person in a real-life environment are caused by the infrasonic field of the vehicle that acts as a very-low-frequency conic transducer [3…5]. For this reason the training systems to which the flight simulator in question belongs are to provide a more complete and most accurate reproduction of information environment of a real-life object with due regard for the performance features of various human analysers (auditory sense, visual sense, odour sense, tactile and kinaesthetic sense, acceleration and psycho-physiological sensations, etc.) [1].

With regard to all these essential components of the space flight crew training a flight simulator model was developed by the authors with its improved training performance based on additional representation of new information flows that occur in real-life objects with allowance for representation of the human factor aspect at a higher qualitative level. All the above will finally enhance a general confidence in the flight simulators by validating their characteristics and high-realism performance. The model suggested is based on the method of psycho-physiological sensations simulation in a vehicle simulator [6].

Description

In the block diagram shown on Figure 1 a method is presented for simulation of psycho-physiological sensations in an aerospace flight simulator. The simulator system incorporates:

- real object behaviour simulator 1 (ROBS);
- instructor control panel 2 (ICP);
- acceleration stress simulator 3 (ASS);
- voice information simulator 4 (VIS);
- out-of-cockpit visual information simulator 5 (OCVIS);
- in-cockpit visual information simulator 6 (ICVIS);
- tactile and kinaesthetic information simulator 7 (TKIS);
- very-low-frequency generator 8 (VLFG);
- very-low-frequency variable intensity amplifier 9 (VLFVIA);
- very-low-frequency sonic converter 10 (VLFSC);
- infrasonic vibration analyser 11 (ISVA);
- operator workstation 12 (OWS);
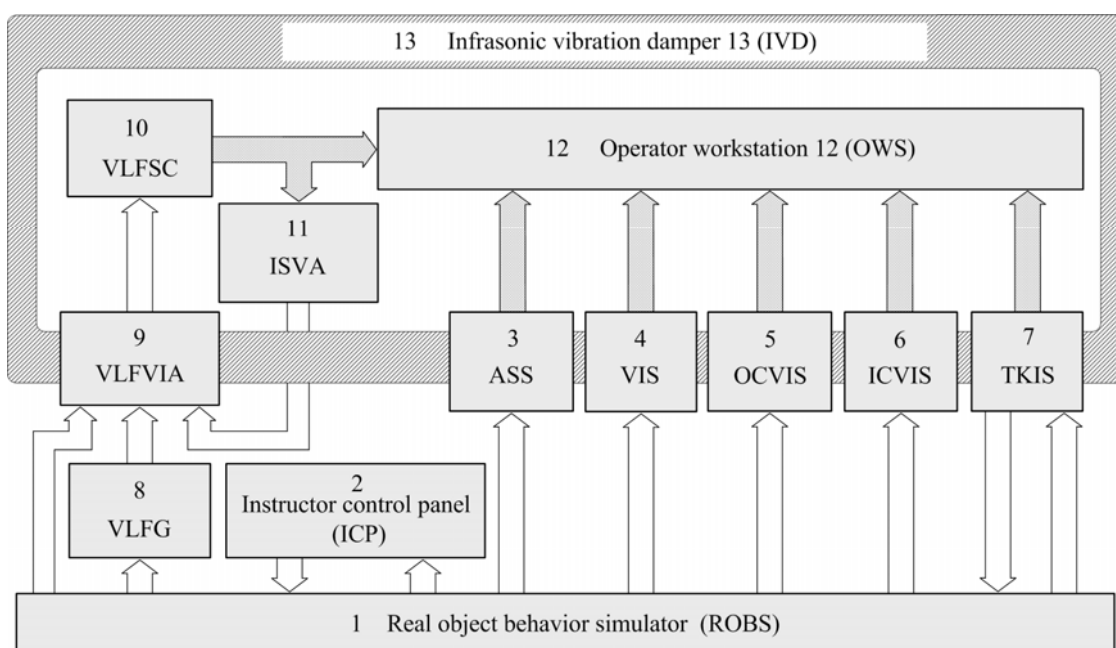- infrasonic vibration damper 13 (IVD).

Figure 1. Flight simulator block diagram

The operator 12 performing a training task activates the control devices located in the tactile and kinaesthetic information simulator 7. As this takes place, the electrical signals formed in the simulator 7 are transferred via the data bus to the real object behaviour simulator 1. The simulator 1 is a hardware and software package used to solve the equations for real-time representation of the behaviour simulator of a real object, e.g. an airspace vehicle. The package also enables calculation of the dynamic factor, the aerodynamic coefficient and other parameters as well as the kinematical relation, logic and differential equations which describe the kinematics of behaviour of the simulated object and its onboard systems.

On the signals received from the tactile and kinaesthetic information simulator 7 the simulator 1 synthesizes the parameters of the real object operation and, by data bus transfer, operates the simulators 3...7, the instructor control panel 2, the VLF generator 8, and the VLF variable intensity amplifier 9. In response to these signals:

- the acceleration stress simulator 3, according to the program of sensation of motion simulation and by means of the dynamic stand, acts on the operator 12 and creates an illusion of spatial motion.
- voice information simulator 4 synthesizes the audible signals and acts on the acoustic apparatus of the operator 12, thus creating for him an illusion of the operating engines, internal modules, the simulated vehicle, the in-cockpit and out-of-cockpit ambient noise, enc.;
- the out-of-cockpit visual information simulator 5 generates the out-of-cockpit space images and creates for the operator 12 an illusion of visual presence in some space environment;
- the in-cockpit visual information simulator 6, via the onboard instruments and indicators, provides the operator 12 with the information on the trajectory parameters of the simulated vehicle;
- the tactile and kinaesthetic information simulator 7 represents the realistic characteristics of the effort experience on the control devices according to the simulated situation;
- the instructor control panel 2 provides the instructor with the information on the functioning of the simulated vehicle systems and the current actions of the operator 12 necessary for further evaluation of his flight performance. During performance of the training task, the instructor 2, without prior warning the operator 12, by using the control panel 2, enters to the simulator 1 input the data on various emergency situations that might occur in a real-life object (vehicle).
- the VLF sonic converter 10 converts the electric signals received from the VLF variable intensity amplifier 9 into infrasonic vibrations. The frequency and intensity of these vibrations are determined by the input signals in generator 8 and the amplifier 9;
- the infrasonic vibration analyser 11 provides continuous monitoring of timing data, energy characteristics, and frequency response of the infrasonic vibrations in the source 10. In case the infrasonic intensity limiting value is reached or exceeded an emergency signal is formed which is applied to the variable input of the amplifier 9 to decrease the amplification factor to the safe level. Considering the operating efficiency requirements to the simulator acoustic system tight standards are established for their quality which must be adhered to over the rated service life. The most suitable among the variety of the systems of the type is the magnetostrictive converter of the motion parameters of the VLFSC acoustic vibration system 10.

With a view to limit the infrasonic effect of the ambient environment the simulator cockpit with the operator workstation 12, analyser 11 and vibration source 10 are enclosed in the damper 13.

Conclusions

The simulation method suggested can be applied in training strategic facility operators, who experience mental stresses and, thus, require emotional maturity, good memory and perceptual ability, endurance and stamina. The multidimensional effects of the simulating device provide the possibility for optimisation of the psycho physiological state of the trainees and for development of the appropriate professional skills essential in both standard and emergency situations.

Significant results were obtained by the students in the course of the research in this area carried at the Automation and Control Department of Penza State Academy:

- an application for an alleged invention was filed and Patent of the Russian Federation was received [6];
- The Intelligent Flight Simulators and Training Systems project Award (Diploma), The "Eureka-2007" All-Russian Higher School Students Scientific and Technical Creativity Review Competition, Novochrekassk;

- The Advanced Scientific and Technical Inventive Activity Award (Medal) for "The R&D of Automated Control System for Airspace Simulator" project in category "The Best Research Project in Engineering Sciences", The All-Russian Youth Projects and Programs Competition ("Scientific and Technical Creativity of Youth –NTTM Exhibition", Moscow, July 2009);

References

1. Proshkina, L. A. *Improving the management of aircraft simulator in terms of economic modernization a monograph*. Penza: PGU, 2008. 156 p. (In Russian)
2. Samolayev, Yu. N. Classification of professionally important qualities of aviation specialist "Trainers and Computerized Vocational Training" In: *Proceedings of IV All-Russian Scientific Methodological Workshop, Gubkin Russian State University of Oil and Gas (GANG)*. Moscow, 1994, pp. 14–16. (In Russian)
3. Izmerov, N. F. *et al. Infrasound as a risk factor for human health / hygiene, medical-biological andpathogenetic mechanisms /.* Voronezh, 1998. 276 p. (In Russian)
4. Novogrudsky, E. E. *et al. Infrasound enemy or friend.* Moscow: Mashinostroyeniye, 1989. 64 p. (In Russian)
5. Pokrovsky, B. L. *The pilots on psychology.* Moscow: The USSR Ministry of Defense Publishing House, 1974. 83 p. (In Russian)
6. Patent 2369909 RF. MKI: G09B9/00. Method for modeling psychophysiological effects in the simulator and a device for its implementation /V. N. Proshkin et al., *Bulletin*, No 28, October 10, 2009. (In Russian)

COLLECTING DATA BY INTERNET ON STATED PREFERENCE FOR TRANSPORT SUPPLY: THREE CASE STUDIES ON SURVEY MODE COMPARISON

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Internet-based data has become an important source for market research in the developed world, following the rapidly improving technology and increase in Internet access and use. Given the existence of an acceptable and accessible sampling frame, sampling by the Internet is much cheaper than any other sampling method. A main issue is to which extent use of different survey modes, particularly the Internet, will affect survey results, and if differences are due to different representation of genders, age groups, etc., or due to the survey mode itself.

This paper presents recent experiences from the use of Internet-based stated-preference surveys combined with other survey modes, particularly postal mail sampling. Preferences were stated as sequential pair-wise choices between transport options. Comparing models with and without weighting with respect to gender, age and unemployment, we show that there is a significant survey-mode effect on a large share of attribute parameters.

Keywords: pair-wise choices, public transport, sampling bias, time savings

1. Introduction

Internet-based surveys (web surveys) have become an important source for market research in the developed world, following the rapidly improving technology and increase in Internet access and use [1]. Given the existence of an acceptable and accessible sampling frame, sampling by the Internet is much cheaper than any other sampling method [2], [3], [4]. That is, if the respondent can be sampled by the Internet, for example by sending a hyperlink to the person's e-mail address, there is no additional shipment or dispatch costs of sampling. Even if the recruitment is to be carried out by telephone or ordinal mail, there will be a cost reduction compared to other sampling methods since the respondent plots and returns the data with no additional costs for the survey administrator. Data collection by Internet has also similar advantages as other computerized interviewing methods, enabling interactive and customized questionnaires [5]. Tailor-made questions for different individuals is also considered advantageous in stated preference surveys, for example, enabling questions and choices to be pivoted from the individuals' actual behaviour and making logical specifications following previous responses [6], [7].

Stated preference (SP) methods are survey-based methods for eliciting values of either new product attributes or (components of) public services [8]. The application of these methods are hampered by the cost of gathering survey data, when considering strict requirements of probability sampling and data quality. Thus, it becomes particularily relevant in the application of stated preference methodology to assess if there are adverse effects from use of Internet that may counterbalance the cost savings and other advantages. A main potential disadvantage of using Internet is related to the still limited accessibility to Internet for some population segments. Also in Scandinavia, where Internet access and use are most extended, there is relatively lower access among elderly and social security recipients, and, in general, lower access/use among women than men (www.ssb.no, www.scb.se). Thus, the characteristics of the respondents to an Internet survey may differ from what obtained by other sampling methods, and, most importantly, differ from the affected (theoretical) population [1]. There is still limited knowledge on how the use of Internet will affect valuations based on stated preference studies [9].

This paper presents experience from use of Internet-based surveying in three different SP studies applied to public transport. Internet was combined with either mail-based questionnaires or computer-aided personal interviews, such that our data enable testing of the Internet mode effect. We can assess if use of Internet influences on value estimates from SP surveys. To our knowledge, quite few studies have presented tests of the Internet effect on SP based values. We also describe differences in respondent characteristics between modes. The remainder of the paper is arranged as the following. The next section lists potential advantages and disadvantages of Internet-based surveys compared to alternative survey methods. The third section provides a description of the stated preference studies investigated. The fourth section presents the findings, and these are discussed and concluded in the last section.

2. Advantages and Disadvantages of Web Surveys

2.1. Growth of Internet access and use enabling cost savings in data collection

During the last decade the use and access to Internet has increased considerably in Norway and Sweden. According to the International Telecommunication Union, ca 77% of the Swedish population had access to the Internet in 2007 (www.itu.int). For the Norwegian population the access rate was 83%; most of these had broadband connection, and they spent on average approximately 1 hour on the Internet per day [10]. The accessibility/usage rate of Internet in Scandinavia is among the highest in the World.[1]

Data collection by traditional computerised methods, as home interviews using portable computer, has become very expensive. Currently a home interview (either face-to-face interview or assisted survey by a laptop computer) will cost approximately NOK1,000 (about €120). There is hardly any economics of scale when increasing the number of respondents up to 500 or 1000, such that 500 interviews will cost around NOK500,000 (€60,000) and 1000 interviews NOK1 million (€120,000). Looking only at the part of answering the questionnaire, the cost of self-administered Internet surveys does not increase linearly according to the number of respondents. The average interview cost per interviewee will decrease as the number of respondents rise. Thus, the greater the sample, the more savings can be made by carrying out self-administered Internet surveys compared to home interviews. The web method has been found significantly cheaper than the mail method when the number of subjects is more than 200 [2]. For a given budget the Internet survey offers much larger sample size than, e.g., the conventional mail survey [4].[2]

Furthermore, an average response time has been estimated to approximately six days in Internet surveys, compared to approximately 16 days in a mail survey [2]. Thus, the speed in Internet-based data collection is approximately four times faster. However, these comparisons are based on the existence of an e-mail register for the Internet-based data collection. If the invitation to participate has to be based on postal mail or phone, inviting the persons to connect to a web address (where the survey is placed) or provide an e-mail address, the speed gain will be less. When e-mail registers are available, the minimum time required from e-mailing the invitation to participate in the survey to receiving a response from the respondent, is the time it takes for the respondent to read the e-mail, click the link to the web-based questionnaire, fill in the questionnaire, and press the submit button.

2.2. Limited access for some segments and lack of public e-mail registers

Access to Internet still differs between population groups in Norway. Among the elderly the access rate is lowest, and those who have access do not use Internet as much as younger people [12]. In general, people with low income and/or only basic education do not use Internet as much as those with higher education and/or high income. Furthermore, more men than women use the Internet (www.ssb.no; www.scb.se). In addition to access and computer know-how, respondents must also have compatible hardware and software in order to successfully complete an Internet survey [3]. When Internet access/use differs between segments, problems concerning sample coverage and sample representativeness may be expected – at least for surveys covering the overall adult population [11]. It poses a much lesser problem if the target population is a subpopulation with very high Internet usage, e.g. university students or government agency staff [13].

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[1] http://www.internetworldstats.com/stats4.htm#europe.

[2] Studies comparing the cost of mail surveys to the cost of internet surveys have found that the former are 20 to 600 percent more costly [2], [11].

A main disadvantage of using Internet sampling and surveying, at least currently, is the lack of extended registers with e-mail addresses, something parallel to telephone number and postal address registers. Thus, if disregarding commercial Internet panels, the first part of the sampling will in most cases have to be based on postal mail or phone, inviting the persons to connect to a web address (where the survey is placed) or provide an e-mail address. Thus, if such a first phase is phone/mail based, also the particular disadvantages of these mediums will apply. This raises costs compared to addressing a register of e-mails, and it reduces the response rate compared to the direct sampling using e-mails. Some potential respondents pay for their Internet access, and will then also have to pay an amount of money to be able to answer a survey. Such costs for the respondents may give an undesirable effect and influence the response rate. Most individuals in Norway access Internet free of charge at work, at school, at the public library, or they have an access at home with a fixed rate and zero marginal costs (not dependent on use). Yet, no e-mail register for the general population exists.

2.3. Potential effects from using Internet-based stated preference (SP) surveys

SP surveys are surveys that include some questions that enable valuation of either new product attributes or (components of) public services [8]. Typically, a SP sequence will involve: i) an introduction to a particular context – a choice/valuation scenario; ii) description of some attribute(s) that may be introduced/improved at some cost; iii) a set of pair-wise choices (or other format for valuation); iv) probe questions related to stated choices (to validate/explain choices and comprehension); and v) individual characteristics (to explain choices and assess representativeness). Generally, there is a demand for high sample quality and, normally, that this should be representative for an identifiable population (e.g., the overall adult population). Also the survey mode should ensure comprehension and incite truthful/ considerate responses.

Relatively few studies involving stated preference (SP) have compared survey mode effects on response rates; and those reported involve contingent valuation rather than choice-based SP [9]. In a contingent valuation study carried out in Portugal, a much lower response rate was obtained in the web-based survey than in in-person interviews, respectively 5% against 84% [14]. This topic of the study was valuation of environmental improvements. However, in a test of Internet against face-to-face interviews, applied to contingent valuation of biodiversity protection in Norway, the null hypothesis of equal valuations between survey modes could not be rejected at the 10% significance level [9]. In another SP study concerning preferences for protecting nature areas in motorway planning in Denmark, pair-wise choices were applied [11]. Similar (and high) response rates were obtained both for Internet-based survey mode and (postal) mail survey mode, respectively 63.6% and 60.3%. Possibly these differences between results in Portugal and Denmark are, to a large extent, caused by national differences – in Internet access/usage as well as other particularities.[3] In another study involving choice-based SP it was observed significant differences in attribute preferences between sub-samples facing different survey modes, and it was concluded that the Internet-based data collection method was judged superior to a traditional pen-and-paper survey mode on the basis of internal consistency and predictive validity [17]. Taken together, the literature shows quite mixed results regarding the survey-mode effect from Internet.

2.4. Tests of survey-mode effects in stated preference (SP) surveys

Our primary interest is to test if use of web-based surveying affects estimated economic values, compared to other survey modes. Thus the main null hypothesis is that there are equal attribute values from web-based samples and samples from other survey modes, i.e., (postal) mail. We will also test formally if some population segments (age group or gender) are less represented when using Internet. Again, the null hypothesis is no difference. Our data will not enable clean tests of overall response rates, since we do not have split samples. However, we will report how many of the recruited respondents choose responding via Internet versus an alternative survey-mode.

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[3] Another national comparative artefact from Scandinavia is the relatively higher response rates in Sweden than in Norway experienced in SP studies with sampling in both countries [15], [16].

If no survey mode effects are found, it will yield some support to the use of Internet or mixed modes in a survey. It may be regarded as a test of convergent validity [18]. If mode effects do exist, our results based on three independent surveys will yield some indication of directions. If patterns are clear, there may be ways of counteracting bias, e.g., by weighting procedures based on the distribution of registered individual characteristics (age, gender, etc.) that can be compared to distributions in the overall population.

3. Material: Three Recent Internet-Based Stated-Preference Surveys

3.1. Valuation of safe public transport – the "Sweden survey"

The first reported Internet-based SP survey was carried out among the adult population in Sweden (in the cities of Gothenburg and Jönköping). The purpose of the study was to value specific public measures to increase accessibility to safe (secure) public transport [15]. Recruitment of the whole sample was done by postal mail. A random sample was chosen from the National Population Register and a letter with an Internet address for the survey and a personal user name and password was sent to this sample by postal mail. The web survey was supplemented with paper forms, i.e., a traditional mail survey (ensuring that everybody could reply and enabling mode testing).

The survey contained two SP choice sequences; one for attributes at the bus stop and one for attributes on board the bus. The attributes in the first choice sequence were safety, bus stop design and fares. The second sequence contained attributes such as information, safety, fares and driver contact. Since the opportunities for customised design with paper forms are limited, the choices in the SP sequence in the paper format were simpler than in the Internet format.

3.2. Valuation of time savings in public transport – the "Oslo survey"

The second reported Internet-based SP survey was carried out among the adult population in Oslo region (the city of Oslo and the county Akershus), in 2002. The purpose was to analyse people's preferences and evaluations of the quality of public transport services [16]. All respondents were recruited in the same way as in the "Sweden survey", by postal mail. The web surveying was also supplemented with a similar pen-and-paper questionnaire, though the web survey was tailor made to a greater extent than the pen-and-paper version.

The survey contained four choice sequences. In three public transport choice sequences the attributes were fares, walking time to bus stop, headway, travel time, interchange, comfort and delays. An additional public transport versus car SP sequence, the attributes were price, travel time and headway. In the Internet format the respondent was given questions that were linked to a familiar journey. This was done in order to make the trade off as realistic as possible, using this in the construction of hypothetical choices [7]. This is not possible on paper in a mail format, and therefore the respondents to the paper mode had to use some average imaginary journey.

3.3. Valuation of time savings in transport – the "Tønsberg survey"

The third reported Internet-based SP survey was carried out among the adult population in the city of Tønsberg (southeast of Oslo), in 2003. The purpose of the study was to develop concrete proposals for changes in public transport services. In order to describe the optimal public transport provision, an SP analysis was carried out to find passengers' preferences for different quality aspects of journeys by bus, car and bicycle [19].

Recruitment was carried out by telephone instead of mail in this survey. Respondents could choose either a self-administered Internet questionnaire or a computer-aided personal interview (CAPI) at home. Those who choose the self-administered web survey received a hyperlink to a website and a personal password/user name by e-mail. The CAPI was carried out using a laptop computer connected to the Internet via a mobile telephone. Different sub-samples received different SP questions, based on their

main transport mode. Bus passengers chose primarily between different bus journeys, while the other transport mode users (car, cycle) received both within-mode choices and between-mode choices against public transportation. The pair-wise choices included attributes such as the cost of the journey, travel time, delays, transfer, walking time to the bus stop, as well as parking for cars and separated bicycle lanes.

4. Results

4.1. Characteristics of respondents and survey mode

The shares choosing to respond by Internet vs. other survey mode are fairly similar between the three surveys, and the share for Internet is consistently somewhat higher (Table 4.1).

Table 4.1. Response rates in three different web based SP-survey

Survey	Web self-administered	Web home interview	Paper	Total
Sweden survey	24%	n.a.	21%	44%
Oslo survey	16%	n.a.	14%	30%
Tønsberg survey	19%	13%	n.a.	32%

The proportion of men was significantly higher in the sub-samples answering with respect to self-administered Internet, in all three surveys. However, the difference was quite limited in absolute terms. The average age among those who responded through Internet was significantly lower than among those who responded by paper or by CAPI. The age difference is stronger than the gender difference. The proportion of those in employment was significantly larger in the sample which replied using the Internet, in all three surveys. This difference was even stronger than the age difference (Table 4.2).

Table 4.2. Gender, average age, and employment; by survey and survey mode

	"Sweden survey"		"Oslo survey"		"Tønsberg survey"	
	Web	Paper	Web	Paper	Web	Home
Men	52%	41%	54%	46%	53%	42%
Women	48%	52%	46%	54%	47%	58%
n	1406	1232	561	593	582	352
Age	37.8	53.9	36.8	50.7	40.3	49.1
n	1406	1204	561	632	599	354
Employed/student (inc. part time workers)	93%	58%	95%	67%	92%	64%
Not employed (on benefits, pensioners)	7%	42%	5%	34%	8%	36%
n	1339	1243	521	591	563	339

Thus, particularly employment and age, and, to a lesser extent, gender, are characteristics that covariate with individual choice of SP survey mode.

4.2. Formally testing the survey mode effect

Formal tests were carried out with standard binary logit models, assuming linear utility functions, and these were estimated by use of ALOGIT [20]:

$$\Pr(Y_i = 1) = \frac{e^{V_{iA}}}{e^{V_{iA}} + e^{V_{iB}}} = \frac{1}{1 + e^{-(V_{iA} - V_{iB})}} \tag{1}$$

where Y_i is individual i's choice between the two alternatives, A,B (and A is set equal to 1 and B is set equal to 0).

In order to test whether the survey mode has an independent effect on the results, we have added survey mode dummy variables to all separate parameters. The dummy takes value one if self-administered Internet was the survey mode, and is zero otherwise. The parameter, γ_m ($m = 1,\ldots M$ attributes), for

the dummy, D_m, then expresses the isolated effect that the choice of Internet mode, compared to an alternative survey mode, has on the respective attribute (X_m); e.g.:

$$V = \beta_0 + \beta_1 \cdot X_1 + \gamma_1 \cdot D_1 \cdot X_1 + \beta_2 \cdot X_2 + \gamma_2 \cdot D_2 \cdot X_2 \ldots \tag{2}$$

The estimated Internet use dummy parameters are presented, together with common parameter estimates ($\boldsymbol{\beta} = \beta_0, \beta_1, \ldots, \beta_M$) from pooled data (data from both survey modes included in estimation), in Table 4.3.

Table 4.3. The survey mode effect, measured for each attribute including an Internet dummy

Choice sequence	Attributes ($\mathbf{X}$)	Parameters ($\boldsymbol{\beta}$) – pooled sample	Parameters (γ) – Internet mode
"Sweden survey"			
1	Security: security guard at bus stop	0.13	0.409
1	Security: surveillance camera at bus stop	0.06	0.083
1	Bus stop with building/lightning/heating	1.90*	-0.672*
1	Bus stop with penthouse/lightning	1.99*	-0.552*
1	Bus stop with penthouse (no lightning)	0.64*	-0.095
1	Fare, bus	-0.04	-0.020
2	Possible to contact the driver	1.16*	-1.28*
2	Security: surveillance camera and security guard	0.71*	0.567*
2	Security: security guard	1.09*	0.108
2	Security: surveillance camera	0.82*	-0.16
2	Real-time display on board and at bus stop	1.11*	-0.535
2	Real-time display at bus stop	1.16*	-0.769
2	Information at bus stop if delayed	1.55*	-1.18
2	Fare, bus	-0.12*	0.008
"Oslo survey"			
1	Headway	-0.04*	-0.13*
1	Access time	0.02	-0.102*
1	Fare	-0.10*	-0.023*
2	Interchange 10 min	-2.69*	1.02*
2	Interchange 5 min	-1.50*	0.494*
2	Interchange 0 min	-0.36*	-0.012
2	In vehicle time, bus	-0.10*	-0.005
2	Cost, bus	-0.15*	0.045*
3	Delay3	-1.73*	0.791*
3	Delay2	-0.83*	0.262
3	Delay1	-0.24	-0.102
3	In-vehicle time, standing, bus	-0.10*	0.017
3	In-vehicle time, sitting, bus	-0.03*	-0.02*
3	Fare, bus	-0.07*	-0.003
"Tønsberg survey"			
A1	Headway	-0.04*	-0.011
A1	Access time	-0.08*	0.070*
A1	Fare, bus	-0.23*	0.074*
A2	Interchange 10 min	-2.65*	0.357
A2	Interchange 5 min	-1.87*	0.526*
A2	Interchange 0 min	-0.61*	0.213
A2	In-vehicle time, bus	-0.02	-0.058*
A2	Fare, bus	-0.13*	-0.017
B1	Parking bicycle, outside	-0.22	0.287
B1	Parking bicycle, bicycle shed	-0.46*	0.294
B1	Parking bicycle, lockers	-0.89*	0.332
B1	Separated cycle/walking path	2.76*	-0.89*
B1	Cycle lane (in street)	1.51*	-0.084
B1	Cycling on pavement	1.26*	-0.091
B1	Travel time, bicycle	-0.06*	0.033
C1	Time from car park	-0.20*	0.086*
C1	In-vehicle time, car	0.01	-0.060*
C1	Parking charge	-0.07*	0.005

* Significantly different from zero, 95% t-test.

In the "Sweden survey" and the "Oslo survey", combining web and pen-and-paper, approximately half of the parameters are significantly affected by survey mode. The use of Internet has yielded both higher parameter (β_m) estimates (γ_m significantly positive) and lower parameter (β_m) estimates

(γ_m significantly negative). In the case of the "Tønsberg survey", combining self-administered web and CAPI, the survey mode effect is significant for fewer parameters than in the other two surveys.[4]

Based on the findings that gender, age and employment differ significantly between those choosing the self-administered Internet versus other survey modes, we assess the effect of weighting procedures on the web dummy parameters (γ_m). That is, we weigh the the Internet-based sub-sample on the under-representative individual characteristics, that is, females, elderly, and unemployed (up to the level of the sub-sample responding by paper). We limit the comparison to the "Oslo survey" and the "Tønsberg survey", concentrating on the comparable within-mode stated pairwise choice sequences for public transport. Table 4.4 shows Internet dummy parameters for the unweighted case (taken from Table 4.3) and for the cases where the Internet-based sub-samples are weighted with respect to individual characteristics.

Table 4.4. The survey mode effect when weighting the Internet-based sub-sample on under-representative individual characteristics

	γ – non-weighted Internet-based sub-sample		γ – weighted Internet-based sub-sample – age and sex		γ – weighted Internet-based sub-sample – unemployment, age and sex	
	"Oslo survey"	"Tønsberg survey"	"Oslo survey"	"Tønsberg survey"	"Oslo survey"	"Tønsberg survey"
Headway	-0.13*	-0.01	-0.00	-0.01	0.02*	0.01
Access time	-0.10*	0.07*	-0.09*	0.04	-0.06*	0.02
Cost (sequence 1)	-0.02*	0.07*	0.02*	0.05	0.42*	0.08*
Interchange, 10 min waiting time	1.02*	0.36	1.17*	0.11	1.32*	-0.07
Interchange, 5 min waiting time	0.50*	0.53*	0.64*	0.23	0.84*	-0.07
Interchange, no waiting time	-0.01	0.21	0.27	-0.03	0.73*	-0.23
In vehicle time (travel time)	-0.01	-0.09*	0.02	-0.04	0.04*	-0.06*
Cost (sequence 2)	0.05*	-0.02	0.09*	-0.02	0.09*	-0.05

* Significantly different from zero, 95% t-test

For both the "Oslo survey" and the "Tønsberg survey", the weighting with respect to age and sex decreases the survey-mode effect (the strength of the dummy parameters, γ). However, the survey-mode effect increases, even beyond the non-weighted case, if the Internet-based sub-samples additionally are weighted with respect to non-employment. At least, this is the case for the "Oslo survey".

Discussion and Conclusions

Compared to other survey modes, Internet surveys have competitive advantages in terms of speed and costs. It also allows for a more efficient way of dealing with respondents. As other computer-based methods, surveys on Internet derive advantage from skip patterns, randomisation of questions and customized design. Customized design is crucial in SP analyses; it makes the attribute levels more familiar to respondents and provides higher variation in the observations. We have assessed a potential disadvantage of using self-administered Internet surveying, the lack of access to the Internet in certain groups of the population which may yield survey mode biases in SP parameter estimates.

We have shown that there is a significant survey-mode effect on a large share of attribute parameters, in three SP surveys focussing public transport attributes. The direction of change in estimated public transport attribute preferences, when applying self-administered Internet surveying instead of postal mail or CAPI, is not clear in our data.[5] What is indicated, though, is that weighting the Internet-based sample with respect to age and sex, to compensate for too low representativeness of these characteristics, will

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[4] If we, alternatively, run split estimations with respect to survey mode, and then compare non-pooled parameters (betas), we find that there are no significant parameter differences in the "Tønsberg survey", comparing self-administered internet and CAPI. Differences remain in the comparison between self-administered internet and ordinary mail in the other two surveys. However, the cost (fare) parameters were significantly different in only one of three sequences in the "Oslo survey", and not in any sequences in the "Sweden survey". Reduced access time and reduced headway obtained significantly higher parameter values for those responding by internet, in the "Oslo survey". For the other public transport quality parameters, differing significantly with respect to survey mode (interchange and delay in the "Oslo survey", bus stop comfort, driver contact and real-time display / information in the Sweden survey), the estimated values were higher for those responding by postal mail.

[5] However, there might be a pattern of increased size/strength of time and headway parameters in the internet case, while comfort and information parameters are decreased.

decrease but not eliminate the survey mode effect on estimated parameters. When we included weighting with respect to non-employment, the survey-mode effect increased (even beyond the non-weighted case, in one of our studies). Other studies have found more characteristics differing between an Internet sample and a postal mail sample, e.g., civil status and health status [12]. Thus, in our cases there might be some unregistered differences in individual characteristics that drive our results to some extent.

There is stronger survey mode difference when comparing self-administered Internet versus postal mail than when comparing self-administered Internet versus CAPI. This is so, even if the latter comparison is similar in terms of registered individual characteristic differences between Internet and the alternative survey mode. Thus, more than just an issue of sampling and representativeness, it is the way of responding *per se* which drives part of the observed survey mode difference. CAPI, in contrast to the pen-and-paper format, resembled very closely the response situation in the self-administered Internet. The pen-and-paper formats were less customized, and it is just another response situation, ticking off choices on a paper questionnaire rather than clicking around on the screen. When comes to the quality of Internet-based data, as such, several authors indicate that it might be equal or even superior to data from mail questionnaires [17], [21].

In the three surveys we report, a small majority of the recruited chose self-administered Internet survey over postal (paper) survey and computer-based home interview, in contrast to findings from other studies enabling respondents to choose survey mode [22], [23]. Nonetheless, the possibility for improving response rates and reducing non-response and coverage errors are such that the use of mixed-mode surveys are likely to increase in the near future [1]. When comparing our results to those few reported from contingent valuation studies, indicating no significant value differences [9], [11], one must bear in mind that a choice-based SP generally provides more value estimates per respondents than contingent valuation. Thus, the differentiated attribute focus in choice-based SP, compared to the composite good focus in contingent valuation, may by itself increase the probability of observing survey-mode differences in choice-based SP. More studies are needed to assess the Internet effect for SP, both with respect to representativeness, data quality and impact on economic valuations using SP methods.

References

1. Dillman, D. A., Smyth, J. D. and L. M. Christian. *Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method (3rd ed.)*. Hoboken, NJ: John Wiley & Sons, Inc., 2008. 512 p.
2. Cobanoglu, C., Warde, B. and P. J. Moreo. A comparison of mail, fax, and web-based survey methods, *International Journal of Market Research*, Vol. 43, No 4, 2001, pp. 441–452.
3. Schonlau, M., Fricker, Jr. R. D. and M. N. Elliot. *Conducting Research Surveys via E-Mail and the Web*. Santa Monica, CA: Rand, 2002. 142 p.
4. Berrens, R. P., Jenkins-Smith, H., Silva, C. and D. L. Weimer. The advent of Internet surveys for political research: a comparison of telephone and Internet samples, *Political Analysis*, Vol. 11, 2003, pp. 1–22.
5. Johnson, R. M., Orme, B. K., Huber, J. and J. Pinnell. Testing adaptive choice-based conjoint designs. In: *Research Paper Series*. Sequim, WA: Sawtooth Software, Inc., 2005. 14 p.
6. Bradley, M. and A. Daly. Use of logit scaling approach to test for rank-order and fatigue effects in stated preference data, *Transportation*, Vol. 21, No 2, 1994, pp. 167–184.
7. Train, K. and W. W. Wilson. Estimation on stated-preference experiments constructed from revealed-preference choices, *Transportation Research Part B*, Vol. 42, No 3, 2008, pp. 191–203.
8. Bateman, I. J., Carson, R. T., Day, B., Hanemann, W. M., Hanley, N., Hett, T., Jones-Lee, M. W., Loomes, G., Mourato, S., Özdemerioglu, E., Pearce, D. W., Sugden, R. and J. Swanson. *Economic Valuation with Stated Preference Techniques: A Manual*. Cheltenham, UK: Edward Elgar, 2002. 480 p.
9. Lindhjem, H. and S. Navrud. Internet CV surveys – a cheap, fast way to get large samples of biased values? Ås, Norway: Department of Economics and Resource Management (IØR), Norwegian University of Life Sciences (UMB), April 2008. 58 p. Unpublished manuscript
10. Vaage, O. F. *Norsk mediebarometer 2007*. Oslo, Norway: Statistics Norway (SSB), Statistical Analyses 96, 2008. 92 p. (In Norwegian)
11. Olsen, S. B. Internet versus mail: are stated preferences affected by the mode of sampling a choice experiment? *Environmental and Resource Economics*, Vol. 44, No 4, 2009, pp. 591–610.
12. Bech, M. and M. B. Kristensen. Differential response rates in postal and web-based surveys among older respondents, *Survey Research Methods*, Vol. 3, No 1, 2009, pp. 1–6.

13. Kaplowitz, M. D., Hadlock, T. D. and R. Levine. A comparison of web and mail survey response rates, *Public Opinion Quarterly*, Vol. 68, No 1, 2004, pp. 94–101.
14. Marta-Pedroso, C., Freitas, H. and T. Domingos. Testing for the survey mode effect on contingent valuation data quality: a case study of web based versus in-person interviews, *Ecological Economics*, Vol. 62, 2007, pp. 388–398.
15. Stangeby, I. and Å. Nossum. *Trygg kollektivtransport: trafikanters opplevelse av kollektivreiser og tiltak for å øke tryggheten – Dokumentasjonsrapport*. Oslo, Norway: Institute of Transport Economics (TØI), TØI Report 704a/2004, 135 p. (In Norwegian)
16. Nossum, Å. *Kollektivtilbudet i Osloregionen. Trafikantenes verdsetting av tid.* Oslo, Norway: Institute of Transport Economics (TØI), TØI Report 633/2003, 31 p.
17. Sethuraman, R., Kerin, R. A. and W. L. Cron. A field study comparing online and offline data collection methods for identifying product attributes preferences using conjoint analysis, *Journal of Business Research*, Vol. 58, 2005, pp. 602–610.
18. Carmines, E. G. and R. A. Zeller. Reliability and Validity Assessment. In: *Sage University Paper series on Quantitative Applications in Social Sciences, series No 07–017.* Thousand Oaks, CA: Sage Publications Inc., 1979. 73 p.
19. Vibe, N., Kjørstad, K. N., Nossum, Å. and A. Ruud. *Kollektivalternativene i Tønsbergpakken: TØIs bidrag til konsekvensutredningen.* Oslo, Norway: Institute of Transport Economics (TØI), TØI Report 698/2004, 258 p. (In Norwegian)
20. Daly, A. J. *ALOGIT 3.2 Users Manual*. The Hague, Netherlands: Hague Consulting Group, 1992.
21. Ritter, P., Lorig, K., Lauren, D. and K. Matthews. Internet versus mailed questionnaires: a randomized comparison, *Journal of Medical Internet Research*, Vol. 6, No 3, 2004. e29.
22. Leece, P., Bhandari, M., Sprague, S., Swinomtkowski, M. F., Schemithsch, E. H., Tornetta, P., Devereaux, P. J. and G. H. Guyatt. Internet versus mailed questionnaires: a randomized comparison, *Journal of Medical Internet Research*, Vol. 6, No 3, 2004. e30.
23. Manfreda, K. L., Bosnjak, M., Berzelak, J., Haas, I. and V. Vehovar. Web surveys versus other survey modes: a meta-analysis comparing response rates, *International Journal of Market Research*, Vol. 50, No 1, 2008, pp. 79–104.

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FUZZY MODEL IN FUZZY-TECH ENVIRONMENT
FOR THE EVALUATION OF TRANSPORTATION'S QUALITY
FOR CARGO ENTERPRISES IN UKRAINE

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The basic criteria of quality vehicle servicing and operation of road transport enterprises in the transportation market of Ukraine have been reviewed, classified, described and structured. Their formalization by linguistic variables with appropriate terms has been done. Usage of methods of fuzzy inference to determine the integral generalized level of freight transportation's quality has been proposed. Corresponding computer model has been developed in fuzzyTECH – a specialized package of fuzzy modelling

Keywords: transport service, the quality of freight transportation, the criteria for the level of transport service

1. Introduction

In conditions of hard competition in the freight market in Ukraine defining components for the commercial success of carriers are both economic performance and quality of transport service for customers. Transport companies must constantly monitor both the level of their own work and activities of competitors by a significant number of diverse economic, technical, technological and market criteria.

This problem can be efficiently solved only by using modern mathematical methods, computer simulation and information technologies [1–3].

2. Overview of the Main Indicators of the Transportation Quality and Customer's Service for Transport Enterprises in Ukraine

Issues of transport service quality in general and freight transportation in particular are constantly receiving considerable attention of researchers in Ukraine. Analysis of the literature and practical state of the problem based on author's expert researches (surveys among carriers and customers of transportation services), allows to identify for further analysis four main groups of service quality criteria in the Ukrainian freight market (of course, the list is not exhaustive) [1–4].

There are the technological characteristics of individual transportation flight, the quality of customer service in Transport Company for a certain time period, the criteria for evaluation of transport service from its customers (clients) and the images characteristics of the transport service producers on the market. Purely economic criteria in this model will not be considered, as they will be the subject of separate investigations. Next, we briefly examine the criteria for each of these groups, given that some of them may simultaneously belong to multiple groups. In this case, the difference will consist in the method and estimation's units for the same parameter.

2.1. Parameters of quality for performance of a single trip

Evaluation of the separate trip is an important part of operative, daily control of quality for a single driver in his performance of a particular trip. This assessment may include, inter alias, the following parameters [2, 3]:
- implementation of speed limits during the process of truck's motion (,,speed mode");
- timely passage of geographic reference points on the route motion (,,time mode");
- performance of the ordered (prescribed) route of vehicle movement (,,route mode");
- fuel consumption within the planned for trip (,,fuel expense");

- the number of recorded traffic violations or accidents („road incidents" and „road rule");
- loss or damage of the cargo at a separate trip;
- delay to the customer upon delivery of the cargo or supply of transport for loading;
- the time of truck's preparing for the next trip after previous („readiness").

2.2. Summary measure of service orders for a certain period of time

For identify and evaluate the work of the transport company as a whole, and during a certain time period, it can be used next indicators:
- powerful of the transport park („park power");
- degree of satisfaction (on the requested amount) of customer orders („park cover");
- total transportation safety – environmental and road motion („road safety");
- overall style of trips („trip style");
- safety of cargo and claims of customers („maintenance" and „claim");
- timeliness of customer service – delays, trucks failures and replacements („delays").

2.3. Criteria for assessing the transport service by clients

With heightened competition and the struggle for the customer to the market in Ukraine rating service, completeness and quality of execution of clients becomes an important component of a lasting market position, competitive advantage for the carrier. For customers it is usually not as important economic components of transportation other than price.

At the same time, customers primarily concerned with the characteristics of service quality and range of additional services provided by freight transport companies:
- speed of movement and safety of cargoes;
- timeliness and flexibility of service conditions;
- information support and maintenance services;
- provision of such services as customs clearance, temporary storage of cargoes etc;
- forwarding and cargo handling services.

2.4. Image components of the transport service producers in the transportation market

We should separately identify some image characteristics of the transport company's on freight transportation market, in particular:
- duration and work's experience in the market;
- presence of large and well known corporate clients and the amount of their services;
- structure of the vehicle fleet (types, models of trucks, its age);
- staffing drivers, availability and feasibility of transport firm's own repair facilities.

Often for owner clients listed characteristics play a role commensurate with the cost and other technological conditions of transportations.

3. Features Practical Estimation of Transport Companies

Practical evaluation of the transport services quality, especially external (from other members of the transport market – customers, competitors, regulatory organizations), is faced with considerable difficulties in gathering accurate and complete source information. Its objectivity is the main basis for obtaining adequate and reliable results. However, we can see corporate secrecy, trade secrets, a small amount and unreliability of statistical data available for outside use. As result, it makes very difficult (and often, almost impossible) to use for the analysis the traditional, classical probability and statistical techniques and approaches. This situation requires the use fundamentally different modelling techniques.

3.1. The appropriateness and necessity of using fuzzy modelling

Obviously, that the competitive transport market, the interaction of producers and consumers of transport service contains a large amount of uncertainty of various actions and backgrounds.

Among them the uncertainty of nature, own market, demands, preferences and desires of clients, customers, actions of competitors, government agencies and other internal and external factors.

Under these conditions, one of the most efficient methods of modelling are presented hikes based on the theory of fuzzy sets using appropriate computer software.

3.2. Features and benefits of using the program fuzzyTECH for computer model's implementation.

In several previous papers of the authors [3–5] multi-criteria estimations of the transport service quality were calculated using fuzzy-set approach and its implementation in the software component Fuzzy Logic Toolbox from the MATLAB package.

However, this tool has some serious limitations, including:

- model can be only one-level and in case of tree-structure data transfer from lower to upper level could be achieved only by writing software code, but is impossible through operations in the user interface;

- for single-level model with the number of input variables more than three, there is excessive number of decision rules that clutters the model and makes the practical work with it very difficult;

- user can select only the standard membership functions of linguistic terms and fuzzy variables from the available limited list, but creation of own custom functions in arbitrary forms is provided that does not correspond with practical situations.

These drawbacks may be are overcome in professional fuzzy modelling package fuzzyTECH, which we have chosen for practical computer implementation of the problem.

4. Definition of the Integral Index of Customer Service Quality

Thus, aims of further study were to develop a practical computer model of multi-criteria assessment for transport service quality of freight customers in an environment of fuzzy modelling fuzzyTECH5.5. The article presents light variant of model with using a demo version of this program tool.

4.1. Taken into consideration the parameters of service quality and their characterization

As a result of holding and processing the results of experts' polls on several large transport enterprises in Kharkiv we have identified for further consideration and inclusion in the model the following parameters (their corresponding numbers are listed in Table 1):

- speed mode (2), time mode (3), route mode (1), which in common define intermediate parameter motion mode (14);

- number of road incidents (4), infringements of the traffic regulation – road rules (5), which in common define intermediate parameter road safety (15);

- time for truck's prepare to next trip – readiness (6), age of trucks (7), which together define intermediate parameter trucks (16);

- park power (9), park cover (8), which both define intermediate parameter park possibilities (17);

- client's claim (10), time delays (11), cargo maintenance (12), which together define intermediate parameter service level (20).

In turn, intermediate parameters (14 and 15) together with fuel expenses (13) define parameter trip style (18); (16 and 17) define parameter park (19).

At last, parameters (18, 19 and 20) define overall integrated, total estimation (21), and (18 with 19) provide for transport enterprise an internal estimation of its work's level (22). Graphic representation for relationships between input, intermediate and output parameters in the model is represented on Figure 1.
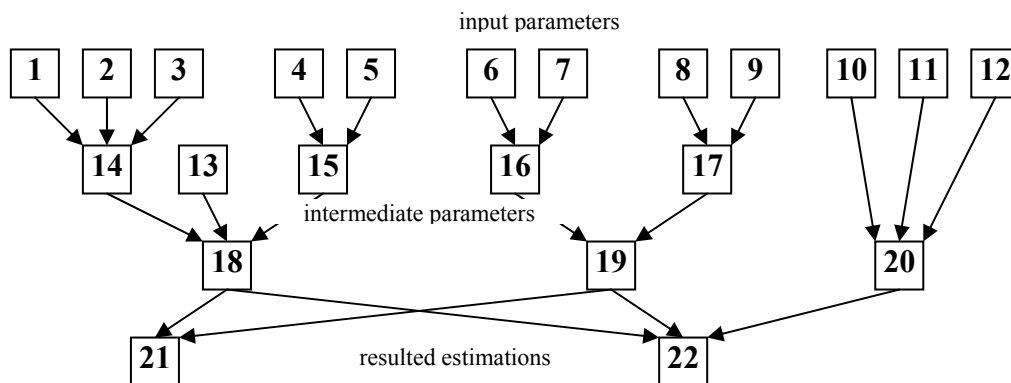

Figure 1. Relationships between input, intermediate and output parameters of trip quality model

Several of these parameters (2, 3, 4, 6, 10, 11, 12, 13, 14, 18) previously have been discussed in detail in [3]. Therefore, let's concern only some of the newly introduced parameters.

Route mode (1) characterizes the degree of deviation of truck's motion from the pre-planned and approved route. It is clear that the change of the route even though it may lead to faster delivery, but on the other hand it may interfere with the truck's weight and size requirements and restrictions, other terms and requirements of safety. And eventually the deviation from the route is an important factor in the reduction of transport safety.

Traffic rules violations (5), which fixed and recorded properly by police (road control, automobile inspection, service safety of the enterprise or by technical means of verification) drastically reduce the safety of transportation.

Age (7) for a single car and for the whole truck's park of transport firm is a serious parameter influencing on technical conditions of park, also it, in many respects, defines the image of carrier, transportation cost and safety, working conditions for drivers etc.

Coverage of orders (8) describes the ability of transport companies to cover peak for orders on transportation of constant clients.

Suppose, during 30 days with regular daily orders of various amount of transport there was required to provide 140 trucks. The carrier has provided 105, and then cover will be 75%. If total requirement was 80, but received was only 40 trucks – covering will be 50%.

Park power (9) is determined as the degree of satisfaction (by the carrier) of orders for transportation from regular clients during a certain period of time.

Let's assume that during the month (30 days), the carrier every day receives requirements of transport (a certain number of trucks) from the client. For example, if 15 requirements (from 30) were made in full (but other 15 – only partially), the power will be 50%. In the case of providing transport in full only for 10 requirements total capacity will be 33%.

4.2. Fuzzy formalization of quality parameters of transportation by membership functions and sets of linguistic variables

As mentioned above, as well as described in [6, 7], first step to develop a model must be formalize of the selections linguistic variables and corresponding membership functions. The corresponding numerical values were obtained from expert surveys and subsequent statistical analysis by the methods described in [7].

Without loss of generality and without compromising the reliability of the model, for its simplified representation in the paper, we will use the linear membership functions (triangular and trapezoidal).

Also, all linguistic variables will be represented by sets of three terms. Their characteristics are presented in Table 1, and process of their construction was described in detail in the works [3].

Now, consider a graphical representation of the input, output parameters and decision rules in the interface software fuzzyTECH5.5.

Graphical representation (kinds and views of membership functions) for input parameters (1–13) are shown on Figure 2, and for the output parameters of all levels are shown on Figure 3. At each of the drawings the picture of one of the options is given in an enlarged form.

It should be noted that given in the table (and reflected on the graphics) performances of variables can be changed directly in the graphical mode, moving the necessary points with the mouse on the relevant parts of the graph, or typed numeric values directly in the appropriate fields interface.

The next step to create a model is construction of fuzzy inference rules for all model variables and sets of their linguistic terms.

For each set of the „group of input variables – the output variable" we construct fuzzy inference rules (a decision on the estimation), similar to those was described in [3, 7]. It should be remembered that we must consider all possible combinations for values of linguistic variables of input parameters. And for each terms combination from this set it is necessary to determine corresponding term from output parameter.

Example of graphical representation of the rules for the input variables „park power" and „park cover" and the corresponding intermediate output variable „park possibilities" in the used package fuzzyTECH5.5 are shown on Figure 4.

Table 1. Characteristics of linguistic variables for the model parameters

№	Name of the parameters and levels	Unit of measurement	Terms of variables, values of membership function					
			Starting		Middle			Finishing
			Equal 1	Decrease from 1 to 0	Increase from 0 to 1	Equal 1	Decrease from 1 to 0	Increase from 0 to 1
1	Route mode (good fair poor)	%	0-10	10-30	15-30	30-35	35-45	40-55
2	Speed mode (good fair poor)	%	0-1	1-5	2-10	10-15	15-20	16-35
3	Time mode (good fair poor)	%	0-2	2-5	3-8	8-12	12-15	13-30
4	Road incident (few normal lot)	%	0-1	1-3	2-3,5	3,5-4	4-5	4-6
5	Road rule (few normal lot)	%	0-3	3-5	4-7	7-10	10-14	12-18
6	Readiness (high medium low)	day	0	0-2	1-4	4	4-5	4-8
7	Trucks age(small medium large)	year	0-1	1-3	2-3,5	3,5	4,5-5	4-7
8	Park cover (low medium high)	%	0-20	20-40	25-40	40-60	60-80	60-85
9	Park power (low medium high)	%	0-10	10-30	15-30	30-60	60-90	60-90
10	Claim (low medium high), number	%	0-2	2-3,5	2,5-7	7	7-10	8-15
11	Delay (low medium high), time	hour	0	0-1,5	1-2,5	2,5	2,5-4,5	3-6
12	Maintenance (low medium high), coast	%	0-1	1-3	2-5	5	5-8	7-10
13	Fuel expenses (normal medium high)	%	0-5	5-10	6-14	14-20	20-30	23-45
14	Motion mode (poor fair good)	point	0	0-5	2,5-5	5	5-7,5	5-10
15	Road safety (low medium high)	point	0	0-5	2,5-5	5	5-7,5	5-10
16	Trucks (satisfactory good excellent)	point	0	0-5	2,5-5	5	5-7,5	5-10
17	Park possibility (low medium high)	point	0-2,5	2,5-5	2,5-5	5	5-7,5	5-7,5
18	Trip style (poor fair good)	point	0	0-5	3-5	5	5-8	6-9,5
19	Park (insufficient medium enough)	point	0-2,5	2,5-5	2,5-5	5	5-7,5	5-7,5
20	Service level (low good excellent)	point	0-2,5	2,5-5	2,5-5	5	5-7,5	5-7,5
21	Work level (poor fair good)	point	0-25	25-50	25-50	50	50-75	50-75
22	Total estimation (low good excellent)	point	0-25	25-50	25-50	50	50-75	50-75
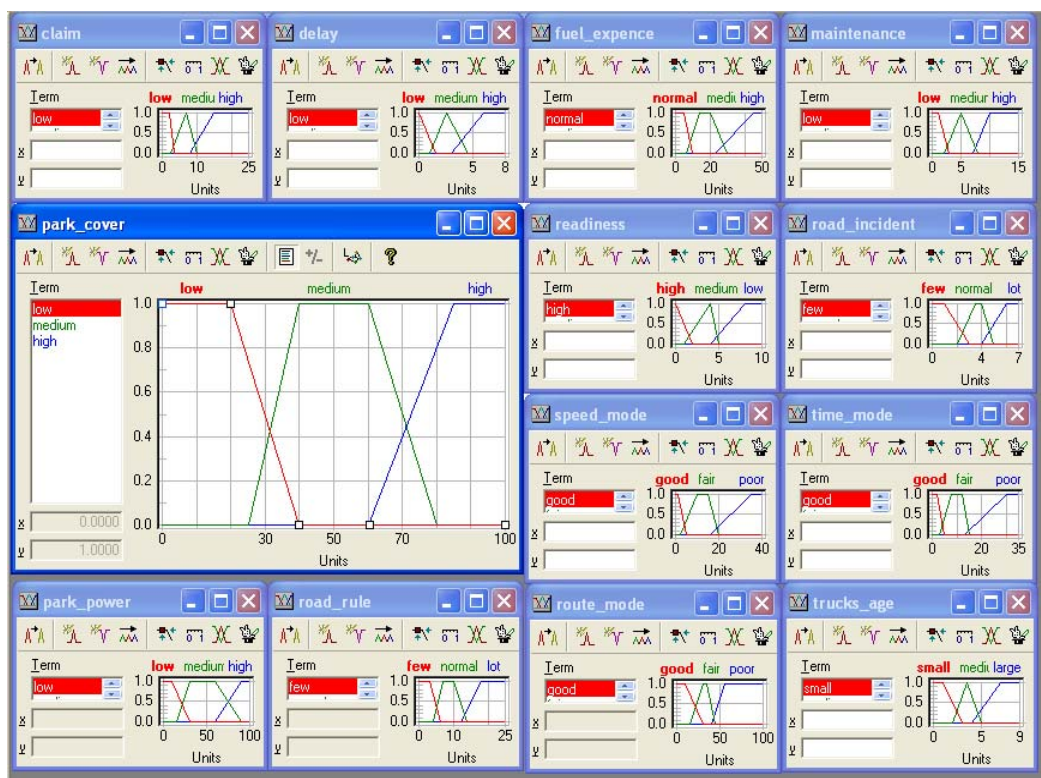
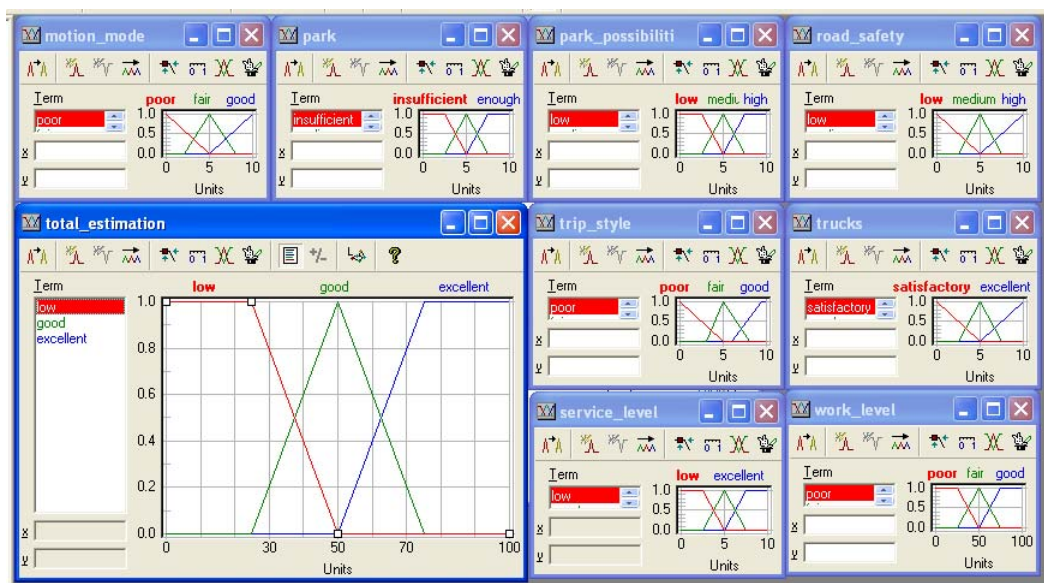*Figure 2.* Computer representation of input variables of model

Figure 3. Computer representation of output variables of model

Parameter DoS (see Fig. 4) determines the relative weight for each of the rules (in this case they are the same weight) and can be changed by the user in the process of setting up a model. In our case, there are 9 of these units make decisions.
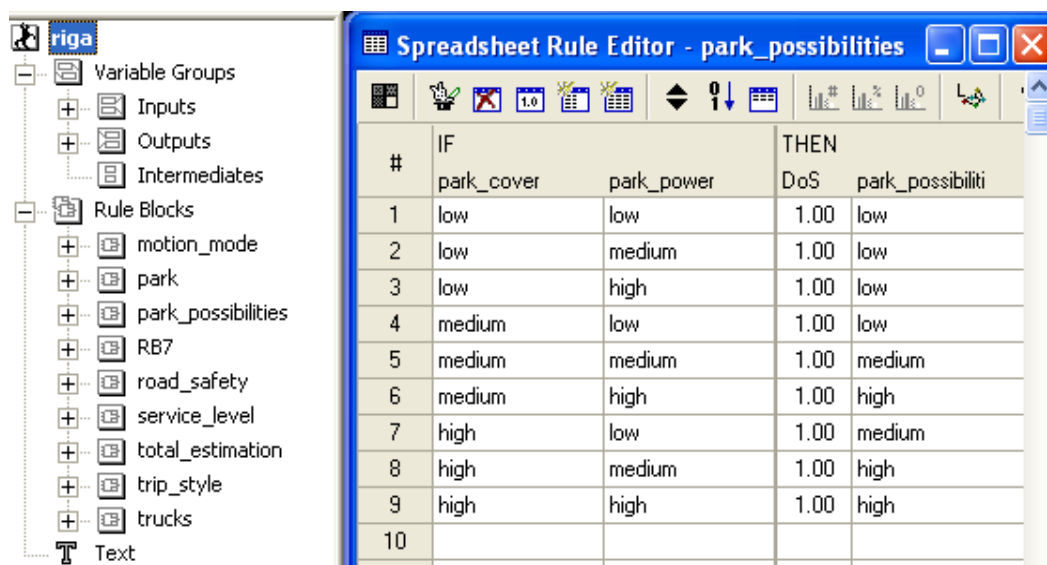

Figure 4. Set of decision making rules for input variables park cover, park power and output variable park possibilities

4.3. The resulting computer model of the problem, making calculations and analysis of its

The general form of a computer model of the problem, in particular, the causal interaction of input, intermediate and output variables in the environment of the fuzzy modelling fuzzyTECH5.5 presented on Figure 5. Clicking on each element of the structure (that take access to corresponding parameters) allows opening the appropriate box and changing the necessary characteristics of the selected variable and the rules of decision-making assessment.

After a description of all variables and entering of all the fuzzy rules all input data and calculation results are displayed in the interactive debug calculation's window which is shown on Figure 6.
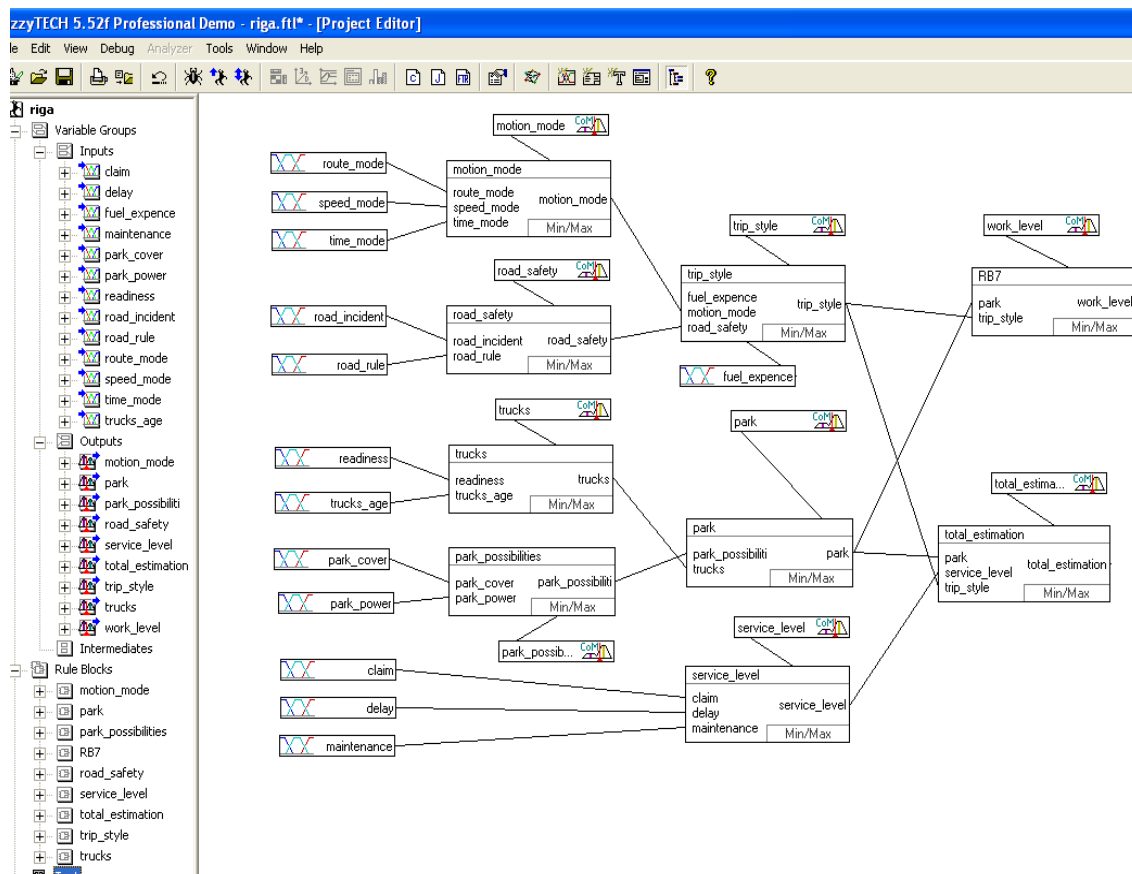
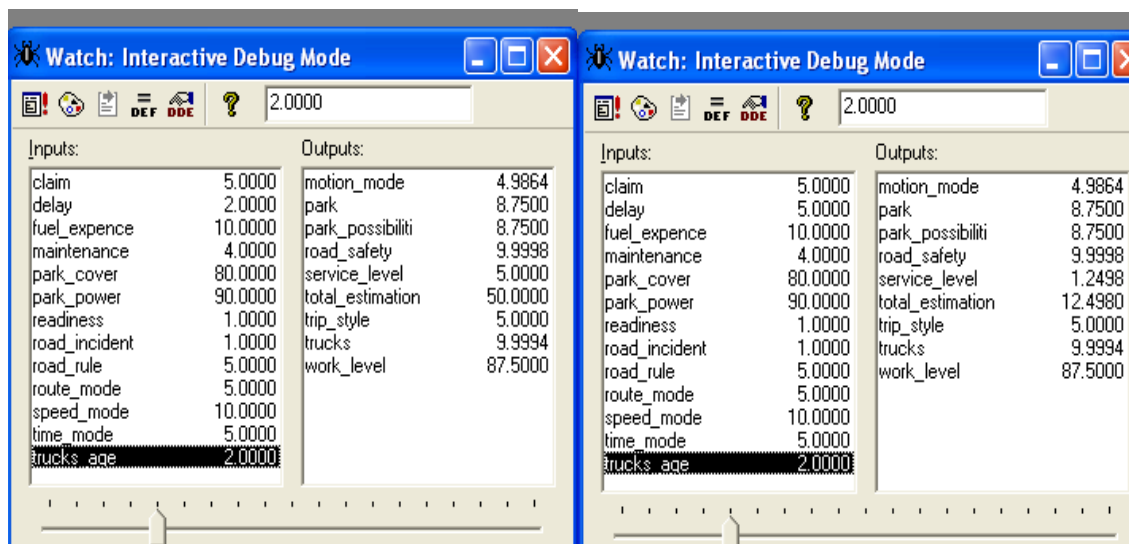*Figure 5.* General computer model

Figure 6. Interactive debug calculation's window

The Figure 6, as an example, shows two screenshots of interactive recalculation windows. In each of them (in the process of work within the program) the user enters (on the left) the numerical values (evaluation) of input parameters and (on the right)) program displays the results of calculations for all output parameters (intermediate and final).

These screenshots differ only in the numerical values of the parameter „delay" (for left – 2 hours, for right – 5 hours). The result is an overall assessment of quality of transportation („total estimation")

varies from 50 points (left) to 13 points (right), which is caused almost unacceptable value „delay" (it is very important for the recipient of transport services) in the second case.

At the same time, the characteristic „work level", which is an internal generalizing measure of the technological side of work for the transport company has 87 points and not changed (for other parameters remaining constant, of course).

A described window (see Fig. 6) enables modelling the general level of transportation, changing some or all input parameters and analysing the results. In the same purposes can be used the surfaces of interdependence between parameters, one of which is shown on Figure 6.
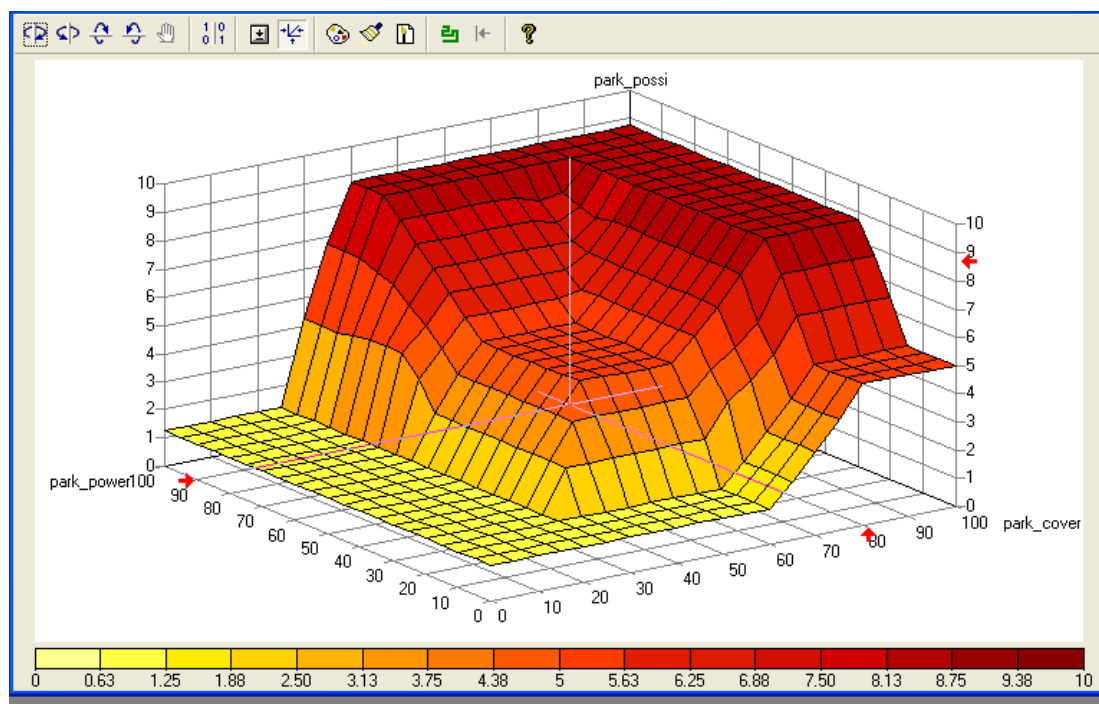

Figure 7. Surface of dependence between park power, park power and resulting park possibility

A more detailed analysis of the direct numerical simulation in the already constructed model is the subject of our further research. We assume, in particular, to consider (the list is not exhaustive and closed) issues such as:

- practical construction of membership functions based on statistical analysis of expert interviews;
- use of more complicated form of membership functions, including custom's (no standard);
- different forms of representation of the resulting data in fuzzyTECH5.5 package and they provide opportunities for analysis;
- opportunities for learning and adjustment of the constructed system of fuzzy inference using neural networks;
- increasing the number of initial parameters in the model;
- expert determination of weights of parameters;
- development of the model to using of different values of the weights for the various initial, intermediate parameters and the relevant rules of decision-making;
- the creation of executable modules (not requiring from the end user to have the program fuzzyTECH5.5) by compiling a model from fuzzyTECH5.5 to the C programming language, and then into an executable code.

The obtained results will be presented in detail in the following publications.

5. Conclusions

Thus, has been developed a multi-criteria model for evaluate the quality of freight transportation. Theoretical basis for constructing the model was the fuzzy set theory and practical tool for the creation was special fuzzyTECH5.5 software. Model is sufficiently substantiated and reliable. It takes into account

a significant number of quality parameters of freight services, and take possibilities to create and use these parameters with corresponding decision rules for generalizing estimates.

User can submit and save the results in a clear, understandable and suitable for further analysis form, and can perform calculations interactively. Using this model, management of transport enterprises and consumers of transport services can efficiently control the quality of transportation, the level of transport and associated services, which are very important tasks in market conditions.

References

1. Nagorny, E. V., Dorokhov, O. V., Verbitsky, V. I., Dorokhova, L. P. Use of decision-making methods in indistinct conditions by subjects of the transport services market. In: *Vestnik SNU: Scientific journal*. Lugansk. 2004. Issue 7 (77). Part 1, pp. 202–209. (In Ukrainian)
2. Dorokhov, O. V. Multicriterial comparison of the transport service's centers at their indistinct consumer's estimations. In: *Vestnik KhNADU: Collection of scientific works*. Kharkiv, 2003. Issue 21, pp. 66–69. (In Ukrainian)
3. Dorokhov, O. V., Dorokhova, L. P., Zorina, E. A fuzzy approach and modeling of service estimations for drugs freight transportation, *Transport and Telecommunication*, Vol. 11, No 1, 2010, pp. 19–25.
4. Dorokhov, O. V., Dorokhova, L. P. Using of information technologies for support of wholesale pharmaceutical firm's industrial-commercial activity for drug's and medical product's distribution. In: *The 1st CEE Symposium „Business Informatics in Central and Eastern Europe"*. Vienna, 2009, pp. 315–319.
5. Dorokhov, O. V., Chernov, V. G., Dorokhova, L. P. Uncertainly as the factor of investment's decisions making processes and usage of fuzzy sets theory for it's modelling, *Montenegrin Journal of Economics*, No 11, 2010, pp. 17–26. (Podgorica)
6. Dorokhov, O. V., Kavun, S., Zolotaryova, I. O., Brumnik, R. The uncertainly-plural model for the estimation of enterprises economic safety level. In: *Social Control in Contemporary Society (Practice and Research) in Central and Eastern Europe: Conference Proceedings of the 7th Biennial International Criminal Justice Conference*. Ljubljana, 2008, pp.53–56.
7. Dorokhov, O. V., Chernov, V. G. The desirability and feasibility of using fuzzy modeling for risk assessment in information systems. In: *Securitatea informaţională 2010: The VII Conf. Intern.* Chichineu, 2010, pp. 18–22.

MEDICAL POINT OF VIEW ON PASSIVE SAFETY

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Only modern passive car safety systems can protect drivers inside vehicle during accident. In addition, there are other important conditions: the residual post-accident life-space in the car and rapid arrival of ambulance. However today there is a new research path – simulation (by using digitised model of an anthropomorphic dummy). The analysis of human body behaviour during crash can give useful information for designers of the new passive car safety systems.

Keywords: HIC, accelerations, passive car safety systems, residual post-accident life-space

1. Introduction

According to The Commission for Global Road Safety in the world every year in road accidents died about 1.3 million people. This problem is called a global epidemic, comparable to the number of deaths from malaria and tuberculosis. In the structure of deadly trauma in general is one of the highest places, and among road traffic injuries is most often the cause of death.

Despite some improvement in mortality rate in road accidents (Russian statistics until 2009 believed to be killed in a traffic accident only to those who die within 7 days after the accident. All those who died later in hospitals, official data do not fall *) in Russian Federation over the past year our rates are high – the number of fatalities per 100 injured in road accident in Russian Federation far exceeds the average for the European Union.

In addition, due to late arrival of the ambulance the number of victims increases up to 60%, and as we know the best chance to survive after serious automobile accidents it is to receive adequate medical care in within half an hour from the time of injury. Lack of assistance during "Golden hour" after an accident increases mortality by 30%.

(* Order of the Government of the Russian Federation № 859 dated: November, 19, 2008, Moscow, -"On Amending the Rules for the recording of accidents" - in 2009 to provide records of accidents and information about the wounded, died within 7 and within 30 days from their consequences; This Order is entered into force on January, 1, 2009)
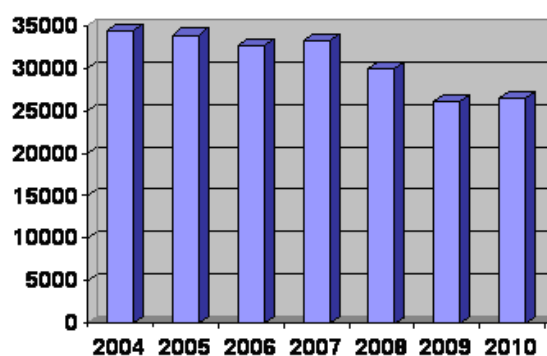

Figure 1. Dynamics of the number of people killed in road accident in Russian Federation for the years 2004–2010.
(According to the GIBDD-traffic police of the Russian Federation)

The problem of personal injury in car accidents is discussed in the literature for a long time [1–5]. We consider the impact of shock acceleration on the human body over 10g (g-acceleration due to gravity) duration of less than 1 second (Fig. 2). During this period included the rise time and decay accelerating at the same time there is a sharp movement of the human body and especially the head, often accompanied by a blow of items of equipment cabin and exceeding the physiological limits of endurance of the human body.

There are two types of car safety: active and passive. The passive safety devices includes: airbags for protection against frontal and side collisions and curtains, seat belts with a system of forced tension etc. The most important factor in car passive safety is the residual post-accident life-space in the car. Restraint systems and the life-space were designed to protect people inside the car by taking it upon itself the main force of impact in the collision and its suppression.

In any case, hit occur in such vital parts of the body such as: head, thorax and abdomen. In the process of hitting a person moves toward the collision point. At a speed of 48 km/h this type of attack against human body can be equated to a fall from the fourth floor on solid ground.
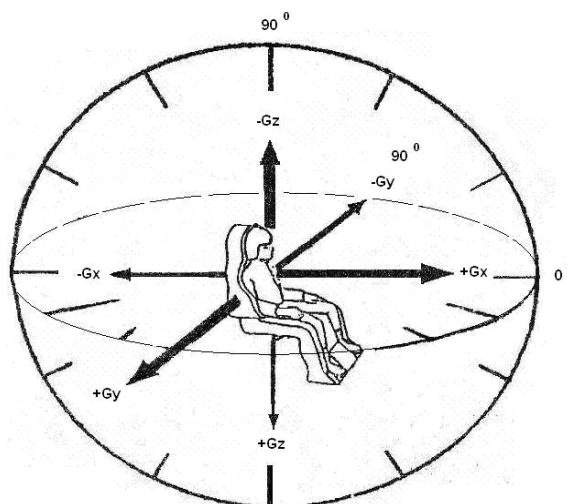

Figure 2. Diagram of the directions of the accelerations

2. Medical Aspects of Problem

From a medical point of view the human skeleton is divided into the following main regions: the skull, spine, chest, upper (including shoulders) and lower (including pelvic girdle) limb. The skull is divided into the following parts: face and brain.

The spine is divided into five regions (Fig. 3): 1 – Cervical (C1–C7) – Seven cervical vertebrae are located between the skull and rib cage. The first cervical vertebra, called Atlas, second – Axis and seventh vertebrae have special characteristics. The four remaining vertebrae are considered as typical. 2 – Thoracic (T1–T12) consists of 12 vertebrae, 3 – Lumbar (L1–L5) consists of 5 vertebrae. 4 – Sacral (five sacral vertebrae), merging with age, form the sacrum. 5 – Coccygeal (four coccygeal vertebrae), in the adult almost merged to form the coccyx.
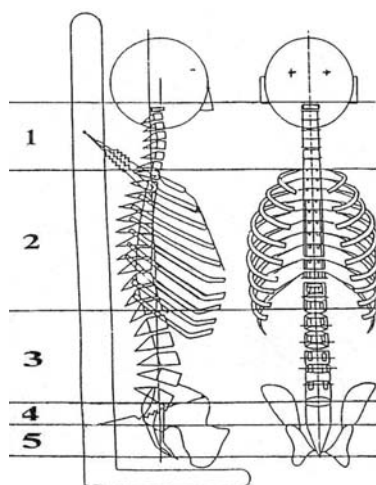

Figure 3. Human spine regions

The impact of a sharp slowdown on the human body is often estimated in the following categories: from tolerant degree till traumatic deaths. Tolerable degree – minor injuries as abrasions and contusions, traumatic – leads to a moderate injury and to a serious injury that can not lead to death. A limiting value under the influence of acceleration of approximately 250g, acting within 0.1 seconds is the limit of tolerance for the + gx axis and for the – gx axis this limit is 150g for 0.1 seconds. The head is attached to the body so that retains a vertical position to accelerate 2g. Cervical vertebral column has the highest mobility. Also need to consider and neck human endurance which is three times lower in hyperextension than hyper flexion and that the neck muscles more endurance load placed on the head in the capital plane. Which is the magnitude of deceleration is considered dangerous? Was found that it depends on the time within which they act on the body. Man is able to withstand large overload for a few milliseconds, or medium overload, but lasts longer.

Now in the world practice assessment head protection from injury based on the so-called "curve of Wayne State", which describes where begins a concussion and how the threshold value of overload depends on the duration of the shock pulse. With Analysing the selected time interval at which the total level overload were maximally.

The fact that the crash tests with anthropomorphic dummies simulating the behaviour of a real human body (the kinematics of the joints, weight and elasticity of body parts, etc.), we can only estimate the probability of injury. And that's not enough for the maximum overload – the brain can withstand short-term overload of 150g (1–2 milliseconds), and may flatten the skull on wall at a deceleration of 100g, but to act within 10–15 ms. So, we need to sum the value of congestion at a dangerous point of impact. This is the physical meaning of the criterion "HIC" – a Head Injury Criteria, criterion for severity of head injuries. It was used abroad as an estimate of traumatic car for the head of the driver and passengers. HIC indicates the maximum of all possible integrals, taken in the time interval no more than 36 ms with a certain ratio, which (like the curve of Wayne State, which based method for calculating HIC) is defined in the course of experiments on animals and human volunteers. It should not exceed the 1000 conventional units HIC. That is, HIC actually shows "the dose absorbed by the slowdown." For example, if an overload of 80g acting on the person within 3 ms, then, putting 3 ms on the abscissa of the curve Wayne State, and 80g – on the vertical axis, we get a value that lies below the threshold curve, that is safe (this value is mentioned in the rules № 12 and № 21 UNECE – they set the border to 80g at the time of 3 ms, and the rules of FMVSS 208 recommend 41g at time of not more than 36 ms.) In addition to be transferred to some other criteria: NIC (Neck Injury Criterion), TTI (Thorax Trauma Index), FFC (Femur Force Criterion) etc.

3. Problem Solve

To prevent injuries and fatalities have been specially studied the process of collision of cars. With high-speed cinematography and high-precision sensors and devices were defined types of collisions and shows what happens with people and vehicles during process. There are two processes occur: the first is when the car hits into something and is stopped and the second (more important) when people (especially), not wearing a seat belt hits on something inside the life space. There is three fundamentally different mechanisms injury or death: man hit something, something hit a man, a man falls out of car.

We consider the following types of car collisions: frontal, front-offset, side, rollover and rear.

1. Frontal type of collision is more than 1/3 of all car collisions. During a crash the front end deforms, absorbing the energy of the collision. However, inside the living space of all items and not wearing the driver and passengers are moving forward. In this case, the driver hits the steering wheel while sitting next to a passenger on the dashboard and the windshield. Rear passengers sit in front of hit or hurt them by pinching between the front seats and dashboard. In addition, at high speed collisions are not wearing your people can fall out of the car, breaking the windshield. Seatbelts minimize or prevent injury to persons in this type of collision. And then come into work airbags that protect the head and some car models even knees.

2. Forward-offset collision is characterized by a partial deformation of the front end (called a blow to the incomplete overlap) and is common, for example, when going into the oncoming lane when overtaking incomplete. Life space with this type of collision is suffering as well as at the front style with complete overlap, the front part of the body absorbs some of the shock energy. However, in connection with the direction of overload, especially by dropping the body back probably misses his head on the headrest and injury on the side surface, in connection with the rotation of the car when the rebound from obstacles. Therefore, for this type of collision be developed seats with integrated seat belts, and remove

the seat away from the inner side panels of the car, as well as to develop a new active head restraints designed to capture a greater surface and a new algorithm for response and side-curtain and side airbags.

3. Side collision type most often – is found in more than 40% of the cases from all other types. However, unlike the anterior type of collision body can not absorb enough energy from the small deformation zone in the lateral part of it. It is compressed, reducing the living space. Not wearing people will move to the side in the direction of impact, often hitting each other with a force equal to the force of the collision. Driver wearing your safety belt can in this case it is better to control the situation and avoid a collision drastically changes the trajectory of motion. However, a large number of deaths in side collisions, suggests low efficiency of seatbelts (as opposed to the front collision) and the need for more in-depth study of this type of collision. Apparently in this case it is necessary to use special means of passive safety (including seats with integrated seat belts) and also need to develop research in the field of virtual crash tests (develop a digitised model of an anthropomorphic dummy for side impact EUROSID II – as is already done by MADYMO for dummy HYBRID III).

Figure 4. Modelling the biomechanics of the human body during side impact (t = 200 ms).
(Cited by Cristina Echemendia, 2009)

Of interest are the data firm TRW: of all deaths in collisions of 31% falls on the side collision; they found that 9,8% cause of death was head injury and in 6% of chest injuries (47% and 29% respectively). These studies suggest that during the analysis of mechanical and functional durability of the human body for a variety of extreme situations special attention should be paid to the head. This is primarily due to the unique role of the brain in the processes of life. On the other hand, the head is one of the most prone to injury segments of the human body when exposed to different mechanical factors, especially during side impact, leading to severe destruction of the neural network and brain vessels. However, the task of providing head injury prevention is one of the most difficult biomechanical problems, and in this case (side impact) is difficult even informed choice requirements for the quality of protection and injury-range of effects.

4. During vehicle rollover people, especially, wear a seat belt at risk of injury is much more severe than in other types – is the most dangerous of all collisions. With a share of 13 per cent of the total number of collisions they kill over 20 percent of all those who are perishing at collisions. This type of collision could happen at a moderate speed, with the fallout from the car can occur during a light shock when people during rotation car thrown from side to side. More than half of all people are unfastened serious injury inside the cabin until the fallout from the car. During the coup belts are the key to help reduce the risk of injury and prevent death. However, insufficiently strong roof rack and can significantly reduce the life space (Fig. 5).

5. At the back the type of collision occurs discarding the body back to his seat. In this case the so-called whiplash strike (neck hyperextension during upset head back), which leads to injury of the cervical spine, and then, if the person was not wearing, the rebound of the seatback forward, he may be injured as a collision front type. In this case, the headrests, which play an important role in minimizing the trauma of the cervical spine and seatbelts prevents loss of a man from the car. Headrests provide a sufficient level of comfort and allow you to save the living space. However, the need to regulate them so that they have never been below the ear. Thus, when type of stroke is presented, seat belts are used, headrests and other systems such as "WHIPS" – VOLVO firms, for example, should reduce the risk of injury to the person.

Figure 5. Biomechanical model human body during car rollover.
(Cited by Cristina Echemendia and Kennerly Digges, 2009)

4. Scientific Novelty

Recently developed tools and elements of passive safety, and generators located in the living space, such as: the strong body structure, reinforced by additional elements in the design of floor, roof and doors, collapsible dashboards, reinforced seats and headrests, but also automatic protection systems, consisting of: air bags and seat belts with positive tension, energy absorption steering columns, etc. convert any car in a fairly safe means of transportation. At the time of the collision, these tools passive safety features all work together to preserve the life-space and prevent serious injury to persons inside the vehicle; particularly affected the head because it is difficult to fix. These tools will work in most cases prevent from severe injuries, if only the driver and passengers will wear seat belts, which fix the body in the cabin of the vehicle and give the time and place for disclosure of airbags.

In addition there is a tendency timing response elements pre-crash active safety.

5. Conclusions

- Research to develop requirements for perspective vehicles cabin construction (with using dynamic anthropometrics and develop a digitised model of an anthropomorphic dummy) under the influence of shock acceleration, in order to optimise the placement of the elements of Occupant Safety Systems and improve human body injury prevention.
- Develop designs perspective automatic Occupant Safety Systems: Multiple Restraint System (MRS) and the rollover protection system (RPS).
- Simulation of the human body, in order to create mathematical computer models to study the kinematics of human movement within the body when the accident types with the use of the physiological and biomechanical approach (not exceeding the limits of endurance of human body parts and taking into account its possible displacements inside the cabin living space at all stages of an accident).
- Modelling the kinematics and biomechanics of head-neck in a frontal collision with an incomplete overlapping and side crashes.
- Studies on the application of active head restraints and new principles of retention with the use of additional biomechanical elements for applications where conventional systems are not applicable.
- Development of requirements for prospective design of cars, taking into account the application of automatic Occupant Safety Systems for the front, and side collisions, in order to release the lateral space for the establishment of a zone to trigger airbags and curtains and increase safe zone for lateral deformation of the car body.
- Use of the physiological and biomechanical approach for designing advanced structural automotive body in order to minimize the degree of injury are people in them, during the accident and operation of automatic Occupant Safety Systems – i.e. deformable body as a protective shell, the maximum quenching peak overload and having adequate life space.
- Assess the economic efficiency of automatic Occupant Safety Systems new generation cars, taking into account the "value of human life".
- Development of technical standards for vehicles, taking into account international experience and perspective and the requirements for vehicles passive safety.

- Design and manufacture of dynamic simulation for the physiological, biomechanical reactions of the human operator on the impact and shock vibration to produce advanced ergonomic and hygienic requirements for the organization of life space.

References

1. Panin, N., Prusov, P. Concept of a Neck Protective Device (CNPD), *Aviation, Space and Environmental Medicine,* Vol. 72, No 2, Washington, USA, February 2001, p. 155.
2. Panin, N. Influence of sign-variable overloads on parameters of activity of the person – operator in a protective helmet, *Human Physiology*, Vol. 33, 2007, p. 9.
3. Douglas, C., Fildes, B., Gibson, T., Bostrom, O., and F. Pintar. Factors Influencing Occupant to Seat Belt Interaction in Far Side Crashes. In: *The 51st Proceedings of the Association for the Advancement of Automotive Medicine*, October 2007, pp. 319–342.
4. Echemendia, C. *Modeling Neck Compression in Rollover*. GW University, April 2009.
5. Echemendia, C. and K. Digges. *Far Side Sled MADYMO Validation*. GW University, April 2009.

APPLICATION OF A DISCRETE CHOICE MODEL
TO ANALYSIS OF PREFERRED TRANSPORT MODE
FOR RIGA–DAUGAVPILS ROUTE

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This paper is devoted to discrete choice analysis of behaviour of bus and train passengers and their choice between alternative transportation modes. We develop a nested discrete choice model and estimate model parameters on the base of data sample collected in our own survey.

We consider Riga-Daugavpils two-way journeys with three possible transportation options – a car, a coach, and a train. Using our survey data we analyse factors, which influence passengers' choices. A set of factors includes travel specific factors (departure time), factors, which describe passengers' age, income, etc. and factors, which describe their behaviour (time of arrival to a station before departure).

The resulting conclusions of the research have a significant practical utility and have been used to improve operations of Riga International Coach Terminal.

Keywords: discrete choice model, transportation, coaches, railways

Introduction

The entry of Latvia into the single European market and political integration of Latvia into the EU have brought with them qualitatively new requirements for passengers transportation; a necessity for higher levels of mobility, intermodality, passenger's comfort and support for passenger's rights, as well as new environmental requirements to transport. Riga International Coach Terminal ("Rīgas Starptautiskā Autoosta") is a leading provider of passenger's bus transportation services in Latvia. It provides international, intercity and regional coach services. Recent studies of a role of buses and coaches confirm excellent safety, environmental and social record of bus and coach transport [1]. In Latvia this mode of transportation competes with railways and also with private cars [2].

Discrete choice modelling is a modern econometric approach to analysis of selection between a set of predefined alternatives. In this research we constructed two discrete choice models for predicting a preferred transportation mode for Riga–Daugavpils two-way journeys. The first model deals with predicting a choice between using a car and using public transport, while the second model is focused on a choice between using a bus and using a train.

A discrete choice model predicts a decision made by a person (such as a mode or a route chosen) as a function explanatory variable set. In the research we investigated an influence of a wide range of factors affecting passenger's choice and estimated their marginal effects. The key factors of passenger's choice were revealed. Direction of these factors' influence on passenger's choice can be used to improve services of bus and railway carriers and stations.

Theoretical Background

There are many examples of economic research where an outcome is considered as a qualitative decision, or more exactly a discrete choice from a set of alternatives. In this work we consider a choice of a transportation mode from three alternatives; a car, a train, and a bus.

For choice modelling it is impossible to use a simple regression (OLS), because an outcome is not a continuous variable. Also there are some more problems with using of a simple regression in this case (related to violations of Gauss–Markov conditions) [3].

In this research a discrete choice model [3, 4] was used for predicting a preferred transportation mode. The mathematical formalization of the model can be presented as:

$$P\left(y_i = 1 \middle| x_i = X_i\right) = F\left(X_i^T \beta\right),$$ (1)

where y – a discrete variable, which equals to 1 if a passenger accepts an alternative and 0 if he/she declines it (a binary choice);
   X – a set of explanatory variables;
   β – a vector of unknown coefficients to be estimated;
   F – a function, transforming a set of real numbers into [0, 1].

An estimation base is different from a simple regression in this case – it is necessary to estimate a conditional probability of a particular choice alternative as a function of a set of explanatory variables.

A selection of a form of F function is an important decision. Usually F is a standardised normal cumulative distribution function (a model is called *probit* in this case) or a cumulative logistic distribution function (a *logit* model). There are no exact practical rules for this selection (some recommendations can be found at [5]). Both logit and probit models give similar results for intermediate values of $X^T\beta$ (a functional form makes a difference for larger deviations where the logistic function has fatter tails). In this research there is no systematic difference in results of logit and probit model estimations, so we include estimation results for logit models only.

Usually the maximum likelihood estimator is used for estimating the coefficients of unknown discrete choice models. This provides asymptotically efficient and consistent estimates. For hypothesis testing it is possible to use a Wald test, a likelihood ratio test, or a Lagrange multipliers test. We use the Wald procedure to test linear hypotheses about coefficients as we need to compare models estimated on different samples due to having a non-balanced data set.

There is a complication with analysis of estimated coefficients $\hat{\beta}$. We can calculate an influence of each explanatory variable x_i as:

$$\frac{\partial P\left(y = 1 \middle| X^T \beta\right)}{\partial x_i} = \frac{\partial F\left(X^T \beta\right)}{\partial x_i} = f\left(X^T \beta\right) \cdot \beta_i,$$ (2)

where f is an appropriate probability density function. So a level of influence of each variable depends on the full set of values of explanatory variables. Usually marginal effects are calculated for each variable using sample mean values for all other explanatory variables.

In our case the majority of explanatory variables are discrete (qualitative), so it is not possible to use derivatives for calculation of marginal effects. Therefore we use a discrete change formula instead:

$$P\left(y = 1 \middle| \bigcup_{j \neq i} x_j = \overline{x}_j, x_i = 1\right) - P\left(y = 1 \middle| \bigcup_{j \neq i} x_j = \overline{x}_j, x_i = 0\right).$$ (3)

The discrete choice model can be extended for more than two alternatives. In our case there are three possible modes of transportation – a bus, a car, and a train. The set of alternatives is unordered, so an appropriate model in this case is a multinomial discrete choice model. A multinomial logit model for K alternatives can be expressed [3] as:

$$P\left(y = j\right) = \frac{e^{X^T \beta_j}}{\sum_{k=1}^{K} e^{X^T \beta_k}}.$$

Using of this model is related with some interpretation difficulties – coefficients of the model are not tied to marginal effects directly. This general variant of the model can be split into a set of separate binary choice models, if model's alternatives are irrelevant. Hausman and McFadden [7] suggested that if an alternative is irrelevant to other, then omitting it from the model will not bias parameter estimates.

To test this irrelevance Hausman and McFadden developed a procedure, usually called a test of independence from irrelevant alternatives.

The procedure is based on a common Hausman specification test:

$$\chi_{obs}^2 = \left(\hat{\beta}_R - \hat{\beta}_U \right)^T \left(\hat{V}_R - \hat{V}_U \right)^{-1} \left(\hat{\beta}_R - \hat{\beta}_U \right), \tag{4}$$

where $\hat{\beta}$ and $\hat{V}$ are estimates of model's unknown coefficients and covariance matrices respectively. The U index means that a full sample is used for estimation (an unrestricted model), and the R index means that irrelevant alternatives are excluded from the sample (a restricted model). A null hypothesis is an absence of systematic differences between these two models, and the test statistics will have a chi-square distribution under the null hypothesis (a number of degrees of freedom is a number of restrictions).

To measure a goodness of fit we use an analogue of a determination coefficient R^2 – McFadden's likelihood ratio index [6]:

$$LRI = 1 - \frac{Ln(L)}{Ln(L_0)}, \tag{5}$$

where

$Ln(L)$ – a value of a log-likelihood function for a full model,

$Ln(L_0)$ – a value of a log-likelihood function for a model with a constant only.

There is another way to measure a goodness of fit, based on comparison of model predictions and observed choices (using a '2x2' table for binary models – a table with values for all 4 combinations of observed and predicted successes/failures).

Outputs of a discrete choice model are probabilities $\hat{p}$ of a particular alternative for all sample cases. So there is a need for a predicted probability threshold value p^* to make a choice prediction $\hat{y}$:

$$\hat{y} = \begin{cases} 1, & \hat{p} \ge p^* \\ 0, & \hat{p} < p^* \end{cases}. \tag{6}$$

The natural threshold value is 0.5 (if a predicted probability value for an alternative is more than 0.5 we predict that this alternative will be accepted, otherwise we predict that the alternative will be rejected). However, because in our case the relative frequencies of selection of different transport modes vary considerably, we will use smaller threshold values for predicting rarely selected alternatives.

Data

We planned and organised a survey of passengers to collect information about their preferred transportation mode. A questionnaire contains 20 questions; main 15 of them are presented to respondents, and other 5 are filled by a pollster (respondent's sex, a language, a place, and date and time of an interview). The survey included 177 respondents.

All questionnaires were collected during a week, so we consider our data as related to one time point (cross-sectional). It's planned to repeat the survey later, to compare results and reveal influence of a season on passengers' choice.

Respondents for this survey were chosen randomly from people visited Riga coach terminal. Riga coach terminal is located aside of a railway station, so it means that respondents are bus passengers only. This definition of a statistical population and a sample has a critical influence on final results' interpretation.

Model Specification

The first practical task is to define variables describing passenger's choice. In this research we use passengers' answers to the question: "Which transportation mode do you usually choose for travelling to Riga/Daugavspils? (If this journey is not a unique event)" with three possible answers: a car, a train, or a bus. So the resulting model is based on two general methods of discrete choice modelling – Revealed

and Stated Preference. Revealed preference method utilises information about real behaviour of respondents, while Stated Preference is based on answers about hypothetical situations.

Note that the sample comprises bus passengers, so a discrete choice can be formulated as: 'a usual transportation mode of bus passengers'.

Passengers who identified this trip as a unique event (31 passengers, 17% of the sample) were excluded from our consideration. Therefore the modelling sample comprised 146 passengers. A distribution of answers to the goal question is presented in Table 1 and on Figure 1.

Table 1. The distribution of preferred transportation modes

Answer	Number of passengers	Percent
Usually use a bus	111	76.03%
Usually use a train	22	15.07%
Usually use a car	13	8.90%
Total	146	100.00%
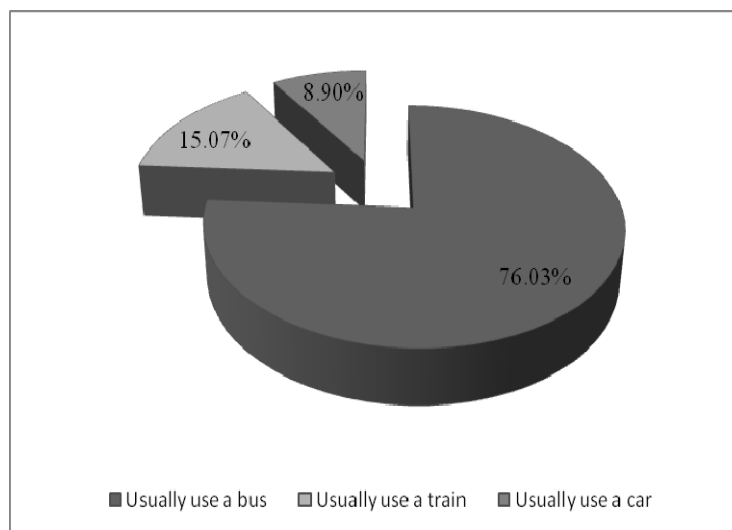
Figure 1. The distribution of preferred transportation modes

It would seem logical that bus passengers in 76.03% of cases identified a bus as their usual mode of transport.

Consequently, there are three possible outputs for our discrete choice model (such models are usually denoted as *multinomial discrete choice* models).

It is presumed that passengers do not choose their usual means of transport from all three possible alternatives directly, but that their decisions include two steps. The first step is to decide to use or not to use their own car (the choice is not applicable when the passenger does not have access to a car). The second stage, if the passenger has decided to use public transport, is to choose between a bus and a train. We used Hausman's and McFadden's test of independence from irrelevant alternatives to test this hypothesis.

In our case we consider the 'use a car' alternative as irrelevant for the choice between a train and a bus. The full model for the 'use a train' outcome includes the full sample, and the restricted model includes the 'use a train' and 'use a bus' answers only (the 'use a car' answer is excluded). The observed value for the Hausman's test and the p-level is as follows:

$$\chi^2_{obs} = 1.77,$$
$$p - value = 0.9946,$$
(7)

Consequently, we can definitely accept the null hypothesis that the choice 'use a car' is irrelevant for the choice between a train and a bus.

Usually such conclusions mean that a nested discrete choice model should be used, but in our case it is lessened to a sequential discrete choice model [8] (Figure 2).
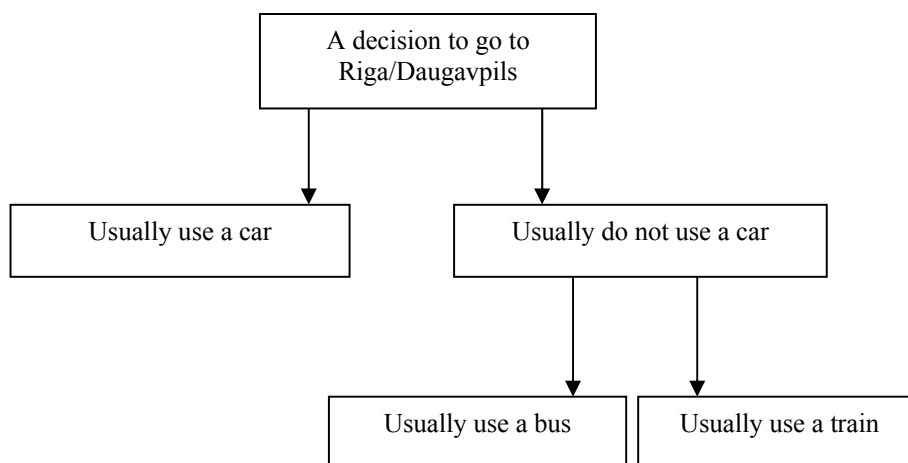

Figure 2. Hierarchy of passenger's decisions

The first stage choice ('use a car' vs. 'don't use a car') is represented by an usual discrete choice model (the Model I) estimated on the basis of the full sample, and the second stage ('use a train' vs. 'use a bus') is represented by a conditional discrete choice model (the Model II) estimated on the basis of the restricted sample.

Estimation Results

Model I is a discrete choice model for passengers' decisions to use a car or not to use a car for regular journeys to Riga/Daugavpils. The original sample contained passengers who stated that this trip was a unique event. Such passengers did not answer the question about their *usual* mode of transport and were excluded from the data set for the Model I. Questionnaires with missing answers were also excluded from the sample.

Some characteristics of Model I and an estimation of its results are presented in Table 2.

Table 2. Model I estimation results

Sample	The full sample with single trips excluded		
Sample size	126		
Dependent variable	'use a car'		
Dependent variable values	1, a person usually uses a car (10 cases, 7.94%) 0, a person usually uses another means of transport (116 cases, 92.06%)		
Log likelihood function value	– 21.448048		
LR test for goodness of fit, χ^2_{obs}	26.96		
LR test for goodness of fit, p-value	0.0007		
LRI value	0.3860		
Explanatory variable	*Description*	*Coefficient*	*p-value*	*Marginal effects*
Why-comfort	A person states a comfort as a reason for bus selection	-1.654	0.151	0.381
Income 500	Person's family income is more than 500 Ls per member	2.400	0.036	0.167

Age 4060	A person is from 40 to 60 years old	-2.025	0.059	0.333
Time6-12	Departure time is from 6 till 12 AM	-1.630	0.165	0.333
Time15	A person arrived at a station in less than 15 minutes before a departure	-0.468	0.635	0.333
Time1530	The person arrived at a station from 15 to 30 minutes before a departure	-3.540	0.007	0.524
Destination-final	The person's destination is the terminal point	-1.537	0.136	0.690
Language-lat	The person preferred to use the Latvian language	-3.399	0.008	0.519
Constant		1.872	0.163	

The value of McFadden's likelihood ratio index (formula 5, *LRI* = 0.3860) is significantly different from 0. The p-value for the likelihood ratio test (0.007) allows us to accept the hypothesis about the goodness of fit for Model I. Both facts identify Model I as a significant model which can be used for analysis and forecasting.

All significant coefficients in the model have expected signs (correct influence directions). In Table 2 we presented coefficient values, p-values for testing the insignificance hypothesis, and marginal effects for each variable. Marginal effects were calculated as discrete changes (formula 3) as all explanatory variables were discrete.

The income per family member variable had a significant influence on the car usage decision. The positive coefficient ($\hat{\beta}_{income500} = 2.400$) indicates that passengers with a higher level of income used a car for travelling to Riga/Daugavpils more frequently.

Passenger's age was also a significant factor in the model. According to the negative coefficient for the *age4060* variable we conclude that older people (from 40 to 60 years old) use a car rarely for this long trip. As the influence of the income level was included in the model separately, we suppose that older people preferred a worry-free trip on public transport to a long drive.

There was a negative sign for the *why-comfort* variable coefficient. This meant that passengers who liked the level of comfort in buses usually did not use a car for this reason. This fact can be explained in two ways. The first explanation (an obvious one) is that a bus is less comfortable (or equal) compared with a car and people who use cars do not consider the level of comfort of a bus one of its advantages. The second option is that passengers who like the level of comfort in a bus usually prefer this mode of transport to a car. We think both factors could be important.

Also we can note that passengers who began their journeys in the morning (from 6 till 12 AM) usually did not use a car. This fact could be useful for bus carriers and railways, as they could pay special attention to morning trips. The level of competition between trains and buses is most intense at this time.

The time of the passengers' arrival at a station is also an important consideration for transport services management. According to the model, the majority of passengers who usually prefer public transport arrived at a station between 15 and 30 minutes before departure time (the *time1530* variable). This information can be used to inform policies related to advertising or improving station services. The 15–30 minutes time range was compared with a long wait (more than 30 minutes) and last moment arrival (less than 15 minutes). No significant difference between two latter ranges was discovered.

We should also note the high marginal effect value for the arrival variable, which proves its importance. The marginal effect value means that if a passenger arrived at a station between 15 and 30 minutes before departure, there was a higher probability value (0.524 or 52.4%) that he would prefer public transport (other conditions being equal).

There was a higher probability that passengers travelling to a terminal point (Riga/Daugavpils) would usually use public transport (the coefficient for the *destination_final* variable is negative). This conclusion could be expected, and that people prefer to use cars for shorter trips (to intermediate stops).

From a practical point of view it is useful to separate the explanatory variables into two groups: observable and unobservable. Values of observable variables (age or destination point, for example) can be obtained without direct contact with a person, but unobservable values (passengers' opinions about the service, for example) cannot be obtained without asking questions.

Observable factors are easier to control in a particular case (by observing potential passengers). In addition, the average values can be obtained from statistical reports for the majority of observable factors. For example, the percentage of people who are from a particular age group in a geographical area can be collected from government statistical reports, or a destination point's distribution can be collected from ticket offices).

We included both observable and unobservable variables in the model, but after the stepwise reduction procedure there were only two unobservable variables that remained significant. The first variable was positive passenger's opinion regarding the level of comfort of buses (*why_comfort*), and the second was high level of passenger's income (more than 500 Ls, *income500*).

We tested the hypothesis concerning the joint insignificance of coefficients for these two variables using the Wald test:

$$\hat{\beta}_{why\_comfort} = \hat{\beta}_{income500} = 0$$

$$\chi^2_{obs} = 6.04$$

$$p-value = 0.0488$$

Therefore we should reject the null hypothesis regarding the joint insignificance at the 95.12% significance level. Consequently, neither variable can be excluded from the model.

The next step was to estimate the forecasting power of Model I. Using the model we predicted the probability values for all sample records. The distribution of these probability levels is presented on Figure 3.
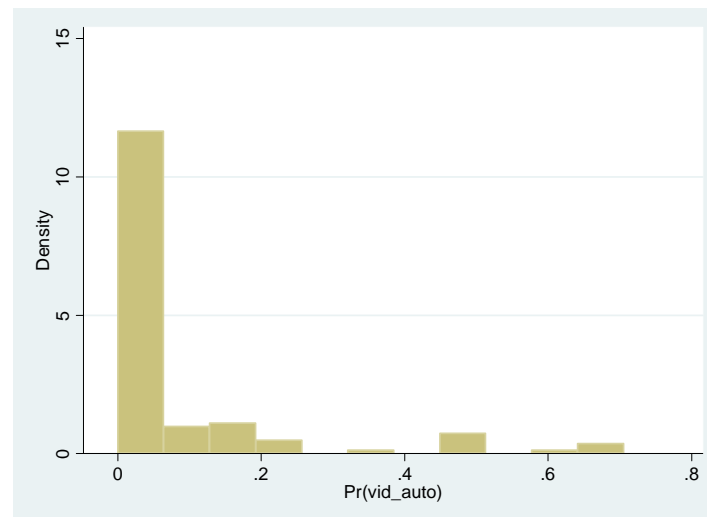

Figure 3. The distribution of predicted probability values for Model I

There are many instances of low probability values (representing a small possibility of using a car). This distribution matches our expectations as only 7.94% of the sample used a car as their usual means of transport (see the dependent variable description in Table 2).

Due to this fact we used a lower threshold value for forecasting. The selected value was 0.45, so all records with lower predicted probability values were classified as 'don't use a car' and all records with higher predicted probability values were classified as 'use a car'. The threshold value was selected to maximise the percentage of correctly classified cases.

We used a 2x2 table for comparing forecasted and observed values (Table 3).

Table 3. Model I forecasting power

The threshold = 0.45	Observed 'use a car'	Observed 'don't use a car'	*Total*
Predicted 'use a car'	5	5	*10*
Predicted 'don't use a car'	5	111	*116*
Total	*10*	*116*	*126*
Correctly classified			92.06%

The percentage of correctly classified cases was high (92.06%). Also a large percentage of persons were correctly classified as 'don't use a car' (111 out of 116). The forecasting of usual car users was not so good (5 from 10) as an absolute value, but nonetheless, 5 usual car users were correctly identified from 126 persons. This shortcoming can be explained by the small size of the usual car user subsample.

Model I is a discrete choice model for passengers' decisions to use a train or use a bus for regular journeys to Riga/Daugavpils. We used a Hausman's test to test the null hypothesis about the irrelativeness of the car alternative to a bus/train choice (formula 7). The null hypothesis was accepted; therefore passengers who usually use a car were excluded from the sample for Model II estimating.

Model II estimation results are presented in Table 4.

Table 4. Model II estimation results

Sample	The sample with 'use a train' and 'use a bus' answers for the goal question only
Sample size	102
Dependent variable	"use a train"
Dependent variable values	1, a person usually uses a train (18 cases, 17.65%) 0, a person usually uses a bus (84 cases, 82.35%)
Log likelihood function value	– 31.69122
LR test for goodness of fit, χ^2_{obs}	31.68
LR test for goodness of fit, p-value	0.0002
LRI value	0.3333

Explanatory variable	Description	Coefficient	p-value	Marginal effects
Time12–18	Departure time is from 12:00 till 18:00	-1.785	0.116	-0.084
Riga	A person travels from Riga	1.976	0.051	0.106
Why-habit	A person states a habit as a reason for bus selection	-2.079	0.088	-0.892
Why-price	A person states a price as a reason for bus selection	2.657	0.005	0.399
age4060	A person is from 40 to 60 years old	-1.988	0.029	-0.115
direct	A trip is a direct one (vs. a return one)	-1.867	0.023	-0.193
Freq-year	A person travels this way once a year or more rare	1.014	0.183	0.084
Destination-final	Person's destination is the terminal point	1.178	0.131	0.069
Alt-cheaper	A person thinks that a train is cheaper than a bus	1.167	0.150	0.100
Constant		-2.919	0.049	

The value of McFadden's likelihood ratio index (*LRI* = 0.3333) is significantly different from 0. We also accept the hypothesis about the goodness of fit for Model II on the basis of the p-value for a likelihood ratio test (0.002).

The majority of variables have the expected direction of influence.

Departure time had a significant influence on the bus/train choice. Evening bus trip passengers (leaving between 12:00 and 18:00, the *time12–18* variable) use a bus as a rule with higher probability. This fact can be used by bus carrier managements to introduce additional features for regular evening bus passengers, and to attract non-regular passengers at other times of day.

The *Riga* discrete variable increases the probability of train selection, so we can conclude that there are more passengers who leave Riga by bus, rather than by train (their preferred means of transport).

This can be explained by a higher level of mobility for passengers leaving Riga, and by the possibility that it is more difficult to switch modes of transport from a train to a bus in Daugavpils.

There are two significant variables related to the reasons for bus selection, and both have obvious meanings. Firstly, passengers who state that habit is their reason for choosing the bus use the bus more frequently than the train. The highest marginal effect value (-0.892) matches our expectations. Also, passengers who choose price as a key factor in their selection prefer to use the train (a train ticket is slightly cheaper than a bus ticket).

Passengers from 40 to 60 years old use the bus more frequently than the train for regular trips. This fact can be useful for the marketing campaigns of railways and bus carriers.

The negative value of a coefficient for the *direct* variable suggests that people prefer their usual means of transport for their direct trips. In other words, the fact that a person chooses a bus for his direct trip indicates that he uses a bus as a rule.

Passengers, who usually travel by bus very seldom (once a year or less), choose to use the train. This could indicate that they have the habit of using trains mainly for longer trips or when there is more information available about railways. The terminal point as a destination predictably increases the probability of train selection.

In order to estimate the model forecasting power we used the same method as for Model I.

The distribution of the predicted values is presented on Figure 4. Again, one of the alternatives is chosen rarely (only 17.65% of respondents use a train as their usual means of transport. This figure may possibly be due to limitations in the sample), and this could explain why there are many records with a low level of forecast probability. Using the same principle we defined the threshold as 0.35 for forecasting (all records with a predicted probability value less than 0.35 were classified as 'use a bus' and all records with a predicted probability value more than 0.35 were classified as use a train).
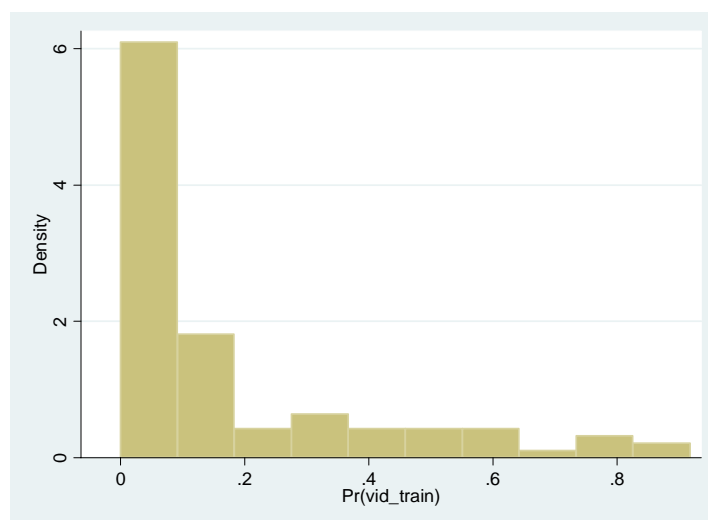

Figure 4. The distribution of forecast probability values for the Model II

The Table 5 contains the comparing of forecast and observed choices.

Table 5. The Model II forecasting power

The threshold = 0.35	Observed "use a train"	Observed "use a bus"	*Total*
Predicted "use a train"	13	9	*22*
Predicted "use a bus"	5	75	*80*
Total	*18*	*84*	*102*
Correctly classified			86.27%

86.27% of cases are classified correctly. Also we note a high level of coincidence for the unusual alternative (13 of 18 passengers who usually use a train are classified correctly).

Conclusions

We developed two discrete choice models for a choice of transportation mode for Riga–Daugavpils two-ways journeys. The first model allows the prediction of the choice between using a car and using public transport, and the second model focuses on the choice between using a bus and using a train. Both models have a high percentage of correctly classified cases (92.06% and 86.27% respectively).

We investigated an influence of a wide range of factors, which affected passenger's choice, and estimated their marginal effects. Some key factors were discovered. Directions of these factors' influence could be used by bus and railway carriers and stations to improve their services. A set of most important significant factors includes departure time, ticket price information, and passenger's personal characteristics like age and income. Also a significant influence of a destination point is discovered.

We are planning to extend this research with additional surveys, executed at different time points (seasons of a year). We assume that passengers' preferences and explaining factors can change depending on seasonal variables like weather and workload.

References

1. Gromule, V., Yatskiv, I. Coach Terminal as an important element of transport infrastructure. In: *Proceedings of the International Scientific Conference "Transbaltica 2007", Vilnius 11–12 April 2007, Transport.* Vilnius: Technika, 2007. Vol. 22, No 3, pp. 200–206.
2. Gromule, V., Jackiva, I. Information System Development for Riga Coach Terminal. In: *Conference on System Science and Simulation in Engineering, Venice, Italy, November 21–23, 2007*, pp. 170–175.
3. Greene, W. H., *Econometric Analysis, fifth edition.* NJ: Prentice Hall, Upper Saddle River, 2003. 1024 p.
4. Ben-Akiva, M., Lerman, S. *Discrete Choice Analysis: Theory and Application to Travel Demand (Transportation Studies)*. Massachusetts: MIT Press, 1985. 384 p.
5. Amemiya, T. Qualitative Response Models: A Survey, *Journal of Economic Literature,* Vol. 19, No 4, 1981, pp. 481–536.
6. McFadden, D. The Measurement of Urban Travel Demand, *Journal of Public Economics,* Vol. 3, 1974, pp. 303–328.
7. Hausman, J., McFadden, D. A Specification Test for the Multinomial Logit Model, *Econometrica,* Vol. 52, 1984, pp. 1219–1240.
8. McFadden, D. *Econometric Analysis of Qualitative Response Models: Handbook of Econometrics,* Amsterdam: North Holland, 1984. Vol. 2, pp. 1395–145.

MATHEMATICAL MODEL OF A HYDRALIC DRIVE
FOR A DYNAMIC TEST STAND

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One of the priority areas in development of science and technology is the flight simulator engineering, and this top target is determined by the pressing necessity to improve the quality of air staff training, to assure flight safety and reliability technologies against the background of cuts in expenditures for aircrew training, instruction and drill. The flight training systems, or flight and equipment simulators, are provided with computing and modelling systems enabling the crew the facilities to acquire and reinforce the skills of aircraft handling, flight control, air navigation, and aircraft equipment service. The military aircraft pilots are given the opportunity to use the simulators for operational flight training.

An integrated flight simulator is a complex of interrelated components designed for regular aircrew training regardless of meteorological condition, availability and operational status of the aircraft make and model, and with no reference to the air conditions and air-traffic restrictions. It is particularly important that flight simulators provide safe ground conditions for aircrew emergency-response training with due consideration of possible high sustained G-loads and complex aircraft movements.

A dynamic test stand is a basic element of the flight simulator intended to develop the acceleration effects similar to those experienced by a person operating, in live environment, a moving vehicle (an aircraft, a tank, etc.)

Keywords: flight simulator, dynamic test stand, hydraulic drive, mathematical model

Introduction

The performance of the dynamic test stands currently in use is substantially limited as a result of the weight loads of both the moving platform itself and the equipment mounted thereupon acting on the servo drive.

In the downward motion of the moving parts their weight force is combined with the force set by the hydraulic drive, while in the upward motion the above forces counteract, which results in the skewness of the drive speed/load curve and finally distorts the electric input signals traced. This disadvantage is particularly notable during the response of a high-frequency input.

Description of the investigation

To remedy the deficiency a hydro-dynamical static load compensator HDSC [1] is added to the hydraulic servo drive of the two-degree-of-freedom vertical-cylinder dynamical test stand.

The principle of operation of the HDSC hydraulic drive is illustrated by functional block-diagram given on Figure 1.

Figure 1 displays: HA – hydraulic accumulator; HDSC – hydro-dynamical static load compensator; HC – hydraulic-cylinder; FV1, FV2, FV5, FV6 – nozzle-flapper valves; TV3, TV4, TV7, TV8 – calibrated throttling valves; PrS – pressure sensor; DS – displacement sensor; DPP – differential-pressure pickup; VS – velocity sensor; CS – current sensor; CSS – compensating signal setter; HSD – hydraulic servo drive; IMS – information and measuring system; SRV – safety relief valve; PF – position (spring) feedback; OV 1, OV 2 – operating valve; NA 1, NA 2 – nozzle assembly; CU 1, CU 2 –control unit; CAC – control action conditioner; EHA – electrical hydraulic amplifier; EMT – electromechanical transducer.

A triple-chamber hydraulic-cylinder (HC) is the working element of a servo drive. Its two chambers are used as the working cavities while the third one serves as a compensation chamber. In the HC compensation chamber a constant pressure is maintained which is to balance the static load weight acting on the longitudinal axis of the HC rod. Due to this design of the hydraulic cylinder the functional capabilities of a hydraulic drive are expanded and its curve symmetry is achieved. The hydraulic cylinder

is operated by the control unit (CU) via the operating valve (OV) and the electrical hydraulic amplifier (EHA). The servo driver SD also comprises a differential-pressure pickup DPP.
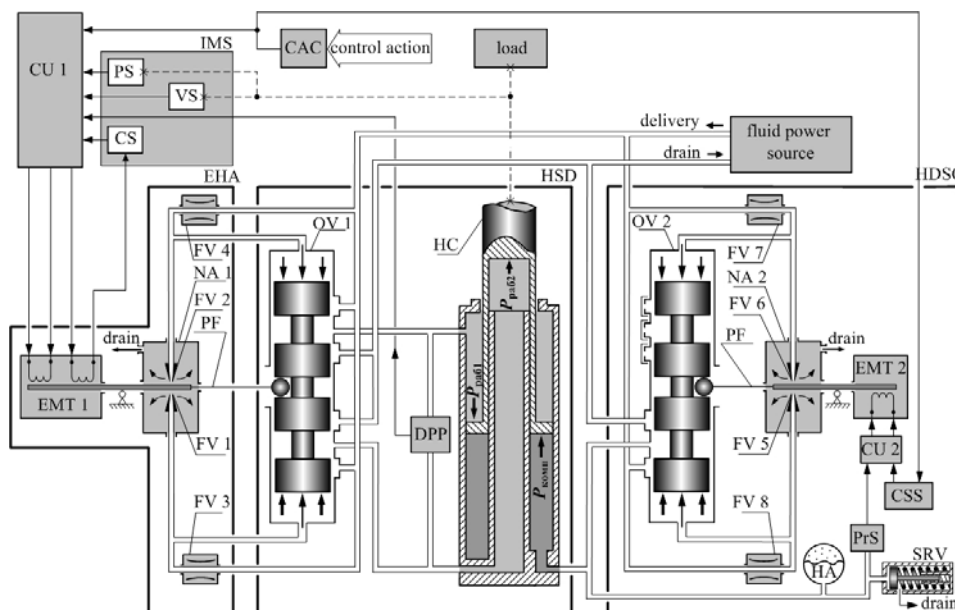

Figure 1. Functional block-diagram of a HDSC hydraulic servo drive

The travel of the hydraulic cylinder rod is made possible due to the pressure difference in the working chambers P$_{work1}$ и P$_{work\ 2}$ resulting from the control by the EHA of the operating liquid flow: a signal is applied through the CU1 to the EHA input which is proportional to the difference between a drive signal from the control action conditioner CAC and a feedback control signal from the position sensor PS. As may be seen from Fig. 1 the position sensor PS, pressure regulator valve, the electrical hydraulic amplifier EHA and the hydraulic-cylinder HC make up a reverse position feedback servo which provides a means of representation of acceleration differential by reference-input signals [2].

From the prospective of system approach a hydraulic drive unit is a complex of interrelated elements, its quality is not limited to a summation of single properties, and this complex rather comprises a number of functional components (Fig. 1). Therefore, a mathematical model of the whole hydraulic system can be represented as an interconnected complex combination of units – mathematical models of separate elements, and, primarily, models of the hydraulic servo drive and hydraulic amplifier which make up a stable invariable part of the system and combine the linearized equations given below:

- movement of load mass m reduced to the HC axis

$$m\frac{d^2x}{dt^2} = c_{\hat{E}}\left(x_{\ddot{I}} - x\right) - c_{\emptyset} \cdot x - b\frac{dx}{dt} - F; \tag{1}$$

- movement of the HC piston of $m_{\ddot{I}}$ mass

$$m_{\ddot{I}} \frac{d^2x_{\ddot{I}}}{dt^2} = A_{\ddot{I}}\,\Delta P - \tilde{n}_{\hat{E}} \cdot \left(x_{\ddot{I}} - x\right); \tag{2}$$

- the hydraulic drive flow rate

$$K_E \frac{d\Delta P}{dt} = -A_{\ddot{I}} \frac{dx_{\ddot{I}}}{dt} + K_{QL} \cdot L - K_{QP}\Delta P\,; \tag{3}$$

- velocity of the OV displacement

$$\frac{dL}{dt} = \frac{K_{Qh}}{A_{\c{C}}} \cdot h\,; \tag{4}$$

- movement of the RHA armature

$$m_{\text{â}} \frac{d^2 h}{dt^2} = K_{FI} I - K_{Fh} h - b_{\text{â}} \frac{dh}{dt} - \tilde{n}_{\text{Ï Ñ}} \cdot (h + L) - K_R h; \qquad (5)$$

- control winding of the EHA EMT

$$L_{\text{Ý}} \frac{dI}{dt} = U - RI - K_{\text{Ý}} \frac{dh}{dt}. \qquad (6)$$

Here x – coordinate of the platform movement, $[x] = \text{ì}$; $x_{\text{Ï}}$ – HC piston displacement axis, $[x_{\text{Ï}}] = \text{ì}$; $\tilde{n}_{\emptyset}$ – positioning (hinge) load factor, $[\tilde{n}_{\emptyset}] = \frac{\text{Í}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}^2}$; $A_{\text{Ï}}$ – piston active area, $[A_{\text{Ï}}] = \text{ì}^2$; $\Delta P = P_1 - P_2$ – HC pressure differential, $[\Delta P] = \text{Ï à}$; F – downward (gravity) force of the platform movable part, $[F] = \text{Í}$; L – OP displacement axis, $[L] = \text{ì}$; K_{QL} – OV transmission factor by flow rate, $[K_{QL}] = \frac{\text{ì}^2}{\tilde{n}}$; K_{QP} – sliding factor by flow rate, $[K_{QP}] = \frac{\text{ì}^4 \tilde{n}}{\text{êã}}$; $K_{\text{E}} = V_0 / 2 \cdot E$ – coefficient based on the liquid compressibility with adjusted value of modulus of volume elasticity E, $K_E = \frac{\text{ì}^4 \tilde{n}^2}{\text{êã}}$; $V_0 = 1,2 \cdot A_{\text{Ï}} \cdot x_{\max}$ – volume of HC working cavity; $K_{FI} = \left(\frac{\partial F}{\partial I} \right)_0$ – EMT current transfer factor, $[K_{FI}] = \frac{\text{Í}}{\text{À}}$; $K_{Qh} = \left(\frac{\partial Q_{\text{Ä}}}{\partial h} \right)_0$ – flapper-nozzle bridge transfer factor by flow rate, $[K_{Qh}] = \frac{\text{ì}^2}{\tilde{n}}$; $Q_{\text{Ä}}$ – HC flow rate, $[Q_{\text{Ä}}] = \frac{\text{ì}^3}{\tilde{n}}$; $K_{Fh} = \left(\frac{\partial F}{\partial h} \right)_0$ – EMT transfer factor by flapper working point displacement, $[K_{Fh}] = \frac{\text{Í}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}^2}$; K_R – coefficient based on the fluid-dynamic action on the flapper, $[K_R] = \frac{\text{Í}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}^2}$; $K_{\text{Ý}}$ – back emf factor, $[K_{\text{Ý}}] = \frac{\text{Â} \cdot \tilde{n}}{\text{ì}}$; R – equivalent effective resistance of EMT control winding, $[R] = \text{Î ì}$; $L_{\text{Ý}}$ – EMT control winding inductance, $[L_{\text{Ý}}] = \text{Ãí}$; $\tilde{n}_{\text{Ê}}$ – coefficient of power wiring stiffness, $[\tilde{n}_{\text{Ê}}] = \frac{\text{Í}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}^2}$; b – viscous friction coefficient, $\tilde{n}_{\text{Ï Ñ}}$ – coefficient of the EHA feedback spring stiffness, $[\tilde{n}_{\text{Ï Ñ}}] = \frac{\text{Í}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}^2}$; b – viscous friction coefficient,, $[b] = \frac{\text{Í} \cdot \tilde{n}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}}$; $b_{\text{â}}$ – viscous damping factor of the EMT armature, $[b_{\text{â}}] = \frac{\text{Í} \cdot \tilde{n}}{\text{ì}} = \frac{\text{êã}}{\tilde{n}}$; $m_{\text{â}}$ – value of the EMT armature and flapper masses adjusted (reduced) to the nozzle axis, $[m_{\text{â}}] = \text{êã}$; $A_{\text{Ç}}$ – OP passage area, $[A_{\text{Ç}}] = \text{ì}^2$; h – throttle gate displacement axis, $[h] = \text{ì}$; U – EMT winding voltage, $[U] = \text{Â}$; I – EMT control current, $[I] = \text{À}$.

The complete mathematical model of the hydraulic drive with provision for a nonlinear nature of several structural elements exclusive of (1) – (6) contains a set of functionalities based on relationship between some of the variables, as well as flow rate and pressure saturation, friction and response timeout.

With regard to a noticeable narrowing of the control action range in the HDSC hydraulic servo drive a linearized mathematical model can, with a sufficient degree of operating accuracy, be taken for analysis of the control laws applied to the hydraulic drive units.

We think of the hydraulic drive, i.e. a controlled member, as a transducer, and take the load mass displacement x as its output (controllable) coordinate. The control action u_1 is the voltage in the EMT winding U, the principle disturbing actions z_0, z_1 – downward (gravitation) force of the platform movable part F and load-motion and load-variation forces.

Taking account of the hydraulic drive configuration we imagine the model (1) – (6) in terms of a state space. We designate the state variables as: v_1, v_6 – control current values in the EHA EMT; v_2, v_7 –

velocities of the EHA flapper displacement $\dfrac{dh}{dt}$; v_3, v_8 – axes of flapper displacements h; v_4, v_9 – axes of OP displacements L; v_5, v_{10} – pressure differential $\Delta P = P_1 - P_2$, and compensating pressure in the triple chamber HC compensation chamber; v_{11} – velocity of load mass displacement $\dfrac{dx}{dt}$; v_{12} – axis of load mass displacement x.

If $\tilde{n}_{\hat{E}} = \infty$ axes of displacements of HC mass x and piston $x_{\ddot{I}}$ are the same $x = x_{\ddot{I}}$, the dynamic state of the hydraulic drive with static load compensation can be set in the space of the state vector $\overline{V} = \begin{bmatrix} v_1 & v_2 & v_3 & v_4 & v_5 & v_6 & v_7 & v_8 & v_9 & v_{10} & v_{11} & v_{12} \end{bmatrix}^{\grave{O}}$ by a model of a combined block and matrix form

$$
\begin{bmatrix} v_1^{(1)} \\ v_2^{(1)} \\ v_3^{(1)} \\ v_4^{(1)} \\ v_5^{(1)} \\ v_6^{(1)} \\ v_7^{(1)} \\ v_8^{(1)} \\ v_9^{(1)} \\ v_{10}^{(1)} \\ v_{11}^{(1)} \\ v_{12}^{(1)} \end{bmatrix}
=
\begin{bmatrix}
\begin{bmatrix} A_1 \\ 5\times5 \end{bmatrix} & \begin{bmatrix} 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \end{bmatrix} & \begin{matrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ -\dfrac{A_{\ddot{I}}^1}{K_E^1} & 0 \end{matrix} \\
\begin{bmatrix} 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0 \end{bmatrix} & \begin{bmatrix} A_2 \\ 5\times5 \end{bmatrix} & \begin{matrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ -\dfrac{A_{\ddot{I}}^2}{K_E^2} & 0 \end{matrix} \\
0\,0\,0\,0\,\dfrac{A_{\ddot{I}\,1}}{m}\; & 0\,0\,0\,0\,\dfrac{A_{\ddot{I}\,2}}{m}\; 0 & \dfrac{\tilde{N}_{\O}}{m} \\
0\,0\,0\,0\,\;0 & 0\,0\,0\,0\,\;0 & 1 \quad 0
\end{bmatrix}
\cdot
\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \\ v_7 \\ v_8 \\ v_9 \\ v_{10} \\ v_{11} \\ v_{12} \end{bmatrix}
+
\begin{bmatrix}
\dfrac{1}{L_{\grave{O}1}} & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & \dfrac{1}{L_{\grave{O}2}} & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & -\dfrac{1}{m}
\end{bmatrix}
\cdot
\begin{bmatrix} u_1 \\ u_2 \\ z_0 \end{bmatrix}.
\tag{7}
$$

The matrixes $\begin{bmatrix} A_1 \end{bmatrix}$ and $\begin{bmatrix} A_2 \end{bmatrix}$ have similar structures and the same 5×5 sizes [2], they represent the models of electro-dynamic amplifiers and flow rates of the dynamic servo drive, and the model of the hydrodynamic compensator of static load:

$$
\begin{bmatrix} A_j \end{bmatrix} =
\begin{bmatrix}
-\dfrac{R^j}{L_{\grave{O}}} & -\dfrac{K_{\acute{Y}}^j}{L_{\grave{O}}} & 0 & 0 & 0 \\[2mm]
\dfrac{K_{FI}^j}{m_{\ss}^j} & -\dfrac{b_{\ss}^j}{m_{\ss}^j} & -\dfrac{K_{Fh}^j + K_R^j + \tilde{n}_{\ddot{I}\,\tilde{N}}^j}{m_{\ss}^j} & -\dfrac{\tilde{n}_{\ddot{I}\,\tilde{N}}^j}{m_{\ss}^j} & 0 \\[2mm]
0 & 1 & 0 & 0 & 0 \\[2mm]
0 & 0 & 0 & \dfrac{K_{Qh}^j}{A_{\c C}^j} & 0 \\[2mm]
0 & 0 & 0 & \dfrac{K_{QL}^j}{K_E^j} & -\dfrac{K_{QP}^j}{K_E^j}
\end{bmatrix}.
$$

Based on the mathematical model (7) developed in MathCAD a study was conducted of the hydraulic drive response to the control actions for displacement defined as expression

$$Y(t) = \frac{a_0 t^2}{2} \tag{8}$$

in the uniformly accelerated motion at various acceleration and defined as expression

$$Y(t) = \int\limits_{t_1}^{t_2}\int\int \dot{a}dt^3 \tag{9}$$

at a constant load in accordance with the method suggested.

Conclusions

A hydraulic drive control system was developed based on the hydro-dynamical compensator of the static weight of the stand and cockpit movable parts taken up by servo drives. The system allows loading of the servo drives only with inertia load, which is found to eliminate the skewness of the drive speed/load curve and correct the distortion of the electric input signals traced.

A mathematical model of the hydraulic drive was synthesized and the analysis was made of the hydraulic drive control system based on the hydro-dynamical compensator of the static weight of the stand and cockpit movable parts.

Experimental studies were carried out that showed the increase of phase margin in the hydraulic drive in question.

In practice, the above methods, processes and hydraulic drive models suggested for manufacture of the dynamic test stands to be used in aircrew flight training simulators proved to be highly efficient. In particular, they facilitate a more accurate reproduction of the control actions, improve simulator controllability and reliability, and reduce the input power.

Basically, the research resulted in the development of the control system based on a hydro-dynamical static load compensator for a simulator hydraulic drive, a mathematical model of the hydraulic drive, and acquisition of the relevant simulation data.

The research findings are of considerable scientific and practical interest.

References

1. Proshin, I. A., Proshkin, V. N., Timakov, V. M. Improving dynamic stands flight simulators based on hydraulic, *Mechatronics, Automatization, Management*. No 11, 2008, pp. 21–26. (In Russian)
2. Proshin, I. A., Timakov, V. M., Proshkin, V. N. The simulator of floating object for crew training actions in emergencies In: *Reports of Astrakhan State Technical University*. Series: *"Maritime Engineering and Technology"*. Astrakhan: Astrakhan State Technical University, 2009. No 1, pp. 82–87. (In Russian)

MATHEMATICAL MODELLING OF CONTROL LAWS
BY DYNAMIC TEST STAND OF FLIGHT SIMULATOR

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Flight simulator dynamic test stands intended for flight crew training are considered in this paper, with the focus of particular interest being on the improvement of the dynamic test stands. The practical value of the project results from the significant quality improvement in the control of the real-life flight simulators based on the research results applied. The high efficiency of the project has been proved by both application of the research results to the flight training and the experimental investigation of the new system in the working environment.

The originality of the project is determined by the system suggested for control of the hydraulic drive with static load compensation as well as by the hydraulic drive models and the control laws developed. Due to the developments mentioned the accuracy of the response to the control input signal is improved and the loads created in the test stand are approximated to the real-life loads.

As a primary result of the investigation a simulated model has been developed and control laws have been improved for the flight simulator dynamic test stands.

The research findings prove to be of major scientific and practical interest and can be recommended for application in the flight simulator control systems.

Keywords: flight simulator, gradient, dynamic test stand, G-load, acceleration data

Introduction

Nowadays, the flight simulating technology is among the most rapidly growing branches of the aircraft industry. Due to the intense interest to these areas of research a number of major conferences as well as local meetings and workshops are held on these subjects. It is by no means surprising because the development of the flight simulating technology has a distinct positive effect on the flight safety, economic and ecological efficiency of civil and military aviation, as well as on the peacetime fighting capacity of the latter.

Dynamic test systems, or stands, are the basic and the most important elements of the flight simulators designed for reproduction of acceleration data for its further perception by a person.

The need to develop the stands of this type has emerged for a variety of reasons such as the design and development of simulators suitable for training motor vehicle drivers, pilots, tank drivers, etc. and capable of reproduction of angular and linear acceleration data according to the simulated conditions of the actual (real-life) objects.

Description of the Investigation

Studies carried out in Russia and abroad [1–5] show that there is no need to create special conditions for long-term acceleration (G-effect). According to the papers mentioned, the acceleration data are received by a human when the acceleration values are altering, rather than they are steady.

As to the gradient, its effect is basically nondurable, and the mobile platform can be moved within short travel (displacement) ranges.

In this case, the configuration and design of drive units responding the motion parameters may be notably simplified, and, further, no long movements are needed during operation.

The fidelity of acceleration data reproduction by the flight simulator depends on the dynamic test stand qualitative adjectives and dimensional features as well on the law selected to control the platform motion; it is to be determined by the performance capability and specifications of the drive unit.

The actual value of height within the time interval between t_1 and t_2 under alternating acceleration is determined by the expression as below:

$$h(t) = h_0 + v_0 t + \frac{a_0 t^2}{2} + \int\limits_{t_1}^{t_2}\!\!\int\int \dot{a}\, dt^3 \ , \tag{1}$$

where h_0, v_0, a_0 – the initial values of height, velocity and acceleration at the time of G-load change; t – time.

As follows from the analysis of equation (1) and with regard to the human factors (i.e. psychological and physiological characteristics of a person), the most informative ingredient carrying the acceleration data is the last term of the right-hand member of the equation that, compared to the other members of the equation, requires the minimum range of the stand displacements for its representation. An improved accuracy and cost efficiency method is suggested in [6] for axis control of the dynamic test stand. The differential characteristic of the method is the unified closed cycle control of the displacement, velocity, acceleration, and G-load.

To represent, by applying the method suggested, the component

$$\Delta h(t) = \int\limits_{t_1}^{t_2}\!\!\int\int \dot{a}\, dt^3$$

on the dynamic stand during simulation of the real object processes a signal is calculated proportional to the third derivative from the vertical displacement and by the real-time triple integration thereof a signal is determined proportional to the current value of height $h(t)$ in the fixed time frame

$$\Delta h(t) = \int\limits_{t_1}^{t_2}\!\!\int\int \dot{a}\, dt^3 = C_1 + C_2 + C_3 + \Delta h_2(t), \tag{2}$$

where C_1, C_2, C_3 – constants of integration, with $C_1 = \dfrac{a_0 t^2}{2}$; $C_2 = v_0 t$; $C_3 = h_0$.

Without entering the constants of integration into the solution of equation (2), we obtain the desired law of coordinate variation (trajectory) $h_{\text{ÑÒ}}(t)$ of the dynamic stand

$$h_{\text{ÑÒ}}(t) = \Delta h_2(t) = \int\limits_{t_1}^{t_2}\!\!\int\int \dot{a}\, dt^3 \ ,$$

which can be represented by minimum displacements of its movable platform.

According to the method suggested for reproduction of the acceleration data, e.g. for reproduction of acceleration parameter, a wave-shaped signal proportional to the acceleration-time displacement is applied to the servo drive input. In case of an error-free operation of the servo drive, the travel of its working element (i.e. the hydraulic-cylinder rod) shall be quadratically time-dependent in relation to the control signal behaviour, thus reproducing the actual accelerations of the rod. It is assumed that the servo drive shall meet the accuracy of response to an input signal, speed performance and smooth running requirements.

The system suggested for the control of the dynamic test stand is inertial due to the presence of energy storage units, moments of inertia, masses, that cannot be displaced by using the sources of infinitely high power.

The control characteristics specified for a dynamic stand can be generally maintained in a closed cycle n-order system shown on Figure 1. The lowest possible order of a system in which conditions are provided for generating, by applying the method suggested, the laws to control a dynamic test stand in a closed cycle astatic system corresponds to the third order. At the same time, the real-life drive systems (hydraulic or electric drive units) can most commonly be described using the mathematic models of higher orders.
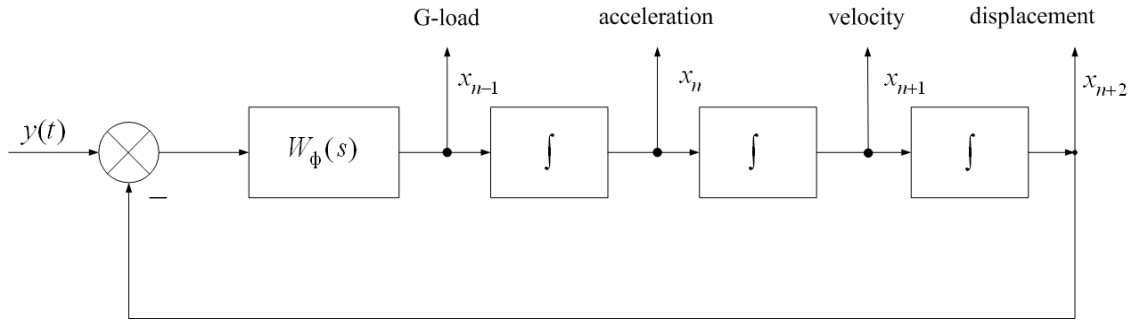
Figure 1. Block-diagram of the control law generation

With a view to analyse the basic characteristics of dynamic stands and specify the requirements to their drive units in generating the specified laws to control the axes of displacement, velocity, acceleration, G-load a mathematic simulation model has been generated intended to simulate the control laws in a random-order closed cycle system with specified performance parameters.

A mathematic model of a dynamic $n-$ order system is given [7], which describes the process of specification (generation) of control laws in a closed cycle system for displacement of controllable axes $\bar{X}=[x_{n-1} \ x_n \ x_{n+1} \ x_{n+2}]^{\text{O}}$ by means of a vector including the axes to control the displacement x_{n+2}, velocity x_{n+1}, acceleration x_n, G-load x_{n-1}.

$$
\begin{bmatrix} v_1^{(1)} \\ v_2^{(1)} \\ v_3^{(1)} \\ \dots \\ v_{n-1}^{(1)} \\ v_n^{(1)} \\ v_{n+1}^{(1)} \\ v_{n+2}^{(1)} \end{bmatrix} = \begin{bmatrix} -a_{n-2} & -a_{n-1} & \dots & -a_1 & -a_0 & 0 & 0 & -\lambda_0 \\ 1 & 0 & \dots & 0 & 0 & 0 & 0 & -\lambda_1 \\ 0 & 1 & \dots & 0 & 0 & 0 & 0 & -\lambda_2 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \dots & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ \dots \\ v_{n-1} \\ v_n \\ v_{n+1} \\ v_{n+2} \end{bmatrix} + \begin{bmatrix} \lambda_0 \\ \lambda_1 \\ \lambda_2 \\ \dots \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix};
$$

$$
X = \begin{bmatrix} x_{n-1} \\ x_n \\ x_{n+1} \\ x_{n+2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \dots & 1 & 0 & 0 & 0 \\ 0 & 0 & \dots & 0 & 1 & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 & 1 & 0 \\ 0 & 0 & \dots & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ \dots \\ v_{n-1} \\ v_n \\ v_{n+1} \\ v_{n+2} \end{bmatrix}.
$$

The stimulated model of the system with generation of the control laws by the method suggested was synthesized in terms of the standard coefficients and dynamic compensation methods. The system characteristics are to be specified by selection of the system order n, damping factor ξ, transient acceleration time τ.

Mathematic models of third-, sixth- (both single-zero and double-zero types), seventh-order have been synthesized, and a study was conducted of the effects of the system order, overcorrection, and control time on the accuracy of response to a control law.
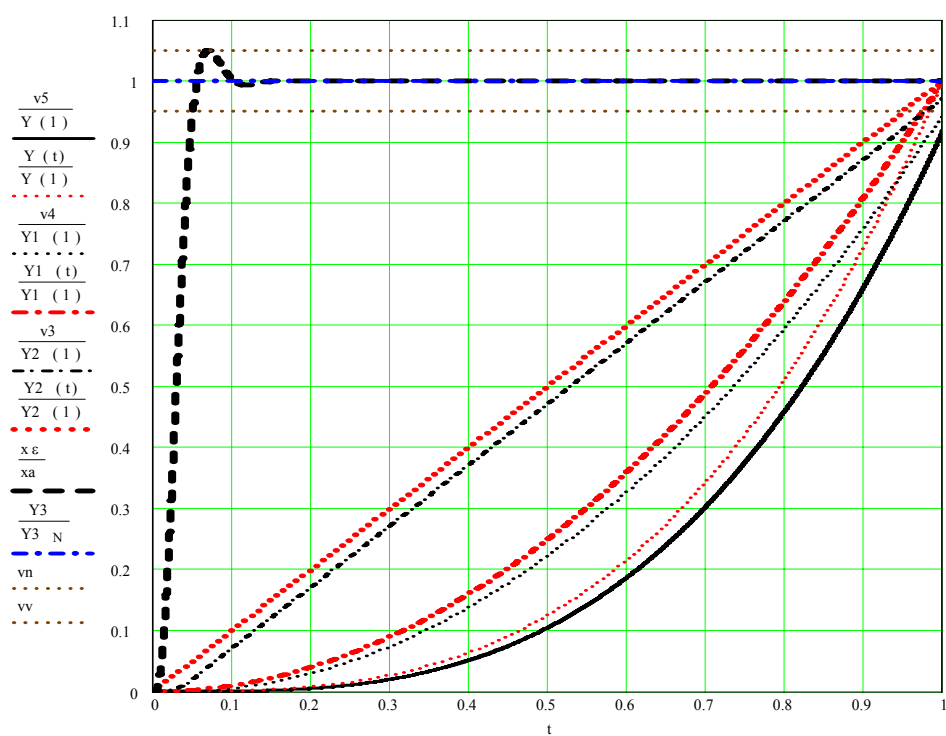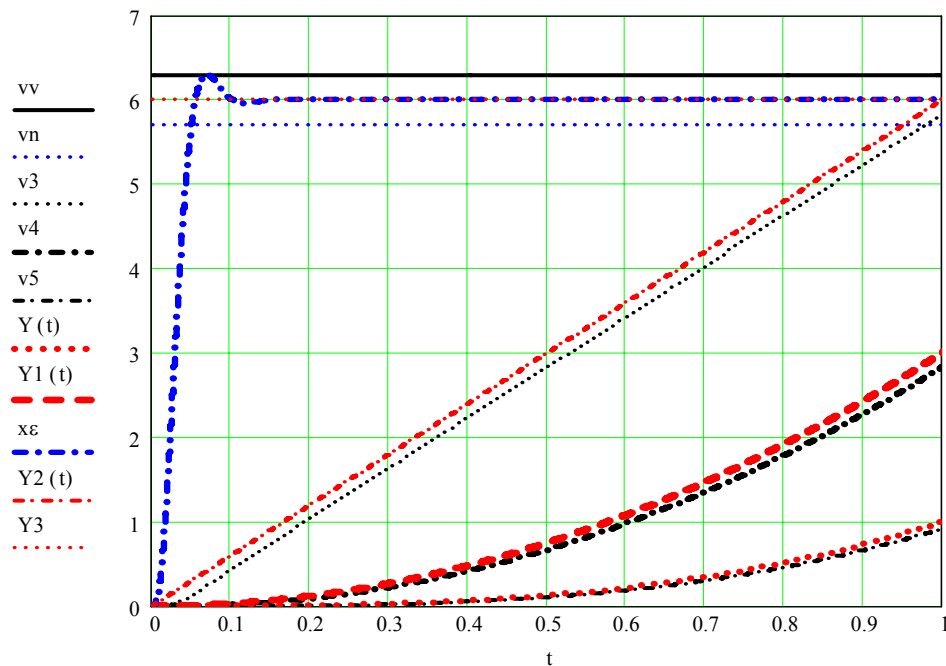
Motion with uniform G-load

Displacement of the platform is set up by the function $y(t) = \dfrac{at^3}{6}$;

The velocity of the platform displacement $y1(t) = \dfrac{at^2}{2}$;

The platform acceleration is set up by the function $y2(t) = at$;
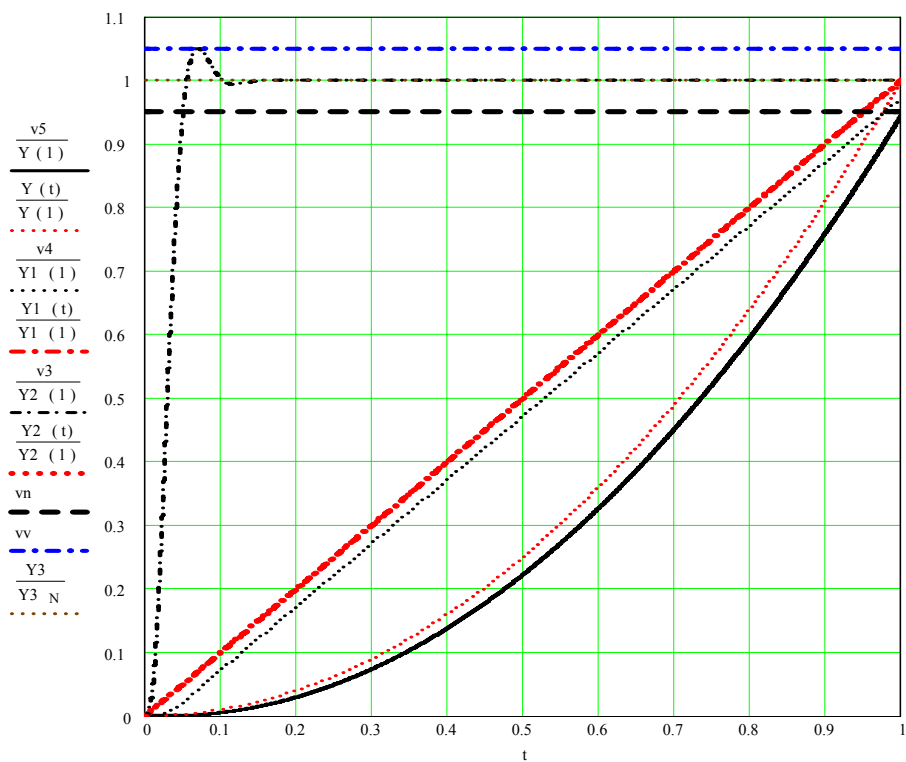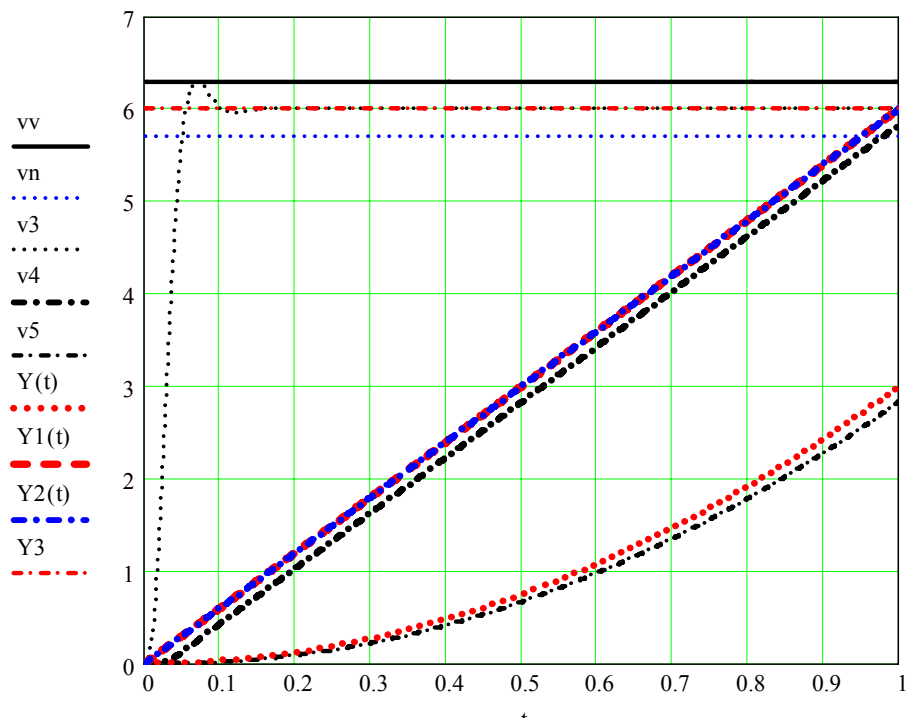
The G-load $y3(t) = a$

Motion with uniform acceleration

Displacement of the platform is set up by the function $y(t) = \dfrac{at^2}{2}$;
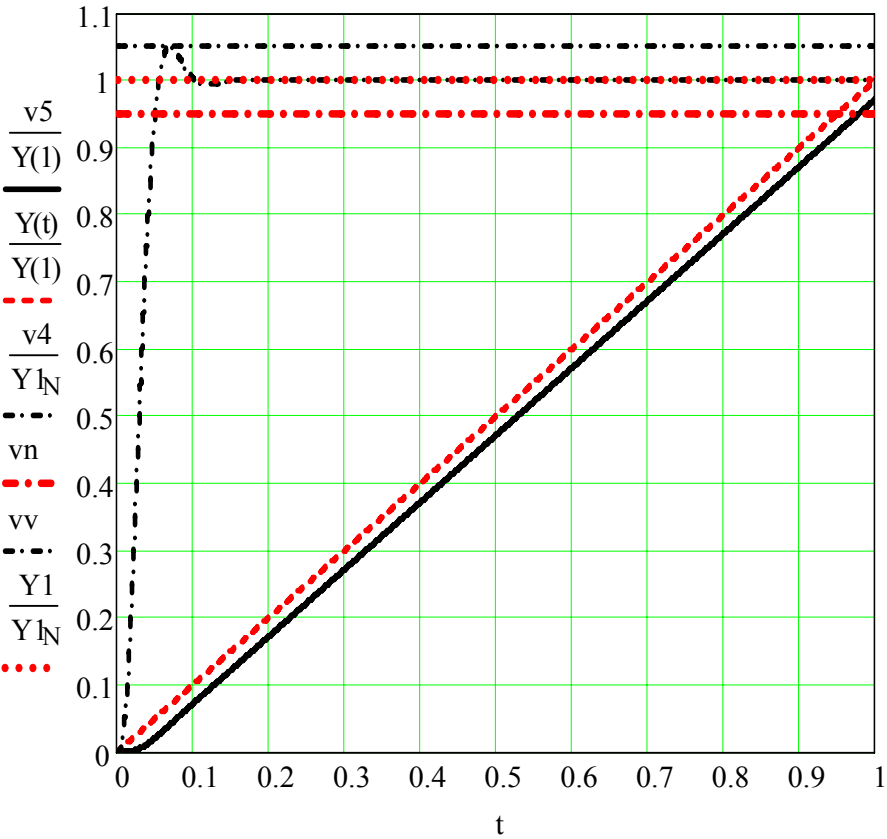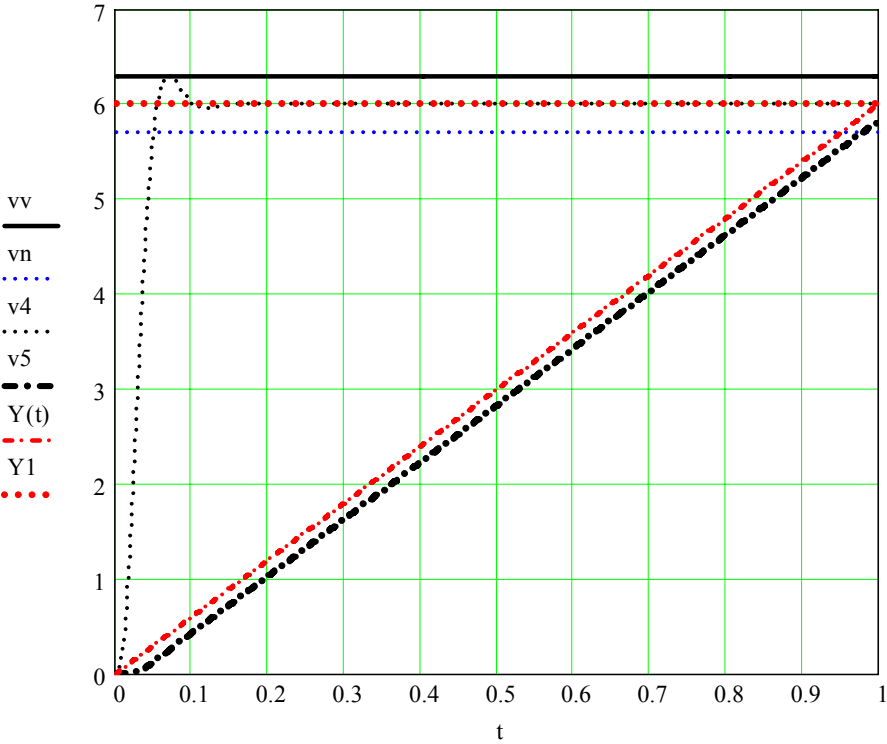
The velocity of the platform displacement $y1(t) = at$;

The platform acceleration $y2(t) = a$

Motion with uniform velocity

Displacement of the platform is set up by the function $y(t) = \grave{a}t$;

The velocity of the platform displacement $y1(t) = a$

Conclusions

The research effort resulted in development of the mathematical model of an *n*-order system that simulates the suggested algorithms of control of the flight simulator dynamic test stand according to the dynamic performance specifications to the system. In addition, a study was conducted of the effects of the system order, overcorrection, and control time on the accuracy of response to a control law.

As follows from the studies carried out:

1) During the response to the displacements that are changing by law of $y(t) = \dfrac{at^3}{6}$; $y(t) = \dfrac{at^2}{2}$;

$y(t) = at$; $y(t) = Y_0$ a model transient response is generated in the system to the G-load, acceleration, velocity and displacement, correspondingly.

2) Since the system is characterized by the nonzero control time the response timeout values are found to be equal during the response to all controllable parameters (G-load, acceleration, velocity, displacement) with the accuracy of their representation in astatic zero-error automatic control systems.

3) The timeout during the response to a control signal is found to be less or equal to $0.6 \cdot t_y$ of the control time with $\sigma \leq 5\%$.

4) Excessive overcorrection of the system is found to both increase the oscillativity and impair the accuracy of response to a control law due to:

- G-load with the displacement set up as $y(t) = \dfrac{at^3}{6}$;

- acceleration with the displacement set up as $y(t) = \dfrac{at^2}{2}$;

- velocity with the displacement set up as $y(t) = at$;

- position with the displacement set up as $y(t) = Y_0$,

but such excessive overcorrection proves to reduce the response timeout.

5) The increase of the system order is found to increase both its oscillativity and the control time.

6) With regard to the demands to the simulators and the dynamic test stands, the requirements to the stand hydraulic drives were specified as below:

  - control time: up to 0.1 sec.;
  - overcorrection: $\sigma \leq 20\%$;
  - statistical error: $\delta = 0$.

References

1. Stanley, F. S. Conrad, B. Conrad. *Movement Control Signals for Pilotage Flight Simulator.: Report of the ARC Analytical Mechanics Association, 1968 /Transl. by KNIGA*, 1974.
2. Vorona, A. A., Gander, D. V., Ponomarenko, V. A. *Theory and practice of psychological support of the flight work.* M.: Voyenizdat, 2003. 278 p.
3. Sotnikov, D. A., Kvasha, M. M., Timakov, V. M. Creation of technical means and technologies of dynamic flight simulation. In: *Training technologies and learning: new approaches and challenges // Collected papers, II Scientific Workshop, Zhukovski: Central Aerodynamic Institute (TsAGI),* 2003, pp. 44–50.
4. Geratewohl, Z. *Human psychology in flight.* Moscow, 1956.
5. Vorona, A. A., Gander, D. V., Ponomarenko, V. A. Psycho-pedagogical bases of professional training of flight personnel. M: MACHAK, 2000. 340 p.
6. Proshin, I. A., Proshkin, V. N., Timakov, V. M. Improving dynamic stands flight simulators based on hydraulic, *Mechatronics, Automatization, the Actual Management,* Vol. 11, 2008, pp. 21–26.
7. Proshin, I. A., Timakov, V. M., Marin, S. S., Nikitashin, S. A. *Simulation model of dynamic control laws of stands simulators of vehicles.* Penza: PGTA, 2006, pp. 73–78.

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, Volume 12, No 1, 2011
(Abstracts)

Gertsbakh, I., Shpungin, Y. Predisaster Design of Transportation Network, *Transport and Telecommunication*, Vol. 12, No 1, 2011, pp. 4–11.

In this paper we consider transportation network optimal reinforcement problem. We mean by that network reliability improvement achieved by reinforcement of a certain number of its most important links (road segments), which are subject to failure (destruction). This reinforcement is made given a budgetary constraint, and its goal is to maximize the global network performance measure, which depends on the source-terminal reliability of a fixed set of origin-destination routes or network all-terminal connectivity.

The central role in the proposed optimization is played by a combinatorial Monte-Carlo algorithm for estimating the network $s-t$ reliability or the probability of all-terminal connectivity, and the gradient vector. The proposed optimization method is tested on an example described in [1] of a road network of Istanbul. The link failures are caused by natural disasters like earthquakes, and link e reinforcement means its replacement for a cost $c(e)$ by a more reliable one. Another example is a 4-terminal 34-link with 25 nodes network in which the reinforcement raises the link reliability up to 0.9 and the problem is stated as find the minimal cost reinforcement policy to guarantee the prescribed value of the probability of all terminal connectivity

Keywords: network Monte Carlo, reliability gradient vector, network design, link failure, earthquakes, $s-t$ network reliability, all-terminal connectivity

Kuznetsov, B., Serebryakov, M., Proshkin, V., Bormotov, A. Upgrading the Efficiency of Airspace Flight Simulators for Emergency-Response Training of Space Crewmembers, *Transport and Telecommunication*, Vol. 12, No 1, 2011, pp. 12–15.

Both the flight safety and space crew efficiency depend for the most part upon the crewmembers' professional qualities achieved with the aid of different training systems. The inconvenience of such systems consists in their failure to provide an overall simulation of some psycho-physiological sensations experienced by the crewmembers in real space flight conditions, e.g. air sickness, distortion of equilibrium sense, fatigue, apprehension, anxiety, pain sense modality, etc. With regard to the significance of the above component of space crew training a simulator model with improved training efficiency was designed. The multidimensional effects of the simulating system suggested provide facilities for quality improvement in the crewmembers' training and development of the appropriate decision-making, managerial and other skills essential to the crew in both standard and emergency situations.

Keywords: Flight simulator system, operator, psycho-physiological sensations, emergency situations

Nossum, Å., Veisten, K. Collecting Data by Internet on Stated Preference for Transport Supply: Three Case Studies on Survey Mode Comparison, *Transport and Telecommunication,* Vol. 12, No 1, 2011, pp. 16–24.

Internet-based data has become an important source for market research in the developed world, following the rapidly improving technology and increase in Internet access and use. Given the existence of an acceptable and accessible sampling frame, sampling by the Internet is much cheaper than any other sampling method. A main issue is to which extent use of different survey modes, particularly the Internet, will affect survey results, and if differences are due to different representation of genders, age groups, etc., or due to the survey mode itself.

This paper presents recent experiences from the use of Internet-based stated-preference surveys combined with other survey modes, particularly postal mail sampling. Preferences were stated as sequential pair-wise choices between transport options. Comparing models with and without

weighting with respect to gender, age and unemployment, we show that there is a significant survey-mode effect on a large share of attribute parameters.

Keywords: pair-wise choices, public transport, sampling bias, time savings

Dorokhov, O., Dorokhova, L. Fuzzy Model in Fuzzy-Tech Environment for the Evaluation of Transportation's Quality for Cargo Enterprises in Ukraine, *Transport and Telecommunication,* Vol. 12, No 1, 2011, pp. 25–33.

The basic criteria of quality vehicle servicing and operation of road transport enterprises in the transportation market of Ukraine have been reviewed, classified, described and structured. Their formalization by linguistic variables with appropriate terms has been done. Usage of methods of fuzzy inference to determine the integral generalized level of freight transportation's quality has been proposed. Corresponding computer model has been developed in fuzzyTECH – a specialized package of fuzzy modelling

Keywords: transport service, the quality of freight transportation, the criteria for the level of transport service

Panin, N. Medical Point of View on Passive Safety, *Transport and Telecommunication,* Vol. 12, No 1, 2011, pp. 34–39.

Only modern passive car safety systems can protect drivers inside vehicle during accident. In addition, there are other important conditions: the residual post-accident life-space in the car and rapid arrival of ambulance. However today there is a new research path – simulation (by using digitised model of an anthropomorphic dummy). The analysis of human body behaviour during crash can give useful information for designers of the new passive car safety systems.

Keywords: HIC, accelerations, passive car safety systems, residual post-accident life-space.

Pavlyuk, D., Gromule, V. Application of a Discrete Choice Model to Analysis of Preferred Transport Mode for Riga-Daugavpils Route, *Transport and Telecommunication,* Vol. 12, No 1, 2011, pp. 40–49.

This paper is devoted to discrete choice analysis of behaviour of bus and train passengers and their choice between alternative transportation modes. We develop a nested discrete choice model and estimate model parameters on the base of data sample collected in our own survey.

We consider Riga-Daugavpils two-way journeys with three possible transportation options – a car, a coach, and a train. Using our survey data we analyse factors, which influence passengers' choices. A set of factors includes travel specific factors (departure time), factors, which describe passengers' age, income, etc. and factors, which describe their behaviour (time of arrival to a station before departure).

The resulting conclusions of the research have a significant practical utility and have been used to improve operations of Riga International Coach Terminal.

Keywords: discrete choice model, transportation, coaches, railways

Proshin, I., Timakov, V., Nazarov, E., Sapunov, E., Mathematical Model of a Hydralic Drive For A Dynamic Test Stand, *Transport and Telecommunication,* Vol. 12, No 1, 2011, pp. 50–54.

One of the priority areas in development of science and technology is the flight simulator engineering, and this top target is determined by the pressing necessity to improve the quality of air staff training, to assure flight safety and reliability technologies against the background of cuts in expenditures for aircrew training, instruction and drill. The flight training systems, or flight and equipment simulators, are provided with computing and modelling systems enabling the crew the facilities to acquire and reinforce the skills of aircraft handling, flight control, air navigation, and aircraft equipment service. The military aircraft pilots are given the opportunity to use the simulators for operational flight training.

An integrated flight simulator is a complex of interrelated components designed for regular aircrew training regardless of meteorological condition, availability and operational status of

the aircraft make and model, and with no reference to the air conditions and air-traffic restrictions. It is particularly important that flight simulators provide safe ground conditions for aircrew emergency-response training with due consideration of possible high sustained G-loads and complex aircraft movements.

A dynamic test stand is a basic element of the flight simulator intended to develop the acceleration effects similar to those experienced by a person operating, in live environment, a moving vehicle (an aircraft, a tank, etc.)

Keywords: flight simulator, dynamic test stand, hydraulic drive, mathematical model

Proshin, I., Timakov, V., Nikitashin, S., Savelyev, A. Mathematical Modelling of Control Laws by Dynamic Test Stand of Flight Simulator, *Transport and Telecommunication,* Vol. 12, No 1, 2011, pp. 55–61.

Flight simulator dynamic test stands intended for flight crew training are considered in this paper, with the focus of particular interest being on the improvement of the dynamic test stands. The practical value of the project results from the significant quality improvement in the control of the real-life flight simulators based on the research results applied. The high efficiency of the project has been proved by both application of the research results to the flight training and the experimental investigation of the new system in the working environment.

The originality of the project is determined by the system suggested for control of the hydraulic drive with static load compensation as well as by the hydraulic drive models and the control laws developed. Due to the developments mentioned the accuracy of the response to the control input signal is improved and the loads created in the test stand are approximated to the real-life loads.

As a primary result of the investigation a simulated model has been developed and control laws have been improved for the flight simulator dynamic test stands.

The research findings prove to be of major scientific and practical interest and can be recommended for application in the flight simulator control systems.

Keywords: flight simulator, gradient, dynamic test stand, G-load, acceleration data

TRANSPORT and TELECOMMUNICATION, 12.sējums, Nr.1, 2011
(Anotācijas)

Gertsbahs, I., Špungins, J. Transporta tīklu pirms katastrofas projektēšana, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 4.–11. lpp.

Šajā rakstā autori apskata jautājumu par transportēšanas tīklu optimālu nostiprināšanu. Ar to autori domā tīkla drošuma uzlabošanu, kas tiek panākts ar noteikta skaita svarīgu savienojumu (ceļa segmenti) nostriprināšanu, kas ir pakļauti pasliktināšanās (destrukcijai). Šī stiprināšana tiek veikta, ņemot vērā budžeta ierobežojumus, un tā mērķis ir palielināt globālā tīkla darbības pasākumus, kas savukārt ir atkarīgs no pamata termināla noteikta kopuma galamērķa maršrutu vai tīkla visu terminālu savienojuma drošuma.

Piedāvātajā optimizācijā galvenā loma tiek iedalīta Monte Karlo kombinētajam algoritmam, lai novērtētu tīkla $s - t$ drošumu vai visu terminālu savienojumu varbūtību un gradienta vektoru.

Piedāvātā optimizācijas metode tiek testēta ar vairākiem piemēriem.

Atslēgvārdi: Monte Karlo tīkls, drošuma gradienta vektors, tīkla projekts, savienojuma pasliktināšanās, zemestrīces, visu terminālu savienojamība

Kuzņecovs, B., Serebrjakovs, M., Proškins, V., Bormotovs, A. Aviācijas un kosmosa simulatoru efektivitātes uzlabošana astronautu ātras reaģēšanas apmācībai, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 12.–15. lpp.

Kosmisko lidojumu drošība un kosmonautu darbības efektivitāte zināmā mērā ir atkarīga no viņu profesionālo nepieciešamo iemaņu attīstības pakāpes, kuras iegūst ar dažādu apmācības sistēmu palīdzību. Šo sistēmu trūkums ir dažu psiho-fizioloģisko izjūtu izpalikšana, kas parādās ekipāžai reāla lidojuma apstākļos, piem., nelabums, traucēta līdzsvara izjūta, nogurums, bailes, nemiers, sāpes, u.c. ņemot vērā šo ļoti svarīgo sastāvdaļu kosmonautu sagatavošanas sistēmā, ir izstrādāts trenažieru modelis ar daudz augstāku apmācības efektivitāti. Daudzpusīga jaunās apmācības sistēmas ietekme paaugstina personāla sagatavošanās kvalitāti, nodrošinot attīstību, vadības prasmes un citus ieguvumus, kas nepieciešamas ikdienas un ārkārtas situācijās.

Atslēgvārdi: lidojuma simulatorsistēma, operators, psiho-fizioloģiskās izjūtas, ārkārtas situācijas

Nosums, A., Veistens, K. Datu vākšana internetā par noteiktu preferenci transporta apgādē: triju gadījumu izpēte par aptaujas veidu salīdzināšanu, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 16.–24. lpp.

Attīstītajā pasaulē Interneta dati ir kļuvuši kā ļoti svarīgs avots tirgus izpētei, sekojot ātri uzlabojušamies tehnoloģijām un Interneta pieejamības un lietošanas palielināšanās.

Tā kā pastāv pieņemami un pieejami iztveršanas kadri, paraugu ņemšana, ko piedāvā Internets ir daudz lētāks nekā jebkura cita iztveršanas metode. Galvenais jautājums ir, cik lielā mērā, izmantojot dažādus apsekojumu veidus, jo īpaši Internetu, ietekmēs aptaujas rezultātus, un, ja atšķirības pastāv dažādās dzimuma pārstāvniecībās, vecuma grupās u.c., vai sakarā ar pašu aptauju.

Šajā rakstā tiek aplūkota nesen gūtā pieredze, lietojot Interneta norādītas-izvēles aptaujas, apvienotas ar citiem apsekojumu veidiem, jo īpaši ar pasta sūtījumu paraugiem. Preferences tika noteiktas kā secīgas pāra izvēles starp transporta iespējām. Salīdzinot modeļus ar un bez izsvēršanas attiecībā uz dzimumu, vecumu un bezdarbu, autori parāda, ka pastāv nozīmīgs aptaujas veida efekts uz lielu daļu atribūtu parametriem.

Atslēgvārdi: pāra izvēles, sabiedriskais transports, iztveršanas neobjektivitāte, laika ietaupījums

Dorohovs, A., Dorohova, L. Fazi modelis fazi-tech vidē transportēšanas kvalitātes izvērtēšanai Ukrainas kravu pārvadājumu uzņēmumos, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 25.–33. lpp.

Dotajā rakstā ir izskatīti, klasificēti, aprakstīti un strukturēti pamata kritēriji kvalitatīvu transporta pakalpojumu sniegšanai un autoceļu transporta uzņēmumu darbībai Ukrainas pārvadājumu

tirgū. To noformēšana ir veikta ar valodas mainīgo lielumu attiecīgajiem terminiem. Rakstā tiek piedāvāta fazi izveduma metožu, lai noteiktu transportēšanas kvalitātes integrālo vispārējo līmeni, lietošana. Tiek izstrādāts atbilstošs datora modelis fazi-TECH – īpaša fazi modelēšanas pakete.

Atslēgvārdi: transporta pakalpojums, kravu pārvadājumu kvalitāte, transporta pakalpojumu līmeņa noteikšanas kritēriji

Panins, N. Medicīniskais viedoklis par pasīvo drošību, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 34.–39. lpp.

Vienīgi modernas automašīnas pasīvās drošības sistēmas var aizsargāt braucējus transporta līdzekļa iekšienē negadījuma laikā. Bez tam pastāv arī citi svarīgi apstākļi: pēc avārijas palikušo dzīves telpa automašīnā un ātrās palīdzības ierašanās ātrums. Šodien ir jauna pētījuma virziens – simulācija, pielietojot antropomorfa manekena digitālo modeli. Cilvēka ķermeņa uzvedības analīze avārijas laikā var sniegt noderīgu informāciju dizaineriem par jaunajām pasīvās auto drošības sistēmām.

Atslēgvārdi: pasīvā drošība, negadījums, ātrā palīdzība, pasīvās auto drošības sistēmas, manekens

Pavļuks, D., Gromule, V. Binārās izvēles modeļa pielietojums izvēlēta transporta veida analīzēm Rīga–Daugavpils maršrutam, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 40.–49. lpp.

Šis pētījums ir saistīts ar autobusu un vilcienu pasažieru rīcības ekonometrisko analīzi. Pētījumā ir izstrādāts ligzdu binārās izvēles modelis, lai prognozētu transporta veida pasažieru izvēli. Modeļa parametri tika novērtēti, izmantojot savāktos datus par pasažieriem.

Šajā pētījumā tiek izpētīti Rīga–Daugavpils virziena braucieni ar trim iespējamiem transporta veidiem – automašīnu, autobusu un vilcienu. Ar mūsu aptaujas datiem mēs analizējam faktorus, kuri ietekmē pasažieru izvēli. Tika analizēti kā ceļojuma raksturojumi (atiešanas laiks), tā pasažiera (gadi, ienākums), kā arī pasažiera rīcības (ierašanas laiks stacijā) raksturojumi.

Pētījumam ir zīmīga praktiska noderība, līdz ar to Rīgas Starptautiskās Autoostas pārvalde izmanto pētījuma rezultātus.

Atslēgvārdi: binārās izvēles modelis, transports, autobuss, vilciens

Prošins, I., Timakovs, V., Nazarovs, J., Sapunovs, J. Hidrauliskās piedziņas matemātiskais modelis dinamiskajam trenažiera stendam, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 50.–54. lpp.

Zinātnes un tehnoloģiju attīstības laukā viena no prioritātēm ir lidojuma simulatora inženierija un tā galvenais mērķis ir noteikts ar spiedošu nepieciešamību uzlabot lidojuma komandas apmācības kvalitāti, nodrošināt lidojuma drošību un tehnoloģiju uzticamību, ņemot vērā izdevumu samazinājumus par gaisa kuģu pilotu apmācību, instruēšanu un vingrināšanu. Lidojumu apmācības sistēmas vai lidojumu un iekārtas stimulatori ir apgādāti ar skaitļošanas un modelēšanas sistēmu, kas dod apkalpei iespējas apgūt un nostiprināt prasmes gaisa apstrādes, lidojuma kontroles, aeronavigācijas un gaisa kuģu iekārtu apkalpošanā.

Integrētais lidojumu stimulators ir savstarpēju sastāvdaļu komplekss, kas izstrādātas regulāro gaisa kuģu pilotu apmācībai neatkarīgi no meteoroloģiskajiem apstākļiem, pieejamības un gaisa kuģa markas un modeļa darbības statusa, un bez atsauces uz gaisa apstākļiem un gaisa-trafika ierobežojumiem. Tas ir ļoti svarīgi, ka lidojuma stimulators nodrošina drošus pamata apstākļus apkalpēm katastrofas seku likvidēšanas apmācībai, pienācīgi ņemot vērā iespējami augstu ilgtspējīgas G-kravu un sarežģītu gaisa kuģu kustību.

Dinamiskais trenažiera stends ir lidojuma stimulatora galvenais elements, kas paredzēts izstrādāt paātrinājuma efektu, kas līdzīgs tam, ko izjūt persona, kas darbojas, kas dzīvo vidē un kas pārvietojas transportlīdzeklī (lidmašīnā, tankā u.c.).

Atslēgvārdi: lidojuma stimulators, dinamiskais trenažiera stends, hidrauliskās piedziņas, matemātiskais modelis

Prošins, I., Timakovs, V., Nikitašins, S., Saveļjevs, A. Kontroles likumu matemātiskā modelēšana ar dinamisko lidojuma trenažiera stendu, *TRANSPORT and TELECOMMUNICATION,* 12.sēj., Nr.1, 2011, 55.–61. lpp.

Šajā rakstā tiek apskatīts lidojuma dinamiskais trenažiera stends, kas paredzēts lidojuma komandas apmācībai, kur autori vērš uzmanību uz trenažiera stenda tehnisko uzlabojumu. Projekta praktiskā vērtība ir nozīmīgajā reālās dzīves lidojumu stimulatoru kontroles kvalitātes uzlabošanā, pamatojoties uz pētījuma rezultātiem. Projekta augstā efektivitāte tiek pierādīta, kā ar lidojuma apmācības pētījuma rezultātu pielietošanu, tā arī ar jaunās sistēmas eksperimentālo pētījumu darbības vidē.

Projekta oriģinalitāte tiek noteikta ar sistēmas izveidi hidrauliskās piedziņas kontrolei ar statisko slodzes kompensāciju, kā arī ar attīstītajiem hidrauliskās piedziņas modeļiem un kontroles likumiem.

Pētījuma rezultāti parāda gan zinātnisko, gan praktisko vērtību un interesi, un var būt rekomendēti pielietošanai lidojumu stimulatoru kontroles sistēmās.

Atslēgvārdi: lidojuma stimulators, gradients, dinamiskais trenažiera stends, G-slodze, akcelerācijas dati

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