**MACIEJ GUCMA**
Maritime University of Szczecin

# MULTI-FACTOR VARIANCE ANALYSIS METHOD FOR OPTIMIZATION OF PILOT SYSTEM INTERFACE

**ABSTRACT**

The paper proposes statistical approach to the solution of problem of optimization problem in field of testing and development of an electronic chart. Multi factor analysis of variance method is applied to optimize type of visualization in the pilot support navigation system. Construction of quantity criteria for assessment and development of navigational chart and interface is one of the article deliverables.

**Keywords:**
visualization, pilot system, electronic chart.

## INTRODUCTION

Navigation at restricted waters is often referred to pilot navigation. In the process of navigating at restricted waters, due the fast changes in the vessel's position, in relation to objects ashore, the observed positions are not plotted by navigator on the chart. The vessel's position is determined in the mind of the pilot or the master of vessel. In the process of conducting pilot navigation the pilot is more and more often by the PNS (Pilot Navigation System). The basic errors of the PNSs currently produced are [2]:

- the information presented is not the optimal information which causes it not to be taken advantage of in the utmost degree and there are difficulties with its being absorbed by the pilot;
- lack of special images useful in pilotage navigation, like: in relation to the shore, in relation to the fairway axis;
- lack of optimal user interface;
- lack of a maneuver prediction system.

These errors result from the fact that systems being only modernizations of the systems functioning in unrestricted water areas (ECS or ECDIS), for the needs of pilotage, and were not optimized for pilot navigation.

A team of researchers from the Navigational Department of the Maritime University of Szczecin, within the framework of a project co-financed by the Ministry of Education and Science, undertook to work out the optimal solution for a pilotage navigational system, making use of scientific methods of constructing navigational systems. As a result of research carried out, two PNS prototypes were developed:

- a stationary one, designed for sea ferries;
- a portable one, designed for pilot use.

At present these prototypes are undergoing experimental research and are being prepared for starting production. The following elements make up these systems:

- subsystem of electronic charts;
- positioning subsystem;
- information processing and imaging subsystem.

## DESCRIPTION OF RESEARCH

Optimization of situational awareness visualization is one of problems in modern support system for aircrafts [3] as well as vessels [1]. For the latter, very special demands are risen by sea pilots and this matter is presented in paper.

Software subsystem of PNS is based at electronic chart, transformed for this special purpose, and this transformation is subject to optimization. Thus development of PNS requires complete simulation solution, where such tool has been created in Marine Traffic Engineering Institute and consists of following elements:

- limited time vessel simulator (pc based) presented in fig. 1;
- fully functional PNS system presented in fig. 2;
- interfaces for visualization and control of simulator.

Analysis consisted of simulations sets from 19 independent experts. Simulations were performed at artificially created area where navigator was maneuvering at restricted (confined) waters. Vessel model was based on real vessel scaling factors. Plan of passage for single experiment is presented in fig. 3. Whole route consists of 2 turns, entrance, exit and straight section. Each expert has performed 3 passages with different presentation orientations – here treated as classification factor for variance analysis. This classification factors are: N — representing North up chart orientation, R10 — representing Route Up with 10 deg change of course axis update, and R20 — representing Route Up with 20 deg change of course axis update.

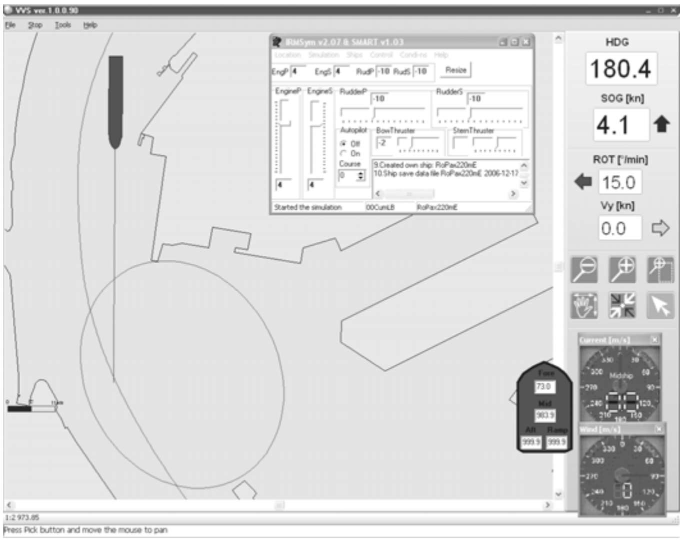


Fig. 1. Visualization in limited time vessel simulator

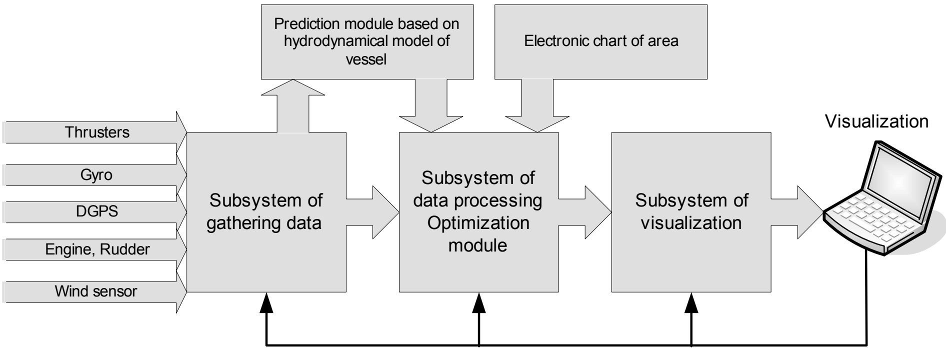


Fig. 2. Model of Pilot Navigation System

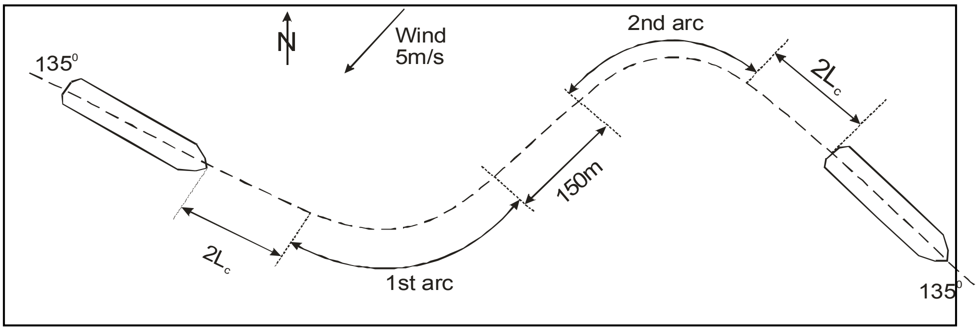


Fig. 3. Simulation experiment overview

Mathematical transformations for route up orientation, are presented by the equation (1). Detailed overview of variables in equitation can be found in fig. 4.

$$\left.\begin{array}{l} |\alpha_i - \alpha_{i+1}| \geq \alpha_z \Rightarrow Z = K_{i+1} \\ |\alpha_i - \alpha_{i+1}| < \alpha_z \Rightarrow Z = K_i \end{array}\right\}, \quad (1)$$

where: $K_i$ — waterway axis with width di and course $\alpha_i$;

$\alpha_z$ — value of waterway axis change in system <10, 20> [°];

$Z$ — orientation used for given waterway axis.

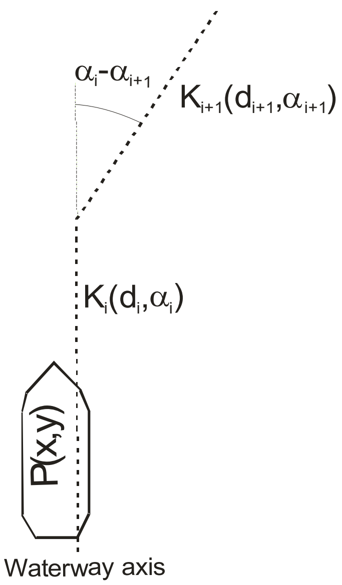


Fig. 4. Change of waterway axis in route up (R) orientation

After completion of experiment, analysis of traffic lanes at restricted area provided variety of information [1]. These data are the consequence of model control with use of PNS, and especially i.e.:

- comparison of waterway width between different simulation runs within same classification factor group;
- conclusions over structure of width of traffic lanes population (maximums, mean values etc.);
- interference between type of area and width of traffic lane.

Initial analysis of observed variances let to establish factorial groups for MANOVA analysis can be obtained. There are 4 sections of data taken into consideration. In fig. 5 95% traffic lanes for each section of data are presented, as well as their total variances. For comparison waterway axis is presented.

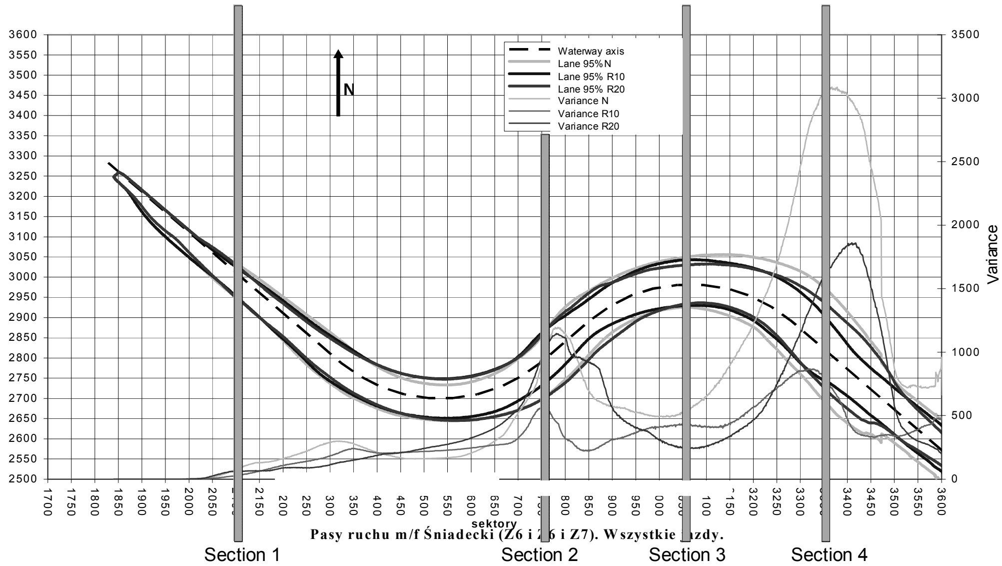


Fig. 5. Sections in experiment and total observed variances

## METHOD OF OPTIMIZATION

Optimization was performed in two steps: one factor variance analysis ANOVA, and multi dimensional MANOVA. ANOVA gave simple answer to existence of correlation between factors, and is not the subject to consider within this text, whilst MANOVA let to observe interactions between these factors. Interaction is here assumed as change of main factor during change of other factor. Sum of squares (SS) are as follows [4]:

$$\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(x_{ijk}-\overline{x})^2=\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(\overline{x}_i-\overline{x})^2+\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(\overline{x}_j-\overline{x})^2+ \\ +\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(x_{ij}-x_i-x_j+\overline{x})^2+\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(x_{ijk}-\overline{x}_{ij})^2 \quad , \qquad (2)$$

where: $x_{ijk}$ — $k$-th result of observation at $i$-th level of factor $A$, and $j$-th level of factor $B$;
$\overline{x}$ — general mean value;
$\overline{x}_i$ — mean of all observations at $i$-th level of factor $A$;
$\overline{x}_j$ — mean of all observations at $j$-th level of factor $B$;
$\overline{x}_{ij}$ — mean value of all observations at $i$-th level of factor $A$ and $j$-th level of factor $B$.

Simplifying (1) sum of squares can be formulated:

$$SS_{total} = SS_A + SS_B + SS_{(AB)} + SS_{error}, \tag{3}$$

where: $SS_A$ — sum of squares deviations related to influence of $A$ factor;
$SS_B$ — sum of squares deviations related to influence of $B$ factor;
$SS_{(AB)}$ — sum of squares deviations related to influence of $A$ and $B$ factors (interactions between them).

Equations defining degrees of freedom (*df*), mean squares (*MS*) and F-test in similar way shall be defined. For statement of hypothesis in detailed problem of optimization there is a need to define model for classification; i.e. model for presentation of both factors. Here two way classification model (i.e. cross classification model), can be used, and is formed as:

$$x_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}, \tag{4}$$

where: $x_{ijk}$ — value from experiment $k$-th value for $i$-th level of factor $A$ and $j$-th level of factor $B$;
$\mu$ — mean value;
$\alpha_i$ — main effect $i$-th level of factor $A$;
$\beta_j$ — main effect of $j$-th level of factor $B$;
$(\alpha\beta)_{ij}$ — effect of interaction $i$-th level of factor $A$ and $j$-th level of factor $B$;
$\varepsilon_{ijk}$ — random error from experiment with normal distribution ($\mu = 0$, $\sigma^2$).

Parameters of this model can be additionally restricted by:

$$\sum_i \alpha_i = \sum_j \beta_j = \sum_{ij} (\alpha\beta)_{ij} = 0 .$$

With such formulated problem hypotheses are:

$H_{0A} : \alpha_1 = \alpha_2 = ... = \alpha_a = 0$ $\qquad H_{1A} : \alpha_i \neq 0$ for certain $i$

$H_{0B} : \beta_1 = \beta_2 = ... = \beta_b = 0$ $\qquad H_{1B} : \beta_j \neq 0$ for certain $j$

$H_{0AB} : (\alpha\beta)_{11}\ 1 = (\alpha\beta)_{11} = ... = (\alpha\beta)_{ab} = 0$ $\qquad H_{1A} : (\alpha\beta)_{ij} \neq 0$ for certain $i, j$.

First one presents lack of differencing influence of factor *A*, second for factor *B* and third represents lack of interaction.

## RESULTS OF INVESTIGATION

In problem of PNS visualization optimization, linguistically formulated parameters can be stated:

- orientation of chart (variants: N, R10, R20);
- waterway part (sections from 1 to 4 i.e.: straight, exit from turn, double turn, exit from double turn).

Evaluated perimeter is number of 95% traffic lane for right and left sides of waterway, overrides. Factors matrix of dimension 3 x 20 can be defined, for this purpose.

After significant number of simulation runs performed by experts, following results can be outlined. Traffic lane overrides, for all sections depending on the visualization orientation, varies and mean values with 95% whiskers is presented in fig. 6. Results for significance test of variance analysis for overrides factor are presented in table 1.

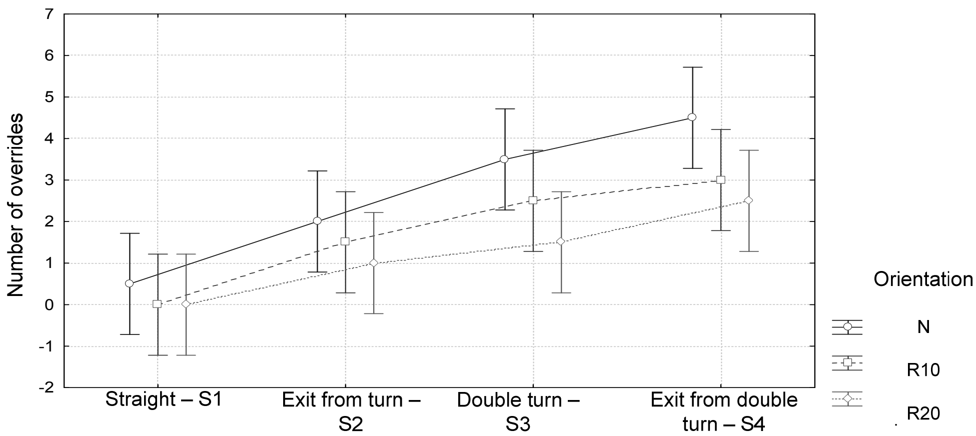


Fig. 6. Waterway overrides in function of section for all orientations

Table 1. Significance of dependant variables for overriding waterway factor

| | *SS* | *Df* | *MS* | *F* | *p* |
|---|---|---|---|---|---|
| Orientation | 7.75000 | 2 | 3.87500 | 6.2000 | 0.014150 |
| Section | 33.45833 | 3 | 11.15278 | 17.8444 | 0.000101 |
| Orientation·Section | 1.91667 | 6 | 0.31944 | 0.5111 | 0.789072 |

Mean square roots deviations values for all orientations as function of waterway overrides is presented in fig. 7. Whiskers on the graph represents 95% confidence levels.

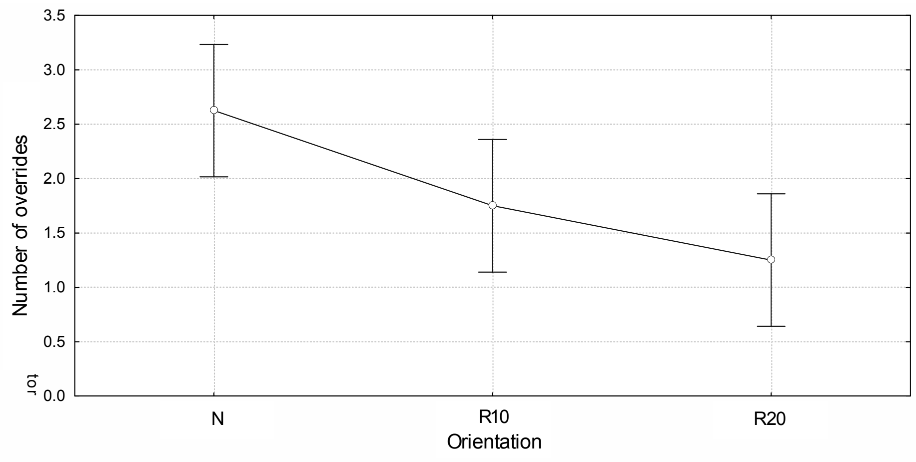


Fig. 7. Orientation of chart in function of waterway overrides

## CONCLUSIONS

In article model of information optimization for Pilot Navigation System is presented. Details of MANOVA analysis for maximum traffic lanes leads to following conclusions:

— highest values of waterway width are at area of exit from double turn (section 4);
— waterway width is larger for third and fourth analyzed section (entrance and exit from double turn);
— analyzing number of waterway overrides, most efficient orientation is waterway axis (R) orientation, with 20 deg change of waterway (R20);
— additional researches, regarding variants R10 and R20 shall be considered.

## REFERENCES

[1] Gucma M., Optimization of navigational information in pilot decision support systems, Unpublished PhD dissertation, Military University of Technology, Warsaw 2007.

[2] Gucma S., Pilot Navigation (in Polish), Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2004.

[3] Leiden K., Keller J., French J., Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing, Report NASA, California 2001.

[4] Stanisz A., The intelligible course of the statistics (in Polish), StatSoft Polska, Kraków 2007.

Received February 2008
Reviewed September 2008