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Confidence Estimates of Operators' Group Activity in Man-Machine Systems

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Abstract

Methods for the selection of candidates for operators of man-machine systems operator are analyzed. Vector mean estimates of group intelligence and estimates defining the group's collective decision-making ability to obtain the unified solution to the problem, to retain the correct original solutions, and estimates of solution quality and interoperability in correct decision-making are proposed. The properties of the suggested estimates are studied with a test example of five candidates. Amongst these properties are estimates of the group's psychological traits, such as average estimates of the professional competence of groups, static components of the intelligence vector for tested candidates, components of the trainability vector for tested candidates, average intelligence estimates for tested candidates, average estimates for the basis of groups, average stability estimates of groups, variations in the like-mindedness of operators, and the stability variation in operators' reasoning.

Keywords: Artificial Intelligence; Man-Machine Systems; Vector Estimates; Average Stability Estimates.

1. Introduction

The problem of optimizing a small group's activity currently grows increasingly more difficult, given the complexity of technical control systems processes and the requirement to expand operator activity in man-machine systems (MMS). In complex systems not only the behavior of one person, but that of an interoperable group of people, whose functions are tightly interconnected, the so-called "small group", have to be analyzed. This group might be a transport crew, a group of military specialists, operators of automated control systems, etc. During the establishment of such groups, specialists encounter a wide range of problems that include such problems as the estimate of the group's ability for correct decision-making under uncertainty conditions, the determination of the optimum number of a group, the compatibility of group members taking into account the personal traits of each individual, etc.

Procedures that are commonly used for the estimation of work effectiveness of a single person as an MMS operator are based on that candidate's test and evaluation, according to one or another scale of their reasoning ability, in completing work necessary for the MMS (Sidorenko, 2002).

An approach to intelligence rating is known [1], based on the computation of an artificial intelligence system using the test results of vector estimates, that include static probability components which estimate the ability to solve indistinct application problems, and dynamic probability components, which estimate the system's ability for self-learning. It is evident that such an approach may be used also for the objective estimate of an operator's professional suitability for work in one or another man-machine system (MMS). In this case the comparison and selection of the best candidates from the group of those tested may rely on a numerical estimate of the dynamic test results, when test results are recorded within various time intervals, into which the whole test run is divided.

However, because of specific differences between the group activity of the operators and a single person – the MMS operator – the recommended formulae for calculating the components of the group operator's vector estimate cannot be directly applied to the estimation of the group operator′s professional suitability, on the basis of the candidates' dynamic test results. In particular, as shown in [2-4], there are factors such as group reaction time, the time required for correct or crucial decision-making, and other characteristics of single operators and groups of operators. The article [5] discussed measurements and perception in MMS. That method deals with a possibility to objectively determine (using purely instrumental methods) human sensor system parameters which influence the operator's adaptability to the natural and technological environment. The approach [6] simulated the cognitive process of an operator and the plant behavior as affected by the operator's actions in accidental situations of an NPP (nuclear power plant). The simulation system consists of an operator model and a plant model which are

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coupled dynamically. The operator model simulates an operator's cognitive behavior in accidental situations based on the decision ladder model of Rasmussen, and is implemented using the AI-techniques of the distributed cooperative inference method with the so-called blackboard architecture. Rule-based behavior is simulated using knowledge representation with If-Then rule types.

Modelling and identification play very significant roles in the present-day analysis of complex dynamic systems. Statistical modelling of any system is necessary to understand its dynamic behavior [7-9]. The structure of a mathematical model involves parameters which characterise the system and these parameters are determined using estimation techniques. Mathematical modelling of aeroplanes is very important since many applications require information in the form of aerodynamic derivatives (also called stability and control derivatives). These derivatives appear in the mathematical model (of the dynamics) of an aeroplane. The aerodynamic derivatives are required to explain aerodynamic stability and the control behaviour of the vehicle, thereby describing its static/dynamic behaviour, in mathematical models for the design of flight control systems, and in high fidelity simulators which need accurate mathematical models for aircraft. For the estimation of these derivatives, three main approaches are generally employed: firstly analytical methods [10], secondly wind tunnel testing of scaled models of aircraft, and thirdly flight testing and subsequent data analysis [11]. In this paper, the third approach is pursued and aircraft parameter estimation techniques to determine the aerodynamic derivatives from flight data are investigated. Some new approaches and results are presented. However, the methods discussed will be applied in a future paper to estimates of the group's psychological traits, such as average estimates of the professional competence of groups, static components of the intelligence vector for tested candidates, components of the trainability vector for tested candidates, average intelligence estimates for tested candidates, average estimates for the basis of groups, average stability estimates of groups, variations in the like-mindedness of operators, and the stability variation in operators' reasoning.

2. Mean Estimates of Group Intelligence

There are a considerable number of MMS's, in which decision-making is performed by a group of operators with equal rights. In this case it is simplest to estimate group intelligence by a vector, whose components are mean arithmetic values of the components of the group members. It is usually recommended to have a group with an even number of members, to maintain parity. A majority of two members will take the decision. In this case it's possible to build five groups of tested and estimated candidates. These groups are:

№ 1: (1 2 3 4); № 2: (1 2 3 5); № 3: (1 2 4 5); № 4: (1 3 4 5); № 5: (2 3 4 5)

Static components of the intelligence vector of tested candidates,

, are given in Table 1 and shown in Figure 1. These components are the following estimates:

Table 1. Static components of the intelligence vector for candidates

I	1	2	3	4	5
I_{Oi}	0,376	0,671	0,633	0,697	0,844
I_{Gi}	0,723	0,64	0,633	0,78	0,617
I_{Hi}	0,536	0,311	0,547	0,633	0,507
I_{Li}	0,434	0,151	0,414	0,526	0,467

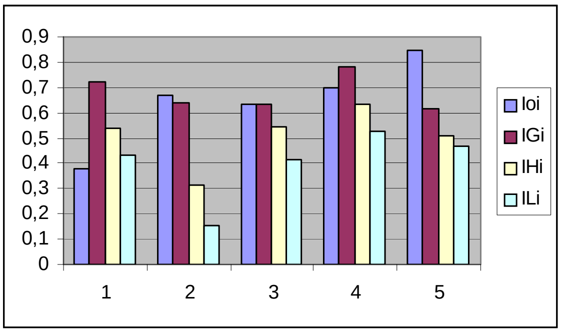

Figure 1. Static components of the intelligence vector for tested candidates

The obtained order differs from the ranking by average estimate of like-mindedness with the exception of the first two places. Therefore, it is appropriate to use an average estimate of the different-mindedness during selection of group members by test results.

The ***basis of a group*** is calculated as follows (Table 2 and Figure 2): $b_i(K) = n_{bi}(K)/n_{ai}(K)$, (21)

where: $n_{bi}(K)$ is the number of coincident correct answers of all members of the i-th group during the solution of all problems by time $K(t - t_0)$.

Table 2. Basis of group.

K	1	2	3	4	5	6	7	8	9	10
b1	0	0,091	0,141	0,088	0,479	0,69	0,442	0,375	0,447	0,485
b2	0	0,062	0,047	0,069	0,463	0,586	0,419	0,432	0,474	0,548
b3	0	0,048	0,033	0,069	0,388	0,567	0,442	0,395	0,486	0,562
b4	0	0,032	0,034	0,135	0,487	0,531	0,6	0,593	0,76	0,75
b5	0,05	0,031	0,048	0,071	0,487	0,548	0,439	0,457	0,514	0,586

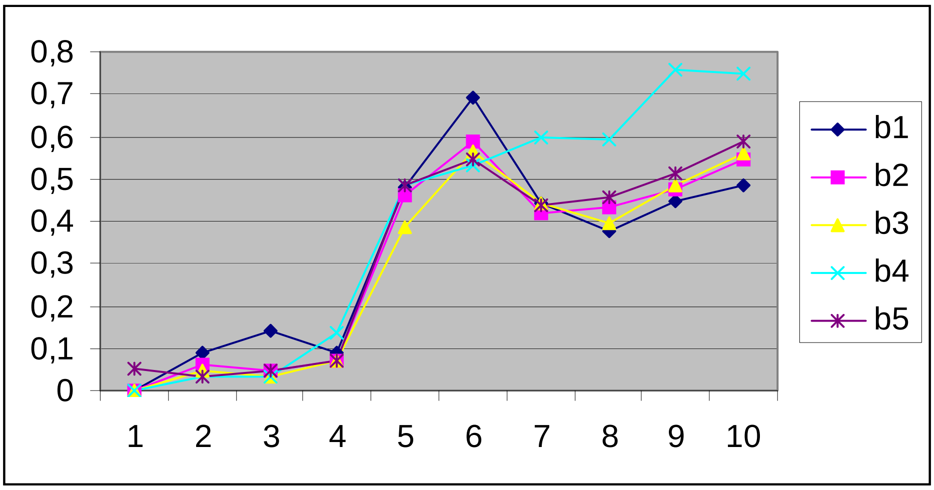

Figure 2 Variation of basis in the cognitive process

Analysis of the variation seen in Figure 2 allows one to judge the capability of group members in choosing correct solutions during the cognitive process. In particular, in the given example, as seen in Figure 2, all groups formed, with the exception of group № 4, exhibit a peak of coincident correct solutions during the test session, followed by a decay. This may indicate some unnecessary uncertainty among the members.

An **average estimate of basis** can be obtained as follows (Table 3, Figure 3):

$B_i = N_{bi}/N_{ai}$

where : N_{bi} is the total number of coincident correct solutions of all members of the i-th group during the solution of all problems for all testing times.

Table 3. Average estimate of basis

i	1	2	3	4	5
Bi	0,259	0,239	0,234	0,284	0,249

Figure 3 shows that the average estimates of basis allow the ranking of the groups. In the given example the reordering of the groups formed with respect to an average estimate of like-mindedness from best to worst yields the following order:

№ 4 , № 1 , № 5 , № 2 , № 3

The order obtained differs from the ranking obtained by the average estimate of different-mindedness in the fourth and fifth places. Therefore, an average estimate of basis can be used to equalize or specialize the operators of groups based on test results.

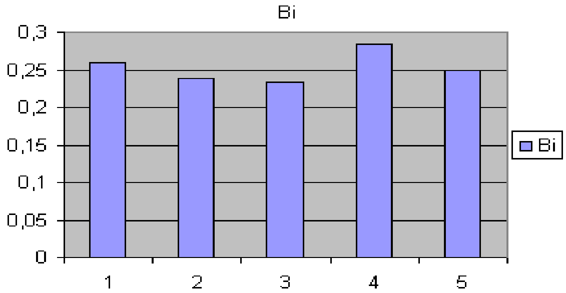

Figure 3. Average estimates of the basis of groups

Group stability is calculated as follows (Table 4 and Figure 4):

$s_i(K) = n_{si}(K)/n_{ai}(K)$

where : $n_{si}(K)$ is the number of problems solved correctly by more than half of all the members of the group during the solution of all problems by time $K(t - t_0)$.

Table 4. Group Stability

K	1	2	3	4	5	6	7	8	9	10
s1	0	0	0	0,017	0,195	0,586	0,302	0,375	0,447	0,576
s2	0	0	0,031	0,052	0,146	0,552	0,279	0,405	0,474	0,613
s3	0	0	0	0,034	0,184	0,567	0,279	0,395	0,486	0,592
s4	0	0	0	0,077	0,282	0,5	0,567	0,714	0,72	0,833
s5	0	0	0,016	0,036	0,205	0,548	0,293	0,429	0,514	0,69

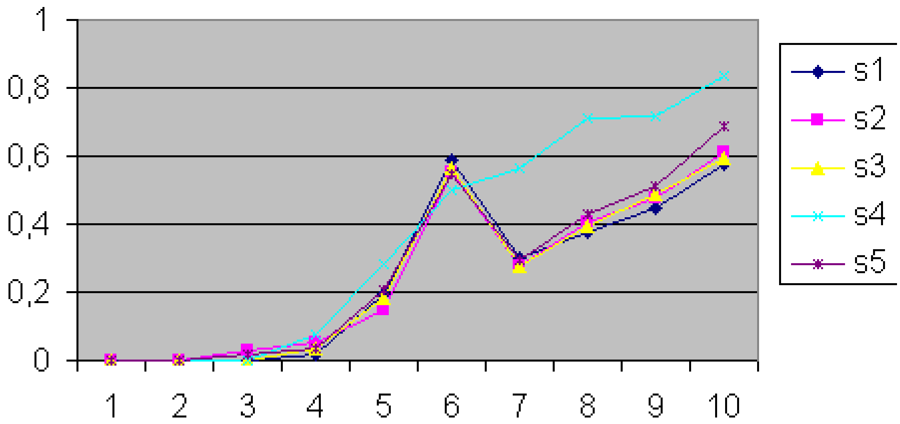

Figure 4. Stability variation in the cognitive process

Analysis of the variation seen in Figure 4 allows one to judge the suitability of groups for proper decision-making during the cognitive process. In particular, in the given example, as seen in Figure 4, only group №4 is not liable to hesitation in proper decision selection and during the cognitive process it systematically augments a number of proper decisions obtained by the majority of group members. All these facts demonstrate the psychological stability of this group of operators.

An **average estimate of stability** can be obtained as follows (Table 5 and Figure 5):

$S_i = N_{si}/N_{ai}$

where : N_{si} is the total number of problems which were properly solved by more than half of all the members of the i-th group during the solution of all problems for all testing times.

Table 5. Average estimate of stability

i	1	2	3	4	5
Si	0,183	0,188	0,187	0,252	0,197

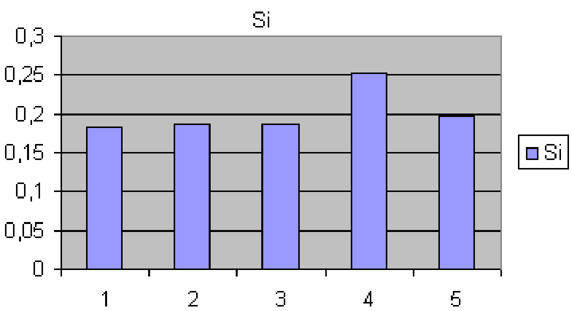

Figure 5 Average estimates of stability for groups

Figure 5 shows that the average estimates of stability allow ranking the groups. However, if the leading group is obviously superior, the remaining groups appear to be very similar. In other words, in practice we can mark out two categories of groups: the psychologically stable and the psychologically unstable. In the given example a reordering of the groups formed with respect to the average estimate of stability from best to worst we obtain the following order: №4 ; № 5 ; № 2 ; № 3; №1.

In this case, only group №4 can be considered to belong to the psychologically stable category. It is important to mention that this group appears to be the best in all other categories.

The ***group confidence*** is calculated as follows (Table 6 and Figure 6):

$f_i(K) = n_{fi}(K)/n_{ai}(K)$,

where: $n_{fi}(K)$ is the number of problems with only correct answers, which coincided among all the members of the i-th group during the solution of all problems by time K($t - t_0$).

Table 6. Group Confidence

K	**1**	**2**	**3**	**4**	**5**
f1	0	0	0	0	0,024
f2	0	0	0	0	0
f3	0	0	0	0	0,02
f4	0	0	0	0,019	0,026
f5	0	0	0	0	0
K	**6**	**7**	**8**	**9**	**10**
f1	0,379	0,023	0,15	0,184	0,273
f2	0,345	0,046	0,189	0,184	0,355
f3	0,333	0,046	0,158	0,216	0,312
f4	0,25	0,333	0,481	0,6	0,667
f5	0,258	0,049	0,171	0,257	0,31

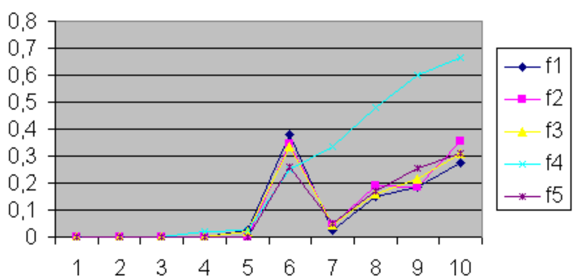

Figure 6 Confidence variation in the cognitive process

Analysis of the variation seen in Figure 6 allows one to judge the inevitability of a group in obtaining correct decisions during the cognitive process. In particular, in the given example, as seen in Figure 6 and in the estimate of the stability factor, only group №4 is not liable to hesitation in making correct decisions and during the cognitive process it systematically augments a number of correct decisions, obtained by all group members. These facts also demonstrate the psychological stability of this group of operators, which are assured in the correctness of their decisions. In this case we do not obtain any new additional information about the psychological features of groups, as in the previous case. However, from a computational perspective, it is easier to obtain this estimate.

An average estimate of confidence can be obtained as follows (Table 7 and Figure 7):

$F_i = N_{fi}/N_{ai}$

where: N_{fi} is the total number of problems with correct answers only, which coincided among all the members of the i-th group for all the testing times during the solution of all problems.

Table 7. Average estimate of confidence

i	1	2	3	4	5
F i	0,071	0,076	0,075	0,154	0,082

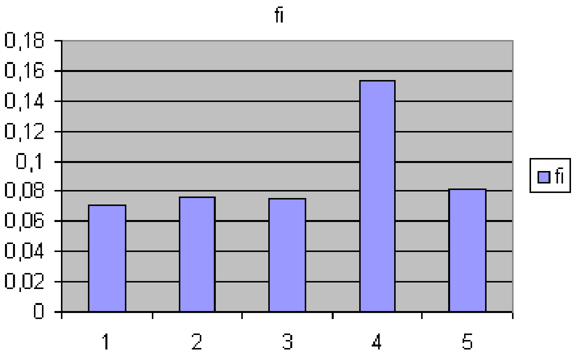

Figure 7. Average estimates of confidence of groups

Figure 7 shows that the average estimates of confidence allow ranking the groups. However, as in the previous case, if the leading group is obviously superior, the remaining groups appear to be very similar. In the given example, when reordering the groups formed with respect to an average estimate of stability from best to worst, we obtain an order that is the same as before. In this case, group №4 can be assigned to the psychologically stable category and the other groups should be assigned to the psychologically unstable category. Therefore, only one stability estimate and confidence estimate can be used. We use an average estimate of stability because it is easier to obtain.

The obtained average estimates of the psychological traits of groups can be calculated as the components of the vector estimate of psychological and professional competence of a group of MMS operators (Table 8 and Figure 8), or some average estimate of psychological and professional competence can be calculated based on the following components (Table 9 and Figure 9):

$P_i^{Gr} = k_C C_i - k_R R_i + k_B B_i + k_F F_i$

where: k_C, k_R, k_B and k_F are some weighting coefficients, which are chosen according to the type of problem. In the given example, with the aim of retaining the approximate equality of contributions from every component of the vector estimate to the average estimate, it was assumed that:

$k_C = k_R = k_B = 1$ and $k_F = 3$

Table 8. Vector estimate of components of psychological and professional competence

i	1	2	3	4	5
Ci	0,299	0,264	0,252	0,303	0,262
Ri	0,267	0,282	0,277	0,264	0,271
Bi	0,259	0,239	0,234	0,284	0,249
Fi	0,071	0,076	0,075	0,154	0,082

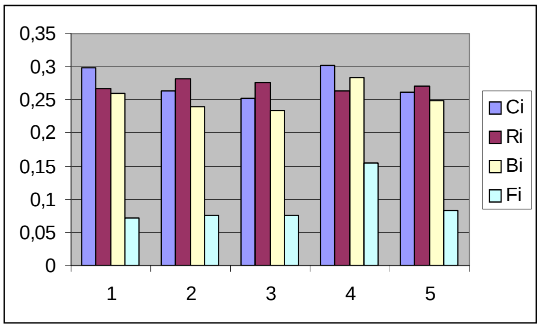

Figure 8. Vector estimate of components of psychological and professional competence

Analysis of Figure 8 allows us to take into account both the psychological features of the formed groups of operators and the preferences of competitive groups. In particular:

- If we allow only for estimates of group intelligence, we obtain an order of groups from best to worst: № 4 , № 5 , № 3 , № 1 , № 2
- If we allow only for estimates of trainability, we obtain the following order: №4 , № 5, № 1 , № 2 , № 3
- If we allow only for estimates of psychological competence, we obtain the following order: № 4 , № 1 , №5 , № 2 , № 3

In this case, based on the psychological competence estimates, all groups can be impartially divided into two classes: the psychologically stable (group №4) and the psychologically unstable (all the remaining groups).

Table 9. Average estimates of psychological and professional competence

i	1	2	3	4	5
Pi	0,504	0,449	0,434	0,785	0,485

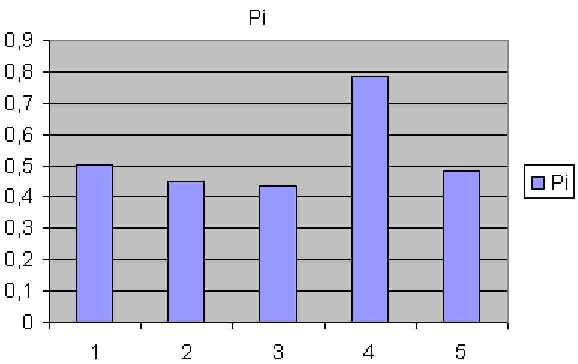

Figure 9. Average estimates of psychological and professional competence of groups

An analysis of the average estimates of psychological and professional competence of the groups formed of tested candidates (see Table 9 and Figure 8) confirms the conclusion that it is possible to mark out only two classes of groups based on their psychological stability. Let us form an average index of professional competence as follows:

$Q_i = k_I I_i^{Gr} + k_P P_i^{Gr}$

where : k_I and k_P are coefficients that allow for the preferences of a competitive group.

In the given example $k_I = k_P = 1$ was taken and the indexes given in Table 10 and illustrated in Figure 10 were obtained.

Table 10. Indexes of professional competence

i	1	2	3	4	5
Qi	0,917	0,842	0,846	1,401	0,924

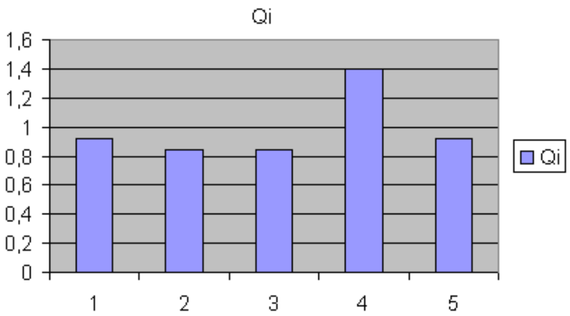

Figure 10. Indexes of professional competence

Figure 10 shows that average indexes of professional competence allow ranking the groups. However, as in the previous case, if the leading group is obviously superior, the remaining groups appear to be very similar. In the given example a reordering of the formed groups with respect to the average index of professional competence from best to worst yields the following order: (№ 4 , №5 , № 1 , № 3 , № 2). This order differs from all previous orders. In this case, the best group №4, as obtained earlier, belongs to the category of psychologically stable groups.

3. Conclusion

Introduced estimates of test results for candidates to work as a member of group MMS operator allow to take account of peculiarities of their thinking and psychology. Firstly, these estimates have static and dynamic components taking into account both, abilities for decision- making under uncertainty conditions and abilities for training in the process of work. Secondly they have components characterizing psychological stability of groups. In some cases vector estimates can be replaced by average estimates, which allow for easy ranking candidates from best to worst. However, in this process some part of information is being lost.

It seems, that more subtle study of a nature of variation in time of suggested group estimates by candidates' testing results will help to reveal a number of other group psychological peculiarities important for operation in MMS, such as indecision, nervousness, patience, thoroughness etc. In this case generation of the most self-descriptive test tasks for concrete MMS is the problem of no less importance.

It's also important to mention that the first two best groups are the same ones (№4 and №5) by ranking by professional convenience, be group intelligence and by trainability estimate of groups. However, the index of professional convenience estimates not only group ability to intellectual work and trainability, but their psychological stability, which in many cases can have a key meaning in proper decision-making under uncertainty conditions.

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