Group Learning Supported by Simulation model an Experiment Design

Mirjana Kljajić Borštnar, Andrej Škraba, Miroljub Kljajić, Davorin Kofjač
University of Maribor, Faculty of Organizational Sciences
Kidriceva 55a, SI – 4000 Kranj, Slovenia
Tel: + 386-4-237-4236, Fax: + 386-4-237-4299
e-mail: {mirjana.kljajic, andrej.skraba, miroljub.kljajic, davorin.kofjac}@fov.uni-mb.si

Abstract

This paper addresses the influence of individual and group information feedback on a decision process supported by the application of system dynamics model. The experiment considered the task of strategy determination with an explicitly defined criteria function under three experimental conditions: a_1) individual strategy determination supported by just Causal Loop Diagram (CLD) explanation, a_2) determination of strategy with application of the system dynamics (SD) model without group interaction, and a_3) determination of strategy with application of the SD model with restricted subject interaction supported by group information feedback. The hypothesis that model application and group feedback information positively influence the convergence of the decision process and contribute to higher criteria function values was confirmed. However, the difference of frequency of simulation runs suggested that group membership might have affected the group work. To eliminate this possibility, we have introduced a pseudo-Solomon experimental design. A model of learning was developed as well.

Keywords: *group decision, system dynamics, simulation, feedback, experiment design (Solomon)*

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, 2003, 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 a system, criteria function and the state of nature. These were intensively discussed in the literature (Chekland, 1994; Forrester, 1973; Rosen, 1985; Simon, 1997; Sterman, 2000). The ideal of learning organizations can be approached by application of SD models (Warren in Langley, 1999). Use of SD models for testing the vision of evolution of business systems is widely used (Forester, 1973; Simon, 1997; Sterman, 2000). However, the interconnection of SD models with group support systems (GSS) for the purpose of decision-making support is not commonly used and

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 is researched in the experiment of Gopinath and Sawyer (1999), where effects of learning during determination of broader business strategy on a business simulator was examined. Application of SD models for strategy determination encourages strategic decision-making and systematic work. In the experiment with the global oil microworld computer of Langley and Morecroft (2004), they explore the effects of various types of feedback on the 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 that efficacy and usefulness of group decision and using simulation model for decision assessment is a demanding task. There are problems of validity in the design of the research (Chun and Park, 1998). It is difficult to create a laboratory environment in which subjects are motivated to creatively participate in finding the solution as they would in a real world. The dilemma is also in planning of the problem (organizational systems), which is inherently complex. Further, it is not merely important that the problem is logically correct, but how the information is framed (Kahneman and Tversky, 1979). There is also a problem 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 (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 simplified business process. The hypothesis that model application and group feedback information positively influence the convergence of the decision process and contribute to higher criteria function values was confirmed. The experiment was enhanced with the new group in order to analyze criteria function as well as frequency distribution of members in using simulation model during searching for optimal parameters. The goal of the repeated experiment was to acquire knowledge of the decision process supported with the SD model and the influence of group feedback information. Although the result of criteria function was similar as in previous experiments, it was surprising that the frequency distribution among experimental groups was different at the beginning of the experiment. The difference of frequency of simulation runs suggested that group membership might have affected the group work.

This paper addresses the influence of feedback information on the group decision process supported by the application of system dynamics models. The model of learning due to group information is developed as well. Additionally, a pseudo-Solomon experimental design will be presented in order to eliminate or confirm the effect of group membership on criteria function and frequency distribution.

2. Method

2.1 Simulation Model

Figure 1 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 the experimental conditions a_1), a_2) and a_3). The task of the participants is to find the parameter values r_i in order to maximize the criteria function. The experiment was conducted under three experimental conditions: a_1) determination of strategy on the basis of a subjective judgment of the task, a_2) determination of strategy with the application of a system dynamics model without group interaction, and a_3) determination of strategy with the application of a formal model with subject interaction supported by group feedback information.

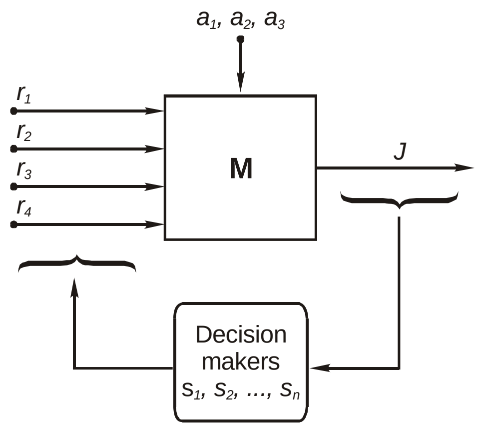

Figure1. Business model with input parameters under different experimental conditions

The model *m* developed by the SD method, which was used in the experiment, described in (Škraba *et al.,* 2003) is shown in Figure 2. The model 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 (u_1) positively influences income. However, as prices increase, demand decreases below the level it would otherwise have been. Therefore, the proper pricing that customers would accept can be determined. If marketing costs (u_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 (u_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 (u_2). Proper stimulation should provide reasonable productivity.

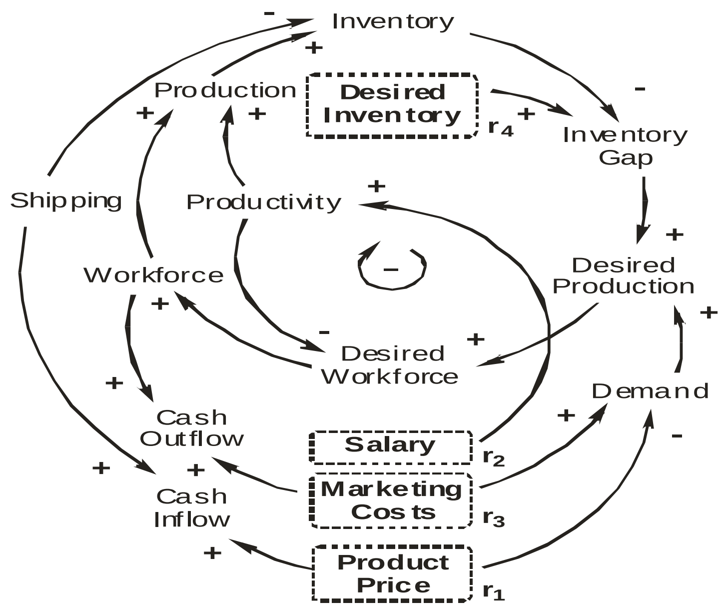

Figure 2: Causal Loop Diagram of Production Model

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 u_i defined in the interval $u_{min} \leq u_i \leq u_{max}$. 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 one year ahead. The criteria function 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. The criteria function was dependent on the chosen values of parameters and stated as:

$$J = \frac{d_0 + \sum_{i=0}^{t_k} d(t_i)}{c} w_1 + \frac{p_0 + \sum_{i=0}^{t_k} p(t_i)}{o_0 + \sum_{i=0}^{t_k} o(t_i)} w_2 - \frac{s_0 + \sum_{i=0}^{t_k} s(t_i)}{p_0 + \sum_{i=0}^{t_k} p(t_i)} w_3 - \frac{v_0 + \sum_{i=0}^{t_k} v(t_i)}{p_0 + \sum_{i=0}^{t_k} p(t_i)} w_4, \quad (1)$$

where d_0 is the initial value of Income, $d(t_i)$ the Income function where $d(t_i) = p(t_i) - o(t_i)$, $p(t_i)$ the Revenue function, $o(t_i)$ the Expenses function, t_k the final time of observation, c Capital, p_0 the initial value of Revenues, o_0 the initial Expenses, s_0 the initial Workforce

Expenses, $s(t_i)$ the Workforce Expense function, v_0 the initial Inventory costs and $v(t_i)$ the Inventory costs function. The weight values were prescribed as: $w_1 = 0.5$, $w_2 = 0.35$, $w_3 = 0.1$ and $w_4 = 0.05$. The goal of the participants was to maximize the criteria function in Equation 1.

2.2 Subjects and Procedure

In our experiment, 146 senior graduate students (86 female and 60 male) from the University of Maribor participated in the experiment in order to meet the requirements of their regular syllabus. The students were randomly assigned to nine groups, which were then assigned to work at one of the three experimental conditions: a_1, a_2 and a_3. 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 an electronic presentation where the model and the task were explained. A printed version of a problem description was provided for each subject. 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 explained for experimental conditions a_2 and a_3. The participating subjects were familiar with SD simulators; therefore, working with the simulator was not a technical problem. The participants formed a strategy according to the stated problem and passed their decisions to the network server or filled in a paper form in the case of the a_1 experimental condition. The search for the best parameter values was conducted under three experimental conditions:

a_1) Individual choice of parameter using CLD of the problem

Experimental condition a_1) assumed the individual assessment of the decision-maker supported only with CLD of the model as shown in Figure 2, paper and pen. It was assumed that the subjects would find the best business parameter values $\{r_1, r_2, r_3, r_4\}$ on the basis of intuitive judgment. At the end of the experiment, the subjects recorded the best parameter values on the form provided.

a_2) Individual optimization using simulation model

Experimental condition a_2) 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 in equation (1), using the SD model. At the end of the experiment, the subjects submitted the best-achieved parameter values to the network server.

a_3) Optimization using group feedback information

Experimental condition a_3) assumed the application of the SD model by the participants with group feedback information. The time of conducting the experiment under this condition was divided into four time intervals, 8+8+8+6 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 $R_i = \{r_1, r_2, r_3, r_4\}$; $i = 1, 2, \ldots n$ 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. Mean value provided the orientation for the parameter search and prevented information overload. In addition to criteria function as the results of decision making at different condition, simulation frequency in order to follow decision maker activity was also analyzed.

Formally, the experiment under conditions a_1, a_2 and a_3 is summarized in Table 1, where J and O_i represent values of observed criteira function at intervals 8^{th} minute, 16^{th} minute, 24^{th} minute, 30^{th} minute in both groups with individual feedback and group feedback. In this case, it means that each participant had to send the selected parameter values to the network server in the prescribed time intervals while their simulation activity continued and analyzed after experiment. Variable F (frequency of simulation runs) represents every simulation run (combination of four parameter values forming the business strategy) recorded for each participant in a second time for the duration of experiment.

Treatment	Observed variable	Pretest	Posttest		
a_1	J				O_{30min}
a_2	J, F	O_{8min}	O_{16min}	O_{24min}	O_{30min}
a_3	J, F	O_{8min}	O_{16min}	O_{24min}	O_{30min}
Note: J – Criteria function values; F – number of simulation runs					

Table 1: Pretest – post-test experimental design of comparing criteria J of Groups a_2, a_3

Table 1 presents the experimental design which assumes one group working individually without the simulator and two groups working under two conditions supported by the simulator (one individually and the other supported by simulator and group information feedback). Members of two groups had to turn in their decisions after 8, 16, 24 and finally after 30 minutes. Members of the first group had to present their decisions only once, after 30 minutes. During the first 8 minutes of working with the simulator, the same technical conditions were in force for both groups (individual exploration supported by the SD model). After they turned in their 8-minute results, group a_2 continued working in the same manner and group a_3 received the group information feedback, therefore such design can be interpreted as a pretest – post-test experiment.

We stated the following Hypothesis:

<u>Hypothesis 1</u>. Individual decision-making supported by the simulation model yields higher values of criteria function than Individual decision-making without the simulation model.

<u>Hypothesis 2</u>. Individual decision-making supported by the simulation model and group feedback information yields higher values of criteria function than Individual decision-making supported only by the simulation model.

<u>Hypothesis 3</u>. There is no significant difference among the criteria function values obtained by the groups a_2 and a_3 after the first eight minutes of the experiment (pretest).

3. Results and discussion

A total of 146 students (86 female, 60 male) randomly assigned into 9 groups of 14 to 15 subjects participated in the experiment; 30 students (two groups) participated in the condition a_1, 58 (four groups) participated in the condition a_2, and 58 (four groups) participated in the experimental condition a_3. For the purpose of results analysis, the criteria function was optimized by Powersim Solver™ 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_3 ($\hat{J}_{a3} = 1{,}1676$, $\sigma_{a3} = 0{,}34205$, $J\min_{a3} = 0{,}01$, $J\max_{a3} = 1{,}49$), followed by the results of the group a_2 ($\hat{J}_{a2} = 0{,}9832$, $\sigma_{a2} = 0{,}37135$, $J\min_{a2} = -0{,}29$, $J\max_{a2} = 1{,}48$) and the lowest results were gathered by the group a_1 supported by just paper and pen ($\hat{J}_{a1} = 0{,}3735$, $\sigma_{a1} = 0{,}59257$, $J\min_{a1} = -1{,}42$, $J\max_{a1} = 1{,}29$). Criteria function values selected by the participants working at three different conditions after 30 minutes of experiment time are presented in Figure 3. On the X-axis the relative number of participants is shown and on Y-axis the values of criteria function arranged from highest to lowest is shown.

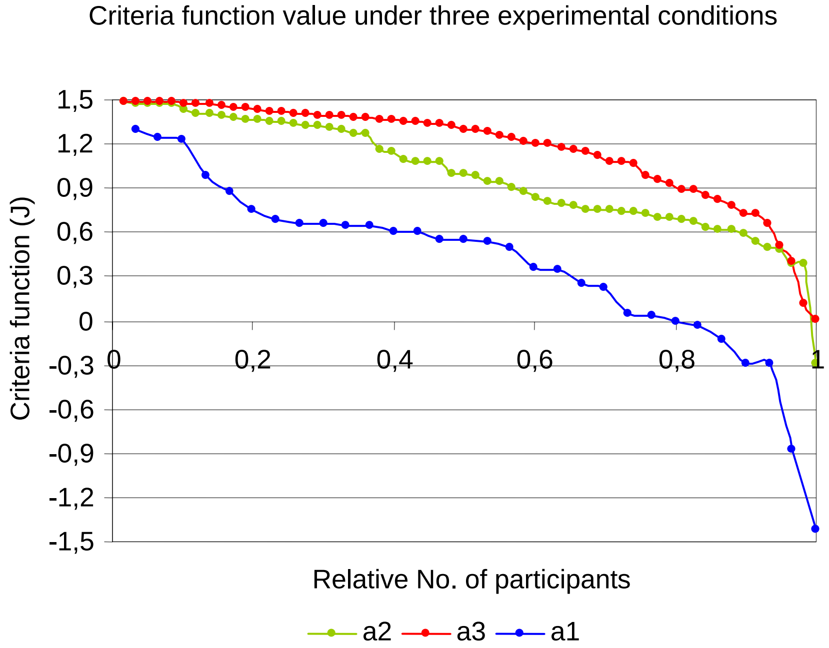

Figure 3: Values of Criteria Function achieved by the participants under experimental conditions: $\underline{a}_1$ (individual decision-making supported by CLD), $\underline{a}_2$ (individual decision-making supported by the simulation model), and $\underline{a}_3$ (decision-making supported by the individual use of the simulation model and group feedback information).

Hypothesis 1, stating that individual decision-making supported by the simulation model yields higher values of criteria function than individual decision-making without the simulation model, was confirmed by the U-test (Mann Whitney) with a p-level of 0,0000.

Hypothesis 2, stating that individual decision-making supported by the simulation model and group feedback information yields higher values of criteria function than individual decision-making supported by the simulation model only, was confirmed by the U-test (Mann Whitney) with a p-level of 0,002.

Hypothesis 3, that there is no significant difference among the criteria function values obtained by the groups a_2 and a_3 after the first 8 minutes of the experiment (pretest), was rejected by the U-test (Mann Whitney) with a p-level of 0,0002. This means the difference in criteria function values cannot be explained by random events.

We had expected the results of the two groups' after the first 8 minutes to be similar, as they had same technical conditions. We have examined the homogeneity of groups and eliminated all possible sources of disturbances (randomization, motivation of participants to actively cooperate, anonymity). Nevertheless, the group that had expected to share their views after the first observation time (8 minutes) might have been motivated by that factor.
For the purpose of further analysis of dynamics of problem solving of Groups a_2 and a_3, we have recorded every simulation run performed by each subject of the two groups during the experiment at a sampling frequency of one second. The cumulative frequencies of the simulation runs during the 30 minutes experiment time of Groups a_2 and a_3 are presented in Figure 4. On the Y-axis, the frequency of testing is presented as the ratio of cumulative frequency of simulation runs and time in seconds. On the X-axis, the time frame of the experiment is presented in seconds, highlighting the observation times at 8^{th}, 16^{th} and 24^{th} minute.

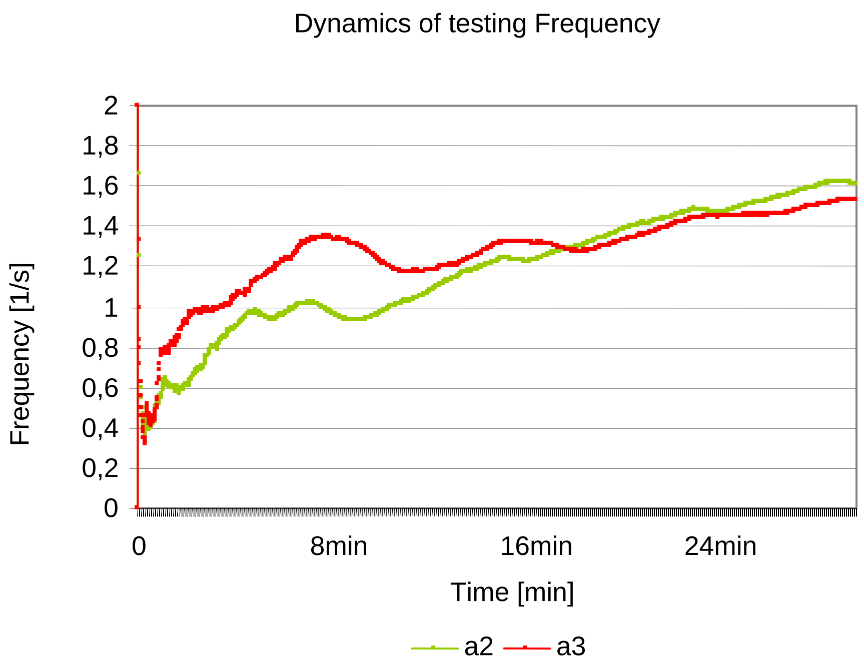

Figure 4: Cumulative frequencies of simulation runs over 30 minutes of experiment time of Group a_2 and Group a_3

We can observe from Figure 4 that the frequencies of Group a_3 are much higher than the frequencies of simulation runs of Group a_2 in the first 8 minutes of the experiment time. After the first eight minutes, the frequency of experimentation on the simulator decreases. This is consistent with the time of passing the selected parameter values to the network server. We can observe such interruptions after the 16th and 24th minutes as well. The frequency of simulation runs of Group a_3 slows down after they receive the group feedback information (after the first eight minutes). But the frequencies of simulation runs of Group a_2 are increasing until the end of experiment. At the end of observation time, the two groups have performed almost the same number of simulation runs (Noa_2=2925, Noa_3=2930), but Group a_3 performed significantly better than Group a_2 in achieving greater values of criteria function. This is shown in Figure 5, where Y-axis represents the ratio of average value of criteria function and cumulative frequency in time (seconds) and X-axis represents timeframe of the experiment in seconds.

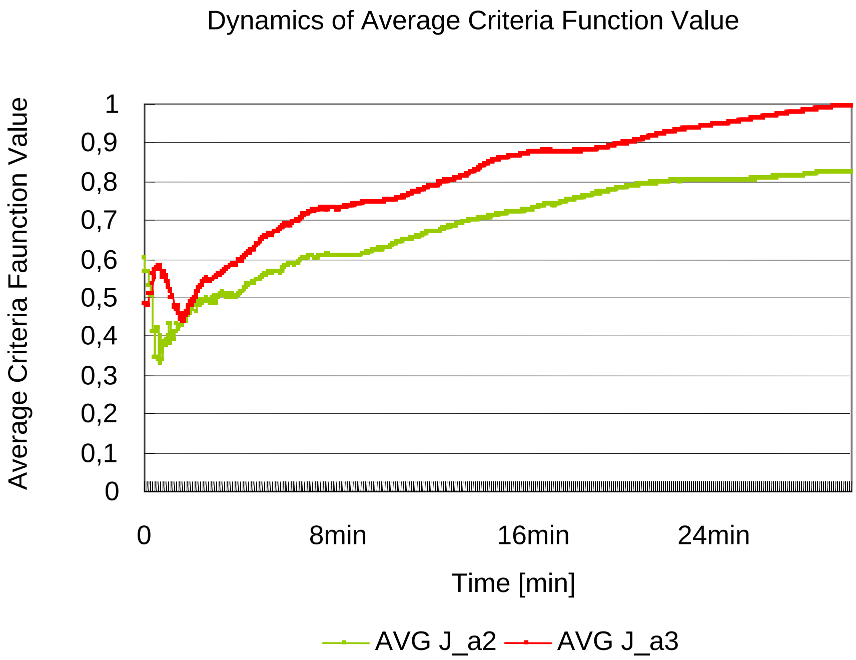

Figure 5: dynamics of average criteria function values within 30 minutes of experiment time of Groups a_2 (individual decision-making supported by simulation model), and Group a_3 (decision-making supported by simulation model and group feedback information)

Two curves in Figure 5 represent the average value of criteria function of Groups a_2 and a_3 during the experiment time. The two curves are increasing almost exponentially until they reach a steady state approaching the optimum value. The average value of criteria function achieved by Group a_2 is lower than that achieved by Group a_3 from the start of the experiment. The disturbance which we can observe at the beginning of the experiment can be accounted for familiarizing with the simulator. The interruptions at each observation time (after 8th, 16th and 24th minute) are notable as well.

Hypotheses 1 and 2 were stated to test the effect of information on problem solving. The results of decision making at three experimental conditions are shown in Figure 3. It is seen that Hypotheses 1 and 2, which test the effect of information on problem solving, are confirmed at the level of significance p=0.00. However, Hypothesis 3, which refers to group homogeneity, was rejected. It is shown in Figures 4 and 5 that in the first 8 minutes both the criteria function and frequency of simulation activity of participants of Group a_3 are higher.

After that time, the criteria function stays permanently higher in Group a_3, as was expected, while the activity (frequency) of the subjects in both groups converges to the equal stationary value.

3.1 Solomon Four-group Experimental Design

Although Hypotheses 1 and 2 were proved at the end of experiment, the main task of optimization was found in the fact that we cannot accept Hypothesis 3. 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 8 minutes would be identical. However, from the time course of variables on Figures 4 and 5 a difference was noted. This phenomenon cannot be explained by the pretest - post-test experiment. Therefore, we plan a new experiment according to Solomon Four-group Experimental Design. We expect to estimate the effect of group belonging and pretest effect on the results using this test. Solomon's design for the suggested experiment is shown in Table 2.

Treatment	Observed variables	Pretest			Posttest
a_2	J, F	O_{8min}	O_{16min}	O_{24min}	O_{30min}
a_3	J, F	O_{8min}	O_{16min}	O_{24min}	O_{30min}
a_4	J, F	-			O_{30min}
a_5	J, F	-			O_{30min}
Note: J – Criteria function values; F – number of simulation runs					

Table 2: Solomon four group experiment design

The first two groups in Table 2 represent the pretest - post-test design described earlier. The last two groups of experiment will solve their task as the first two groups do but without sending the selected parameter values every 8 minutes. They will work on their tasks without interruptions for the whole observed time (30 minutes) and send their selected parameter values at the end of experiment. All measurements will be automatic, which means theat every simulation run will be recorded in the database in a second time thus the information feedback about the group members' decisions will be available at all times. In this manner it would be possible to estimate effect of result sampling every 8 minutes, as well as the factors group belonging or motivation versus group information. For that purpose, a new interface for data acquisition and proceeding has been developed.

In order to explain the influence of individual feedback and group information feedback using simulation model on efficacy on problem solving, we developed a CLD model of learning during decision-making. The model shown in Figure 6 was modified according to (Lizeo, 2005) and consists of three B and one R loops. Loop B1 represents decision problem solving only using CLD from Figure 2 and could associate with experimental condition a_1. Loop B2 represents individual problem solving using simulations of the problem and corresponds to experimental conditions of a_2. Loop B3 represents direct contribution of group information while loop R suggest reinforcing effects of group influence on problem solving at Group a_3. Loop R could probably explain phenomena regarding hypothesis 3. This effect could be deduced from the proposed Solomon's four group experiment design.

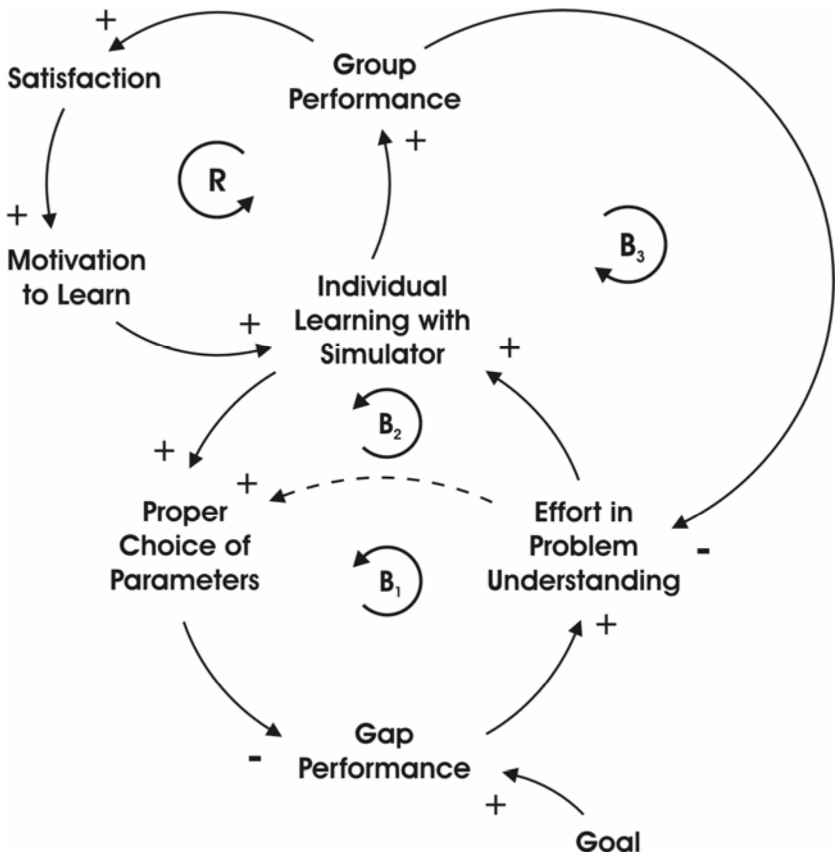

Figure 6: Learning model of decision group, with the feedback information obtained from simulation model

4. Conclusions

In this paper, we have discussed the influence of individual information feedback obtained by the simulation model and group information feedback on a decision-making process during an experiment with decision groups. A system enabling interactive work with a business simulator and restricted group interaction was developed; it was conducted with 146 participants under three experimental conditions: a_1) individual assessment supported by CLD explanation, a_2) individual assessment supported by the simulator and a_3) assessment supported by the simulator and group information feedback. Two dependent variables were observed in the experiment: criteria function (J) and frequency of simulation runs (F). The hypothesis, that groups supported by the simulator achieved higher values of criteria function than groups supported merely by the explanation of the CLD, was confirmed. Also confirmed was the hypothesis that the group supported by the simulator and group feedback information achieved better results than the group supported only by simulator. However, the hypothesis that the results of groups a_2 and a_3 didn't differ in the first 8 minutes of work, when they had identical conditions, had to be rejected. Further analysis of the dynamics of business strategy findings had revealed that the group expecting to share their results after the first 8 minutes performed almost twice as many simulation runs as did the group working with the simulation model alone. For these differences that cannot be explained by the current experiment design, we propose a Solomon four group experiment design. The CLD model of group learning in decision problem solving using simulation models has been proposed with regard to new experiment design in order to explain Hypothesis 3. The research is in the progress.

5. Acknowledgments

This research was funded by the Ministry of Education, Science and Sport of the Republic of Slovenia; Program No. PP-0586-501 and Grant No. Z5-3313.

6. References

Hale R, Whitman P. 1997. *Practical problem solving & decision making*. Kogan Page.

Vennix JAM. 1996. *Group model building: facilitating team learning using system dynamics*. Wiley: Chichester.

Richardson GP, Andersen DF. 1995. Teamwork in group model building. *System Dynamics Review* **11**: 113-137.

Kwok RCW, Khalifa M. 1998. Effect of GSS on knowledge acquisition. *Information & Management* **34**: 307-315.

Škraba A, Kljajić M, Leskovar R. 2003. Group exploration of system dynamics models – Is there a place for a feedback loop in the decision process?. *System Dynamics Review*. **19**: 243-263.

Checkland PB, Haynes MG. 1994. Varietes of systems thinking: the case of soft systems methodology. *System dynamics review*. Vol.10, No. 2-3: 189-198.

Forrester JW. 1973. *Industrial Dynamics*. MIT Press. Cambridge. MA.

Rosen R. 1985. *Anticipatory Systems*. Pergamon Press.

Simon H. 1997. *Models of Bounded Rationality: Empirically grounded Economic Reason*. Vol. 3. MIT.

Warren K, Langley P. 1999. The effective communication of system dynamics to improve insight and learning in management education. *Journal of Operational Research Society* **50**: 396–404.

Lizeo E. 2005. A dynamic model of group learning and effectiveness. Conference proceedings, The 23rd International Conference of the *System Dynamics Society. Boston*.

Gopinath C, Sawyer JE. 1999. Exploring the learning from an enterprise simulation. *Journal of Management Development*. Vol. 18. No. 5: 477-489.

Langley PA, Morecroft JDW. 2004. Performance and learning in a simulation of oil industry dynamics. *European Journal of Operational Research* **155**: 715-732.

Chun KJ, Park HK. 1998. Examining the conflicting results of GDSS research. *Information & Management* **33**: 313-325.

Kahneman D, Tversky A. 1979. Prospect theory: An analysis of decision under risk. *Econometrica* **47**: 263-291.

Howie E, Sy S, Ford L, Vicente KJ. 2000. Human–computer interface design can reduce misperceptions of feedback. *System Dynamics Review* **16**: 151-171.

Senge PM. 1990. *The Fifth Discipline: The Art and Practice of The Learning Organization*. Doubleday/Currency. New York.

Jennings D. 2002. Strategic management: an evaluation of the use of three learning methods. *Journal of Management Development*, Vol. 21 No. 9: 655-665.

Hines J. 1996. *Molecules of Structure, Version 1.1, Building Blocks for System Dynamics Models*. LeapTec and Ventana Systems, Inc., USA.

Sterman JD. 1994. Learning in and about complex systems. *System Dynamics Review* **10**: 291-330.

Sterman JD. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill: Boston MA.