A Model of Group Learning Supported by Simulation Experiment

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Abstract
This paper addresses the influence of individual and group information feedback on a decision process supported by the application of a system dynamics model. For this purpose, we have conducted the four-group Solomon experiment under following conditions: a_1) determination of strategy with application of the system dynamics (SD) model without group interaction with pretest, a_2) determination of strategy with application of the SD model and group information feedback with pretest, a_3) determination of strategy with application of the SD model without pretest, and a_4) strategy determination with application of the SD model and group information feedback without pretest. The observed variables were the criteria function values and frequency of simulation runs. The hypothesis that simulation model application and group feedback information positively influence the convergence of the decision process and contribute to faster decision-making was confirmed. A model of learning during the decision-making process was developed.

Keywords: group decision, learning model, system dynamics, feedback, experiment design

1. Introduction

Decision processes in contemporary enterprises are primarily based on the participating subjects. Decisions generated in organizational systems are, therefore, not dependent on the individual decision of a subject but rather on a group of experts working in a specific field. The group better understands the considered system and provides synergistic effects (Hale, 1997). Their interaction in the process of problem solving (decision-making) supported by advanced group support tools and interactive business simulators could enable more effective individual and group analyses of the problem (Vennix, 1996; Richardson and Andersen, 1995; Kwok and Khalifa, 1998; Langley and Morecroft, 2004; Škraba *et al.* 2003).

Quality decisions can be made only if the decision group has the appropriate information: both feedback and anticipative. This assumes knowledge of a model of the system, criteria function and the state of nature. These factors were intensively discussed in the relevant literature (Chekland, 1994; Forrester, 1973; Rosen, 1985; Simon, 1997; Sterman, 1994, 2000). The ideal of learning organizations can be

approached with the application of SD models (Warren in Langley, 1999). The use of SD models for testing the vision of the evolution of business systems is widely used (Forester, 1973; Simon, 1997; Sterman, 2000). However, the interconnection of SD models with group support systems for the purpose of decision-making support is not commonly used or well researched. An interesting model intended to explain group learning phenomena was described in Lizeo (2005), where the group learning process was modeled from structural, interpersonal and cognitive factors in the form of a causal loop diagram (CLD) and SD technique. Experiential learning as learning from the enterprise simulation was researched in the experiment of Gopinath and Sawyer (1999), where the effects of learning during determination of broader business strategy on a business simulator were examined. Application of SD models for strategy determination encourages strategic decision-making and systematic work. In the experiment with the global oil micro-world computer of Langley and Morecroft (2004), they explore the effects of various types of feedback on individual learning (outcome feedback and structure feedback). Results suggest that structure feedback positively influences the understanding of the problem and time for the task completion.

However, in complex systems, to make a formal experiment to prove the efficacy and the usefulness of group decision making and using simulation model for decision assessment is a demanding task. There are problems of the validity of the design of the research (Chun and Park, 1998). It is difficult to create a laboratory environment in which subjects are as motivated to creatively participate in finding the solution as they would be in a real world. The dilemma is also in the planning of a problem (organizational systems) that is inherently complex. There is also the issue of user interface layout, as it affects the effectiveness of the subject in the process of problem solving (Howie *et al.*, 2000).

Three learning methods (case learning, simulation method, and action learning) were researched in Jennings (2002). The participants rated the simulation method as superior to the action learning and case learning methods.

In the paper of Škraba *et al*. (2003), the process of strategy determination was described as well as the impact of group interaction on subject performance by applying the SD model of a simplified business process. The hypothesis that the model application and group information feedback positively influence the convergence of the decision process and contribute to higher criteria function values was confirmed. The experiment was later enhanced with a new group in order to analyze criteria function as well as dynamics of using a simulation model while searching for optimal parameters (Kljajić Borštnar *et al.*, 2006). The goal of the repeated experiment was to acquire knowledge of the dynamics of the decision process supported by the SD model and the influence of group feedback information. Although the results of criteria function were similar as in previous experiments, it was surprising that the frequency distribution was different among experimental groups at the beginning of the experiment. The decision-making process was divided into four time intervals; in the first interval technical conditions were the same for both the groups using the simulation model. After the first time, interval subjects had to submit their decisions to the network server. After submitting their decisions, one of the groups continued working individually with the simulator and the other group received information about the decisions made by other group members

– the group information feedback. The difference in the frequency of simulation runs suggested that group membership might have affected the group work.

In our paper (Kljajić Borštnar *et al.* 2006) we proposed a four-group Solomon experimental design based on the following hypothesis:

H_1) *Individual information feedback introduced into decision-making process by a simulation model contributes to higher criteria function values (individual learning).*
H_2) *Group information feedback introduced into decision-making process by a group support system contributes to a higher convergence of the group and higher criteria function values (group leaning).*
H_3) *Interaction of pretest (group process facilitation) and treatment (group information feedback) contributes to a higher frequency of simulation runs in the search of optimal parameter values.*

This paper is the continuation of the previous paper and analyses the results of the Solomon four-group design experiment, confirming the hypothesis and explaining learning under various conditions by a causal loop diagram technique.

2. Method

2.1 Simulation Model

The core of the experiment is a model developed by the SD method and is shown in Figure 1. The model which is described in detail in Škraba *et al.* (2003), consists of: production, workforce and marketing segments, which are well known in literature (Forrester 1973; Hines 1996; Sterman 2000).

It was stated that product price (r_1) positively influences income. However, as prices increase, demand decreases below the level it otherwise would have been. Therefore, the proper pricing that customers would accept can be determined. If marketing costs (r_3) increase, demand increases above what it would have been as a result of marketing campaigns. The production system must provide the proper inventory level to cover the demand, which is achieved with the proper determination of the desired inventory value (r_4). Surplus inventory creates unwanted costs due to warehousing; therefore, these costs have to be considered. The number of workers employed is dependent on the production volume and workforce productivity, which is stimulated through salaries (r_2). Proper stimulation should provide reasonable productivity.
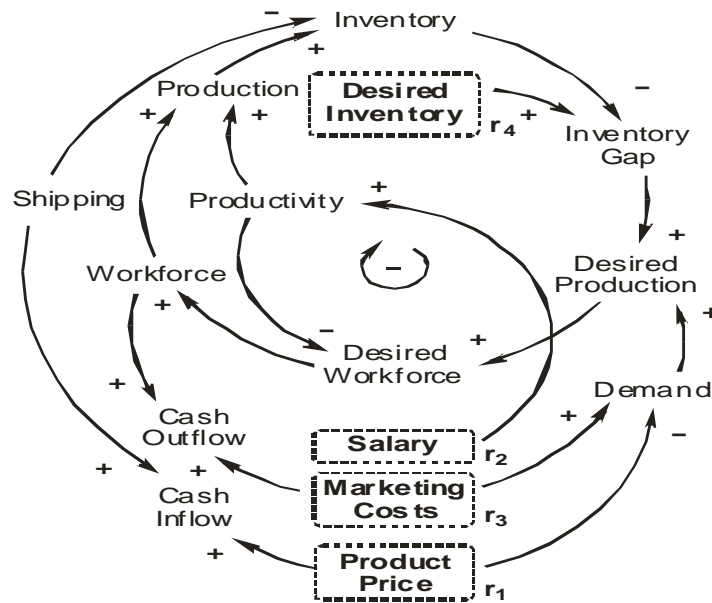
Figure 1: Causal Loop Diagram of Production Model

Participants had the task of promoting a product, which had a one-year life cycle, on the market. They had to find the proper values of parameters r_i defined in the interval $r_{min} \leq r_i \leq r_{max}$. The model was prepared in the form of a business simulator (Škraba *et al.*, 2003). The participants changed the parameter values via a user interface, which incorporated sliders and input fields for adjusting the values. After setting the parameters in the control panel, the simulation could be processed. The end time of simulation was set to twelve months. Output was shown on graphs representing the dynamic response of the system and in the form of a table where numerical values could be observed. Each participant had no limitations of simulation runs, which he/she intended to execute within the time frame of the experiment. The parameter values for each simulation run were set only once, at the start of the simulation. It was assumed that the business plan was made for the following 12 months. The criteria function (CF) was stated as the sum of several ratios, which were easily understood and known to the participants. It was determined that Capital Return Ratio (CRR) and Overall Effectiveness Ratio (OER) should be maximized at minimal Workforce and Inventory costs determined by a Workforce Effectiveness Ratio (WER) and Inventory / Income Ratio (IIR). The simulator enabled simultaneous observation of the system response for all variables stated by the criteria function during the experiment.

2.1. Solomon Four-group Experimental Design

Figure 2 shows the model of the production process as a black box with input parameters r_1, r_2, r_3 and r_4 (where r_1 is Product Price, r_2 Salary, r_3 Marketing Costs and r_4 Desired Inventory) and criteria function J as the output under four experimental conditions (a_1, a_2, a_3, and a_4) described later in text. Decision makers experiment on the simulation model; this assures individual feedback information in the form of

simulation results. The simulation parameters (r_1, r_2, r_3, and r_4) of all participants of the group are then fed back into the system by the group support system to the decision maker. We named this process "group information feedback". It is presented in the form of a table containing the simulated parameters anonymously, together with their average and standard deviations values. This would prevent information overload. The task of the participants was to find the parameter values r_i in order to maximize the criteria function.
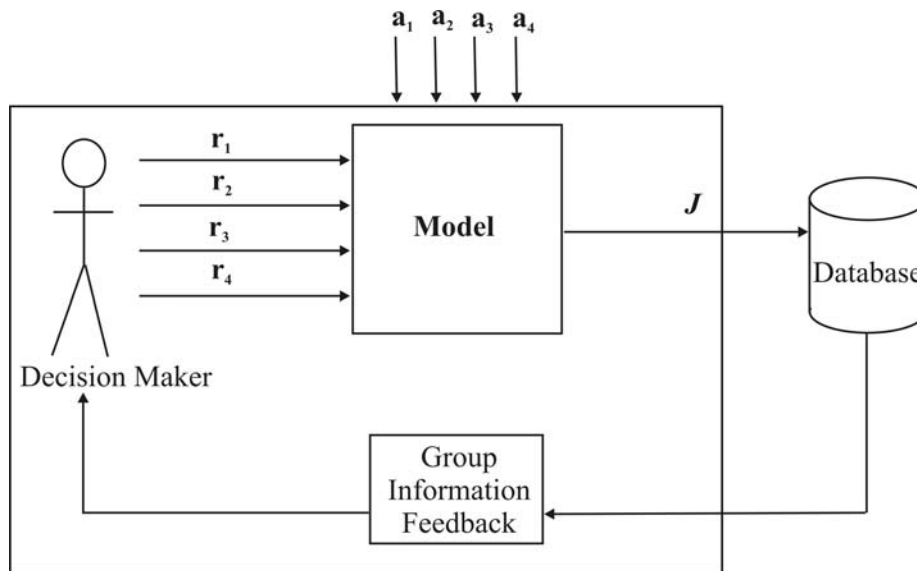

Figure 2. Business model with input parameters under different experimental conditions

Although Hypotheses 1 and 2 were confirmed by previous experiments described in Škraba *et al*. (2003) and Škraba *et al*. (2007), Hypothesis 3 remained unexplained. We expected, due to the homogeneity of population and its random selection into groups, that the results of criteria function and frequency of testing in the first eight minutes would be identical. However, from the time course of variables, differences were noted. This phenomenon cannot be explained by the pretest - post-test experiment in Škraba *et al.* (2003) Škraba *et al.* (2007). Therefore, we conducted a new experiment according to the Solomon Four-group Experimental Design. We expected to estimate the effect of group belonging (as a result of the introduced group information feedback) and the pretest effect (as a result of facilitation of the group decision process) on the decision-making results (criteria function value) using this test. Solomon's design for the suggested experiment is shown in Figure 3.
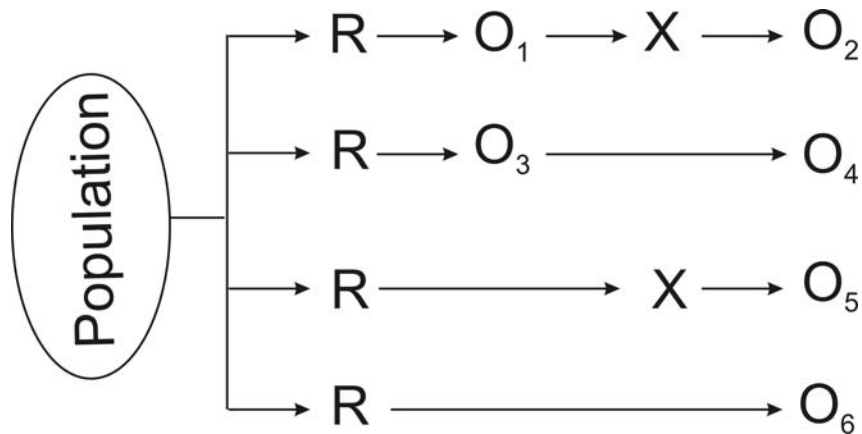
Figure 3: Solomon four group experiment design; R means random, O_i means observed and X treatment groups.

Figure 3 shows the random assignment into four decision groups from a population of senior management students. The first two groups in Figure 3 represent the pretest - post-test design (decision groups are facilitated and measured four times during the experiment, after the 8th, 16th, 24th, and at the end after the 30th minute). The last two groups represent the post-test only design. All four groups were supported by a simulation model of a business system. One of each two groups (a_2 and a_4) had additional group feedback information at their disposal. Thus, we could asses whether the interaction between the pretest (in our case, this also means facilitation of the group decision process) and the treatment (group information feedback) exists. At pretesting, the subjects were directed by a facilitator. They were told to submit their best chosen parameter values into the network database. After the submission of the chosen parameter values, they continued with the search for the optimal combination of the parameter values. In contrast, the decision-making process of the two groups working without pretests was continuous, without facilitation. All measurements were automatic and group information feedback was available at all times for Group a_4. For this purpose, we have developed a new interface for data acquisition and processing.

2.2 Subjects and Procedure

From the University of Maribor, 118 senior graduate students (52 female and 66 male, between the age of 20 and 26) participated in the experiment in order to meet the requirements of their regular course requirements. The students were randomly assigned to eight groups with 14 to 15 subjects, who were then assigned to work in one of the four experimental conditions: a_1, a_2, a_3, and a_4. The subjects who participated in the experiment became accustomed to the business management role facing the stated goal objective, which was, in our case, presented in the form of criteria function. The presentation of the decision problem was prepared in the form of a uniform 11-minute video presentation, which differed only in the explanation of experimental condition at the end of each video presentation. The problem, the task and the business model were explained. The structure of the considered system was presented and the main parameters of the model were explained. The evaluation criteria for the business strategies were also considered. The work with the simulator was thoroughly explained

in the video. A printed version of a problem description was also provided for each subject. The participating subjects were familiar with SD simulators; therefore, working with the simulator was not a technical problem. Subjects were awarded by a bonus grade for their participation in the experiment.

2.3 Experimental conditions:

a₁) individual decision-making process supported by a simulation model with testing after the 8th, 16th, 24th and 30th minutes, assumes that each participant submitted the best-achieved set of parameter values $\{r_1, r_2, r_3, r_4\}$ to the network server at the end of each time interval.

a₂) decision-making process supported by simulation model and group information feedback with testing after the 8th, 16th, 24th and 30th minutes. Each participant submitted the best-achieved set of parameter values $\{r_1, r_2, r_3, r_4\}$ to the network server at the end of each time interval. Information about the best-achieved parameter values was fed back into the group support system. The participants got feedback on the defined strategies of all the participants in the group $R_i = \{r_1, r_2, r_3, r_4\}$; $i = 1, 2,…n$ as well as the aggregated values in the form of parameter mean values $\{\bar{r}_1, \bar{r}_2, \bar{r}_3, \bar{r}_4\}$. For example, if the considered parameter was Product Price and there were ten participants involved in the decision process, then all ten values for Product Price, recognized as the best by each participant, were mediated via feedback as well as the mean value of Product Price. The mean value provided the orientation for the parameter search and prevented information overload. In addition to the criteria function as the results of decision making at different conditions, simulation frequency was also analyzed in order to follow decision makers' activity.

a₃) individual decision-making process supported by a simulation model without a pretest (testing after the 30th min.) assumed the individual assessment of the decision-maker when determining the model parameters values $\{r_1, r_2, r_3, r_4\}$ by maximization of the criteria function using the SD model. At the end of the experiment, the subjects submitted the best-achieved parameter values to the network server.

a₄) decision-making process supported by a simulation model and continuous group information feedback without the pretest (testing after the 30th min.). Each participant submitted the best-achieved set of parameter values $\{r_1, r_2, r_3, r_4\}$ to the network server at the end of experiment. However, information about the instantaneous optimization of the group was always at subjects' disposal.

3. Results and discussion

A total of 118 students (52 female, 66 male) randomly assigned into eight groups of 14 to 15 subjects participated in the experiment. Thirty students (two groups) participated in the condition a_1, 29 students (two groups) participated in the condition a_2, 30 students (two groups) participated in the condition a_3, and 29 (two groups) participated in the experimental condition a_4. For the purpose of results analysis, the criteria function was optimized by Powersim Solver^{TM} using two methods: incremental and genetic

algorithms. The optimal value of the criteria function was thus set to 1.5. The highest values of criteria function were selected by the participants of Group a_2 ($\hat{J}_{a2} = 1,237$, $\sigma_{a2} = 0,210$), followed by the results of the Group a_1 ($\hat{J}_{a1} = 1,170$, $\sigma_{a1} = 0,338$) and the results of Group a_4 ($\hat{J}_{a4} = 1,157$, $\sigma_{a4} = 0,290$). The lowest results were gathered by the Group a_3 supported by simulation model ($\hat{J}_{a3} = 1,147$, $\sigma_{a3} = 0,272$). Criteria function values selected by the participants working at four different conditions after 30 minutes of experiment time are presented in Figure 4. On the X-axis, the number of participants is shown and on Y-axis the values of criteria function are arranged is ascending order. Figure 4 clearly shows that selected criteria function values at four experimental conditions do not differ significantly (this is confirmed by Kruskal-Wallis test at p=.677). This supports our prior experiment results, where we have proven that 30 minutes is a sufficient amount of time for solving this particular decision-making problem when supported by simulation model (Škraba *et al.*, 2007).
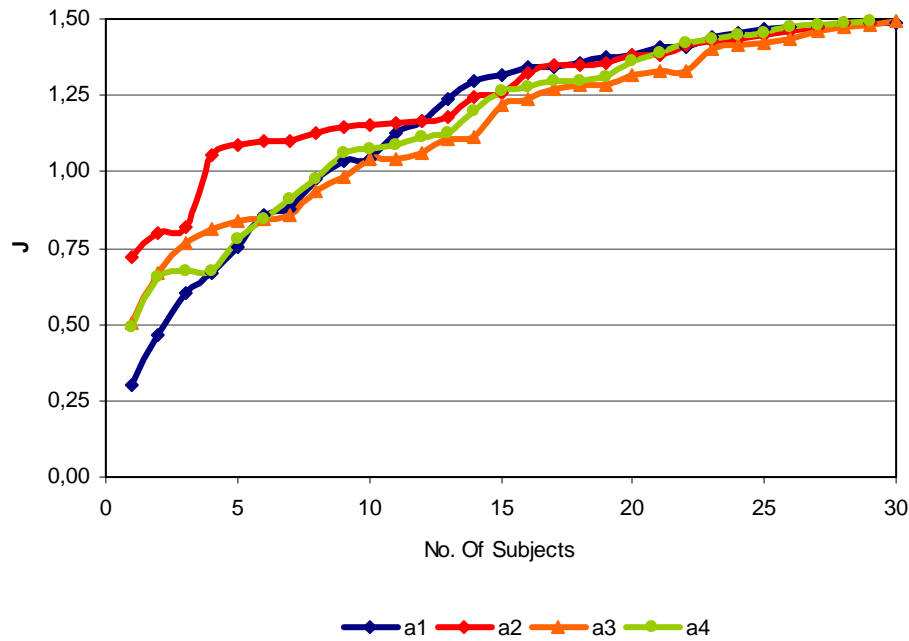

Figure 4: Criteria function values achieved by the participants under experimental conditions: a_1, a_2, a_3, and a_4.

We continue to present the in-depth analyzes of the dynamics of the decision-making process.

3.1 Learning during the decision-making process

Figure 5 shows CF Values achieved by the participants under experimental conditions: a_1, a_2 at the end of each time interval (pretest and post-test). The results of Friedman's ANOVA test confirmed that criteria function values increase during the experiment

time (χ_{a1}=30.57, p_{a1} =.000; χ_{a2}=27.30, p_{a2} =.000); therefore, we can conclude that learning takes place during the decision-making process.
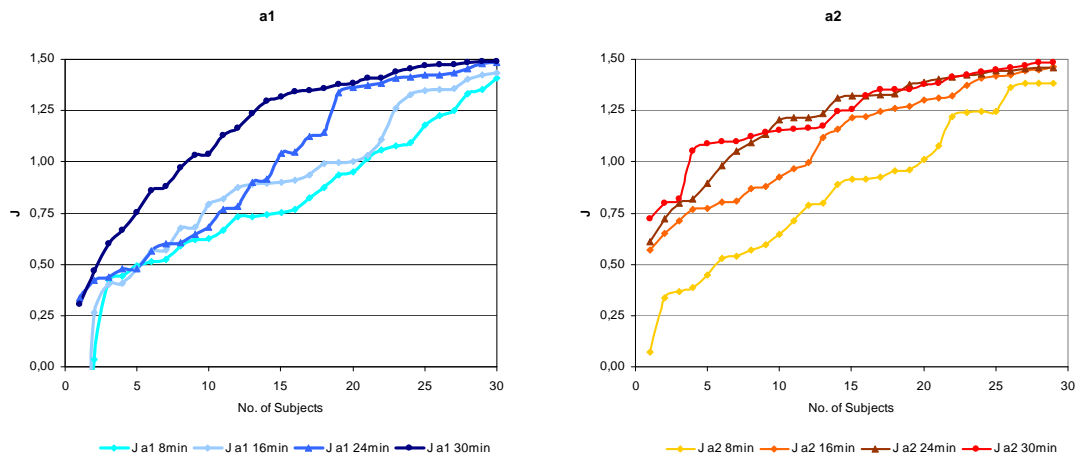

Figure 5: Criteria function values achieved by the participants under experimental conditions: a_1, a_2 at the end of each time interval (pretest and post-test).

Results show that the subjects' decisions did not differ after the first eight minutes, when the same conditions were in place. This was confirmed by Mann-Whitney test (U=415) at p=.762. After Group a_2 had received the group information feedback, they quickly approached the optimum criteria function value. The biggest increase in criteria function values is observed after the first time group information feedback was introduced (after the 16th minute), confirmed by a Wilcoxon test (z=-2.995, p=.002). Criteria function values significantly increase after the 24th minute (confirmed by the Wilcoxon test, z=-3.165, p=.001), but hardly changed towards the end of the experiment (in the last eight minutes). This was confirmed by the Wilcoxon test (Z=-.660, p=.510). In contrast, the group without group information feedback slowly continues to approach the optimal solution and significantly improves their results in the final phase of the experiment (after the 30th minute). The Wilcoxon test confirmed that criteria function values significantly improved after each experimental phase (z_1=-2.584, p_1=.009; z_2=-2.259, z_2=.023; z_3=-2.869, p_3=.004). This means that Group a_2 took eight minutes less to solve the decision-making problem than Group a_1. The results prove that learning occurs in the decision-making process supported by the simulation model. On the basis of analysis, we can conclude that the introduced group information feedback into the decision-making process contributes to a higher convergence of the decision group and helps to improve the speed of decisions in problem solving.

3.2 Analysis of Feedback seeking behavior in two treatment groups

In addition to recording of every simulation run executed by a subject, we have also recorded every insight into group information feedback. Group information feedback was available to subjects at all times for the non-pretest group (a_4) from the beginning of the experiment, while the pretested group (a_2) had group information feedback introduced after each time they had to submit their decisions to the network database. Figure 6a shows feedback-seeking behavior (insight into group information feedback)

of two groups per minute during the experiment, and Figure 6b shows the number of simulation runs of the two groups per minute during the experiment. We have confirmed by a Mann-Whitney test that the feedback seeking behavior of group information feedback of the pretest and non-pretest treatment groups differs significantly (U=202, p=.001). While Group a_2 had shown great interest in the group information feedback and almost constant interest in simulation runs, Group a_4's interest in group information feedback and simulation runs increased almost proportionally. In fact, the frequency of simulation runs of Group a_2 is almost twice as high in comparison with Group a_4 at the beginning of the experiment and had decreased after the 24th minute, while the subjects of Group a_4 had continued to increase the frequency of simulation runs. We can explain this by 40% of subjects of Group a_2 who stopped performing simulation runs at the last experiment phase (after the 24th minute). These were the subjects that had already approached the optimal solution.
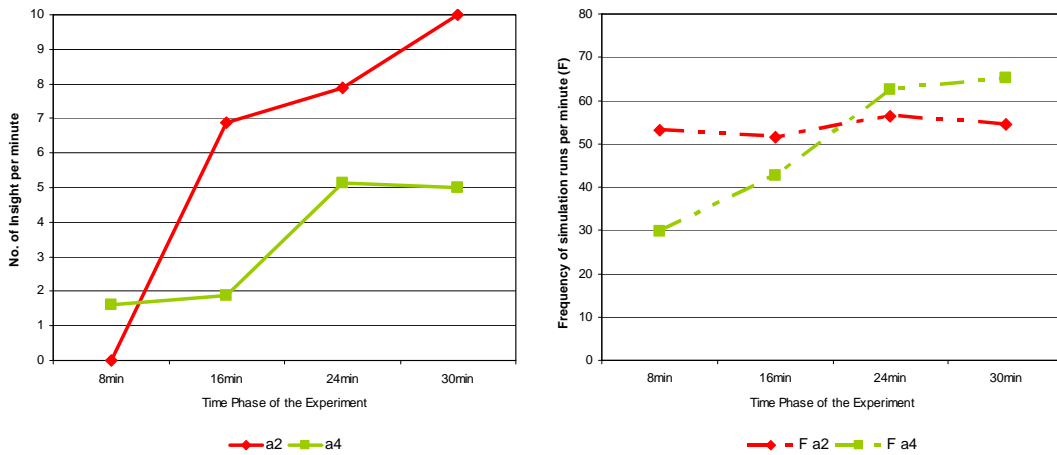

Figure 6: a) Feedback seeking behavior (insight into group information feedback per minute) of Groups a_2 and a_4, and b) frequency of simulation runs over per minute during the experiment time of Groups a_2 and a_4

In order to prove that the correlation between the frequency of simulation runs and criteria function value exists, we performed the Spearman ρ test. The test confirmed that reasonably strong correlation exists between the frequency of simulation runs and criteria function value at experimental conditions a_1 (ρ=.443, p=.014), a_3 (ρ=.432, p=.017), and a_4 (ρ=.500, p=.005), but not at condition a_2 (ρ=.231, p=.227).

3.3 Interaction of pretest and treatment

Figure 7 shows the frequency of simulation runs at pretest and post-test (8th and 30th minute) for all four experimental conditions. It is noticeable that the frequency of Group a_2 (pretest treatment group) in the first eight minutes is slightly higher than the frequency of the pretested non-treatment Group a_1 and that both have higher frequencies of the two non-pretested groups (a_3 and a_4). Towards the end of experiment, all groups show equidistant increases of frequency, except Group a_2 (pretest plus treatment). The groups' frequency of simulation runs is almost constant.
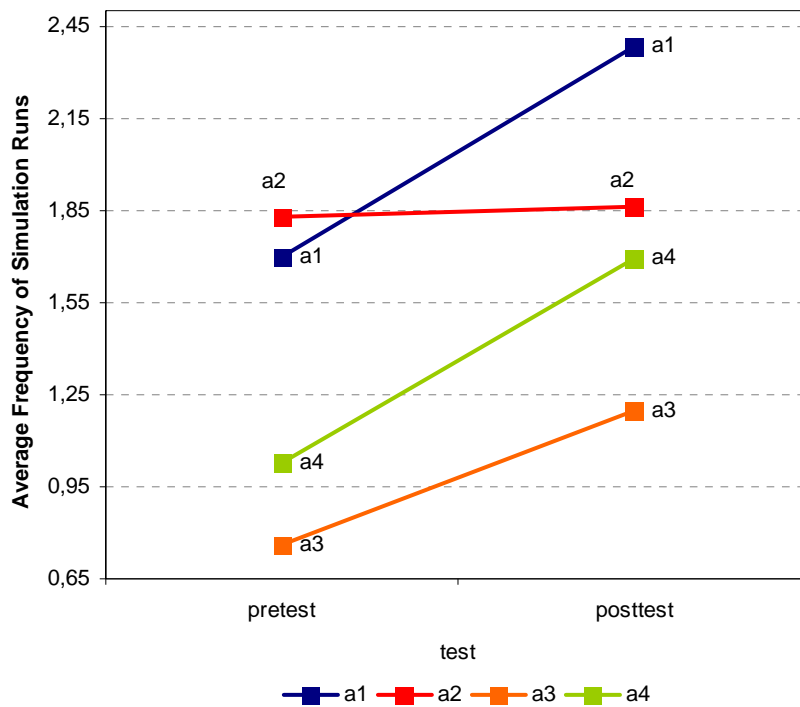
Figure 7: Solomon test for Frequency of simulation runs

From Figure 7, we can conclude that pretest influenced the number of simulation runs performed. Furthermore , it is evident from Figure 7 that group information feedback impacts the number of simulation runs performed. We conducted the two-way ANOVA, which confirmed that treatment alone (group information feedback) does not influence the frequency of simulation runs (F=.000, p=.9982), pretest (facilitation of the decision process) influences frequency of simulation runs (F=6.895, p=.01), and interaction between the pretest and treatment together influence the frequency of simulation runs (F=4.076, p=.046).

3.4 Learning model

In order to explain the influence of individual information feedback (assured by simulation model) and group information feedback (brought into decision-making process by group support system) on the efficacy of problem solving, we have developed a CLD model of learning during decision-making process. The model shown in Figure 8 was modified according to (Lizeo, 2005) and consists of three B and one R loops.
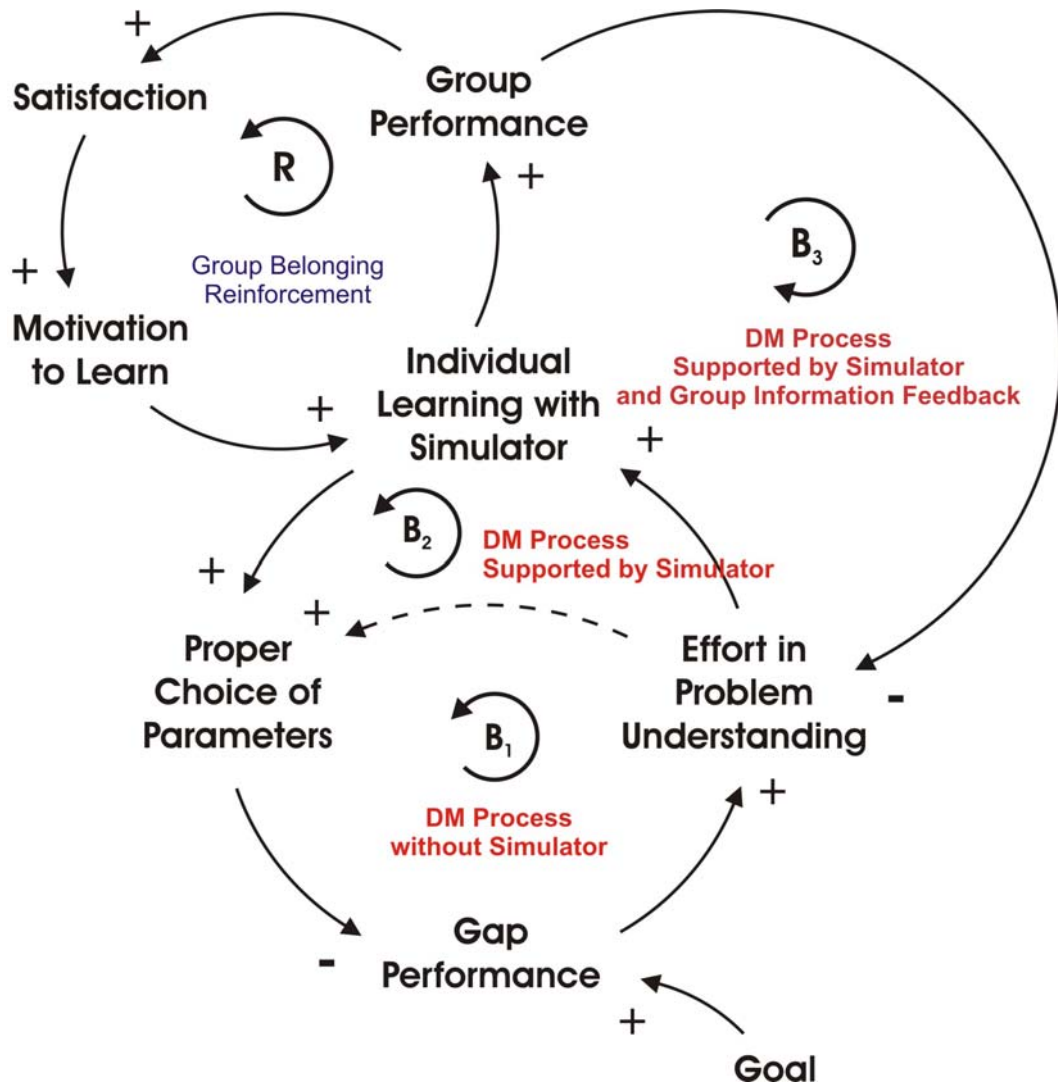
Figure 8: Learning model of decision group under various decision-making conditions

Loop B1 represents decision-making process supported by just a formal CLD model (in Figure 2), paper and pen (described in Škraba *et al*., 2003; Škraba *et al*., 2007). Decision maker solves the problem by understanding the problem and the task. The higher the gap between the goal and performance, the more effort should one put into understanding of the problem. Loop B2 represents the decision-making supported by a simulation model and corresponds to experimental conditions a_1 and a_3 (groups supported by just individual feedback information of a simulation model). The higher the gap between the goal and performance, the higher is the frequency of simulation runs. The search for the optimal parameter values is based upon trial and error. The more simulation runs that the decision maker performs the more he or she learns (on an individual level), the smaller is the gap between performance and goal (in our case the optimized criteria function). Correlation between frequency of simulation runs and criteria function value was confirmed (p_{a1}=.014; p_{a3}=.017). We named this loop "Individual Learning Supported by Simulator". Loop B3 represents direct contribution of group information feedback, while loop R suggests reinforcing effects of group influence on problem solving at Groups a_2 and a_4 (groups supported by individual

feedback information of a simulation model and group information feedback provided by group support system). The decision maker of loop B3 understands the problem and the goal. He or she is supported by simulator and group information feedback. While the use of simulator supports the individual learning, the introduced group information feedback enhances the group performance. Consequently the increased group performance reduces the need to experiment on the simulator. In other words, decision maker supported by group information feedback has broader view of the problem, an insight into new ideas and needs to put less effort in problem solving. On the other hand the group information feedback stimulates group members to actively participate in problem solving so that they perform more simulation runs in the process of the search for the solution. This can be observed from Figure 6 and Figure 7. The frequency of simulation runs of Group a_2 is higher of other groups' in the first 16 minutes of the experiment, when the majority of the subjects were still in search for the solution. When the group is satisfied with its performance the frequency of simulation runs decreases. Loop R can be further explained by interaction between group information feedback and facilitation of the decision-making process. As we have observed in Figure 6 and confirmed by two-way ANOVA, the group information feedback together with facilitation contributes to higher feedback seeking behavior and higher commitment to problem solving. Facilitation in this case serves as motivation and orientation towards the goal. Subjects of Group a_2 had to make their decisions three times during the experiment before they have submitted their final decisions, while their colleagues of Group a_4 were left to their own pace and had to make their final decision at the end of the experiment.

4. Conclusions

In prior experiments (Škraba *et al*, 2003; Škraba *et al.*, 2007) we proved the positive impact of individual information feedback assured by a simulation model and group feedback information on a decision-making process. However, the results suggested that differences in the frequency of simulation runs in the first eight minutes of experiment, where two simulation groups had the same conditions, might be caused by the phenomena of belonging to a group. Hence, the new experiment was introduced, a pseudo Solomon experimental design, and the following experimental conditions were formulated: a_1 - individual decision-making process supported by a simulation model with the pretesting after the 8th, 16th, 24th and 30th minutes, a_2 – decision-making process supported by a simulation model and group information feedback with the pretesting after the 8th, 16th, 24th and 30th minutes, a_3 – individual decision-making process supported by a simulation model without a pretest (testing after the 30th minute), and a_4 – decision-making process supported by a simulation model and continuous group information feedback without the pretest (testing after the 30th minute).

The hypothesis that application of the individual information feedback assured by the simulation model positively influences the learning process of an individual decision-maker was confirmed by Friedman's ANOVA at p=.000. The hypothesis that additional application of the group feedback information contributes to a higher convergence and group unity was confirmed by Mann-Whitney U-test at p=.006. On the basis of the analysis, we can conclude that the introduced group information feedback into the

decision-making process contributes to higher convergence of the decisions group and helps to the faster decision problem solving (eight minutes). The results of analysis have confirmed that there is an interaction of treatment (group information feedback) and testing effects (facilitation) that affects the dynamics of the decision-making process (frequency of simulation runs at p=.046).

On the basis of a review of the literature and experiments, we have developed a dynamic model which explains learning in a decision-making process supported by a simulation model. We have estimated the anticipative information value brought into the decision-making process at different decision-making conditions.

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