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The Role of Information Feedback in the Management Group Decision-Making Process Applying System Dynamics Models

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Abstract

The research project addresses the influence of feedback information on the decision process supported by the application of system dynamics models. A user-friendly application was developed and used in the experiment with decision groups. The participants were 174 undergraduate management science students. They had the task of determining the optimum business strategy by maximizing the multiple criteria function under three experimental conditions: a_1) an individual decision process without the support of a system dynamics model, a_2) an individual decision process supported by a system dynamics model, and a_3) a decision process supported by a system dynamics model and subject interaction via computer mediation. The hypotheses that the individual decision process supported by a system dynamics model yields higher Criteria Function values than one without a system dynamics model, as well as the decision process supported by both a system dynamics model and subject interaction yields higher Criteria Function values than one supported by a system dynamics model alone were confirmed.

Key words: group decision process, feedback, system dynamics, multi-criteria function

The use of system dynamics (SD) models for testing the vision of organizational systems development has a long research tradition (Forester 1973; Simon 1997; Sterman 2000). Simulation models developed by SD methodology are important tools for strategy development and policy planning as an expert support tool (Yim et al. 2004). The main advantages of SD models as an integral part of decision support systems are the possibility of dynamic analysis of the considered problem under different scenarios (Larsen et al. 1997). Information provided by a simulation model is in fact feed forward information about the anticipated business response (effect of the selected input parameter values on the business outcome) in a decision process (Kljajić 1994). The anticipative perspective of such a complex adaptive system is further emphasized, for example, in Shakun (1999) by the contribution to procedural rationality – how decisions should be or are made – in purposeful complex adaptive systems.

Many decision processes in organizations, where knowledge elicitation is the main concern (Ford and Sterman 1998) rely on groups of experts (Beach 1997; Tung 1987; Tung et al. 2001). The study of Isaacs (1999) also agrees that the new approach addressing the development of organizational strategy considers a collective understanding of organizational processes. Group decision-making has some advantages in the sense of a larger knowledge base, different points of view, and the generation of new ideas and synergetic effects (Hale and Whitman 1997; Paulus 1989; Paulus and Yang 2000). In reality this means that the decision group consisting of various experts would cover a wider range of expert fields and constructively contribute to a better decision. An example of expert group involvement in the decision process supported by a simulation model in the context of an expert system is described in Kljajić et al. (2000). Group decision-making also has some disadvantages like a conflict of interests, superiority of an individual decision-maker, etc. The negative aspects of group dynamics can be avoided to some extent by employing group support systems (GSS) (Briggs and De Vreede 1997; Caouette and O'Connor 1998). There are several verifications that the application of a group support system in the design of strategic decisions brings positive business effects (Dennis et al. 1997; Vennix 1996) and improves the decision process. However, the group decision process must be carefully prepared because of problem complexity and the technology used to support the process (Bohlmann 1996). The present research connects many research fields such as: SD, expert systems, decision-making and group support systems (GSS). Similar problems of interconnecting SD methodology and group decision support systems (GDSS) can be found in Richardson and Andersen (1995) and Vennix (1996), where group support in the process of model-building was described. The positive impact of GSS on the development of knowledge, which should contribute to better decisions, was described by Kwok and Khalifa (1998). The results of the study showed that the application of GSS contributes to a higher level of problem understanding compared to other methods. In the research of Powel et al. (2001) the use of simulation methodology in the search for optimum control was described. The authors indicated that involvement of a management team is a prerequisite for the successful implementation of SD models, but involvement of the team was not described in their paper. Group decisions differ from individual decisions in many aspects, from the social and cognitive perspective (Stasser et al. 1989) to a decision rule application (Miller 1989). The research of Paul et al. (2004) describes the role of group memory in the decision process conducting the experiment with 53 groups of 5 participants. The group memory was provided in the form of static feedback information about the decision of the group. The participants had the task of identifying and ranking the decision criteria. Another research project in the field of GDSS based on SD models of Langley and Morecroft (2004) addresses the impact of different feedback information on individual learning. Their experiments are based on the SD Global Oil Simulator. In the experiment (Langley and Morecroft 2004) feedback information about the outcome was provided to the participants. However, both mentioned research projects do not address the impact of group feedback information on the convergence of criteria function in the application of SD models, which is considered in the present paper.

Decisions in organizational systems usually deal with multiple objectives such as minimization of cost while maximization of quality and profit, etc. The decision process is thus a complex one involving the systematic collection and management of information (Wang 1997). It is in fact a learning process which should provide enough knowledge for efficient decision-making. The study of Warren and Langley (1999) argued that the ideal of a learning organization could be approached by the application of SD models. As stated in the research of Kuchinke (2000), feedback is a key component of the learning process. The research considers the amount and frequency of feedback and emphasizes the importance of feedback in training to acquire management knowledge. The author argues that the feedback should provide a proper orientation in a learning process by showing the participants whether they are right or wrong in their understanding. The research of Korsgaard and Diddams (1996) indicated that the richness of a feedback environment should fit the complexity of the task. The results of the study indicated that any type of feedback does not necessarily yield an improvement in performance; instead the study showed that feedback availability and task complexity jointly affected an improvement in decision process performance. In the research of Chun and Park (1998) the question of reality of the researched problem set in a laboratory environment was exposed. In order to obtain valid experimental results the problem must be analogous to the real one, but still manageable in a laboratory environment.

An important phase of expert knowledge elicitation to improve the application and development of GDSS is the interaction between the experts in the process of problem solving (Ford and Sterman 1998; Warren and Langley 1999). In this way different knowledge domains of subjects and problem perceptions could be constructively explored and utilized. The application of simulation models in the frame of GDSS and in particular SD models enhances the mental models of the participants involved. In the task of addressing problem solving by application of SD models Ford and Sterman (1998) state: "Differences among descriptions are inevitable because of the complexity of the relationships being described and the incomplete and particular knowledge of different experts. These differences naturally lead the experts to discuss their mental models and assumptions used to describe the relationship." Such an approach, which is in our case realized by GDSS, enabled a comparison of different views of subjects when determining the proper parameter values of the considered SD model that should result in business strategy determination.

Subject interaction in the form of group model building and application leads to improved learning about the problem and a better insight as shown by the significant number of studies identified in Rouwette et al. (2002). Although it seems rather straightforward to expect that group interaction leads to increased learning about a problem, research into business simulator application to prove these effects formally is a difficult and demanding task (Andersen et al. 1997; Cavaleri and Sterman 1997). One of the reasons is the complexity of the addressed problem in a real situation. From the start of the study, implementation of the policy and the analysis of the results, several years could pass. In the end, it would be difficult to determine what was the actual cause of the change of the business system output; the implemented change or some other change in influential parameters or environment. Therefore the present research does not address the real world implementation directly. However, the described experiment is based on three key elements that emerge from real decision processes: a) the model, b) the criteria function, and c) the time to provide a decision.

In the present research, the classical SD model was applied as the "constructed" reality for the participants (see Sterman 2000; Hines 2005). The criteria function was stated as the abstraction of the system performance.

Experimental time was carefully determined according to the performance of several pilot experiments. It was our intention to provide a time frame that would enable the majority of participants to successfully complete the task.

The results of our previous studies showed the usefulness of SD models and GSS in providing information for decision support in the reengineering process in a factory that produces concrete goods (Kljajić et al., 2000). In Škraba (2000) and Kljajić (2003) we conducted several laboratory experiments with models of various complexities in order to study the role of simulation models in decision processes. In Škraba (2000) the problem of appropriate business strategy determination by employing the simulation model and group feedback information was described. It was found that the use of a simulation model and group feedback information significantly improved the quality of decisions. Furthermore, we observed the convergence of criteria function over time under the condition of group feedback information. In Kljajić (2003) an extended experiment was repeated with three treatment groups. Additionally we observed the convergence of criteria function in time also under conditions employing the simulation model. In the present research a simplified business model was chosen, which still represented a challenge for the decision-makers. At the same time the model was not too complicated so that it could not confuse the decision-makers and hinder the experiment results on account of a misunderstanding.

The goal of this paper is to show the influence of the feedback information on the decision process under three experimental conditions and the significance of using simulation models for real decision support.

For this purpose we have developed a simulation model and method for carrying out the experiment under three conditions. Experimental subjects were randomly assigned to one of three treatment groups: a_1) individual decision-making based on information gained by problem understanding, a_2) individual decision-making based on individual feedback information, provided by the SD model, and a_3) group decision-making based on individual feedback information (provided by the SD model) and group feedback information (provided by subject interaction via computer mediation). Participants in our experiment were senior undergraduate students of management science that attended the courses of "Modelling and System Simulation" and "Systems Theory". The observed variable of the experiment was the value of the criteria function.

Methodology

Figure 1 shows the model as the black box of the proposed laboratory experiment. The core of the experiment represents simulation model M of the simplified business process. DG represents participants randomly assigned to the three Decision Groups, $u_i \in U$ represents decision parameters (u_1 = Product Price, u_2 = Salary, u_3 = Marketing Costs, and u_4 = Desired Inventory), Y control variables, X represents stationary input from the environment, $J = f(Y, U)$ is the Criteria Function, and a_1, a_2 and a_3 represent experimental conditions.

Description of the experimental conditions:

(a_1) *Individual decision-making without the simulation model.* Under this experimental condition a subject had to make an individual judgment about the best possible values of the model parameters (u_1, u_2, u_3, u_4) in order to maximize the value of criteria function. The values were determined according to the subject's understanding of the

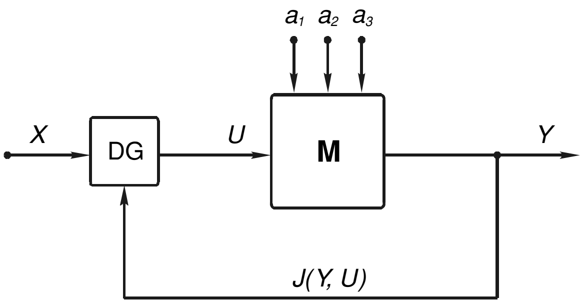

Figure 1. Model of an experiment on the influence of three conditions on achieving the Criteria Function.

problem which was presented by the Causal Loop Diagram (CLD). The participants had 30 minutes time to determine the appropriate values of decision parameters and register their decisions on the paper form.

(a_2) *Individual decision-making supported by the simulation model.* Under the experimental condition a_2 each individual subject was supported by the simulation model, which provided feedback information about the anticipated business outcome (individual feedback information). There was no limitation on the number of simulation runs a particular participant executed on the simulation model within the experimental time. After each predetermined time interval (8+8+8+6 minutes) participants had to forward their selected business strategy to the network server and continue the search for the optimum business strategy. Participants had to make a final decision about the best business strategy and forward the selected decision parameter values (u_1, u_2, u_3, u_4) to the server after 30 minutes.

(a_3) *Decision-making supported by both the simulation model and group feedback information.* For this condition the simulation model was connected to the GSS, which enabled the introduction of group feedback information into the decision process. Under experimental condition a_3 each individual subject was supported by the simulation model, which provided feedback information on the anticipated business outcome. Under this condition subject interaction via computer mediation was enabled. Participants were able to examine the chosen business strategies (decision parameter values) of other participants in the decision group after the strategies were forwarded to the network server. Therefore the participants could look into the "group's achievements" after the 8th, 16th and 24th minute. Group feedback information was presented in the form of a table as shown in Figure 2, which contained input parameter values $U_i = (u_1, u_2, u_3, u_4)$ selected by each participant anonymously, and the average values of the parameters (Mu_1, Mu_2, Mu_3, Mu_4) with the standard deviation. There were no limitations on how many times they could seek group feedback. For example, taking the parameter "Marketing Costs" and there are 15 participants, the selected values for all 15 participants are shown in the table as well as the average and deviation for this parameter (see Figure 2). Each of the participants could compare his/her own parameter values with averaged and original values of all group members before the

Overview of proposed strategies

Index No.	Product price	Salary	Marketing costs	Desired inventory
45944	136	1,149	11,791	4,865
50635	124.2	780	10,990	4,580
44025	135	950	8,500	3,000
42017	120	1,200	8,000	4,500
42053	116.04	1,003.76	10,000	4,343.28
46024	135.5	1,015	10,000	3,300.99
46999	112	995.8	14,209	8,957
50666	123.88	902.99	11,044.78	4,656.72
51079	142.91	1,272.39	15,074.63	5,910.45
50643	125	1,000	11,000	5,700
50633	135	600	10,000	8,000
46786	126.12	779.85	10,895.52	4,447.76
45952	122	1,000	12,000	7,000
45119	125.6	781	10,860.27	4,488.54
43987	124	900	8,700	4,500
Average	126.88	955.32	10,871.01	5,216.65
St. Dev.	8.39	175.96	1,924.45	1,464.85

Figure 2. Example of the feedback table that could be observed by participants in the first phase of condition a_3.

next selection of values was made. After the observation of criteria function value on the model one could proceed with the determination of a new set of values. This sort of presentation and application of the feedback information, on the one hand, provides a direction in the search for the optimum strategy, and on the other, prevents information overload. Such functional mapping could take many other forms, not only the arithmetical mean (Zeleny 1982). The arithmetical mean was selected because the participants were familiar with the measure.

Model of the Business Simulator

Model M in Figure 1, which was used in the experiment, was represented with the Causal Loop Diagram (CLD) technique and implemented in Powersim™ for simulation purposes. The model consists of well-known SD structures that implement production, workforce and marketing segments (Forrester 1973; Sterman 2000). The model is therefore built on validated and thoroughly studied structures which were interconnected and modified. CLD considers the main dependencies between the variables in the model. The reader can find a detailed description of the model and the business simulator interface in Škraba et al. (2003).

The simplified CLD in Figure 3 shows that Product Price (u_1) positively influences Cash Inflow. At the same time it negatively influences demand, therefore the proper pricing that

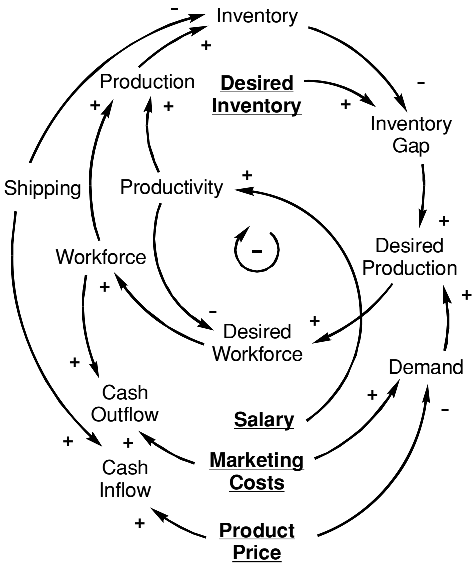

Figure 3. Causal Loop Diagram of Production Model.

customers would accept should be determined. If Marketing Costs (u_3) had increased, demand would increase above what it would otherwise have been if Marketing Costs had remained unchanged. Changes in this segment would represent the effects of marketing campaigns. The production system should provide the proper inventory level to cover demand. This is achieved by a proper determination of the Desired Inventory Level (u_4) value. Surplus inventory creates unwanted costs due to warehousing, therefore these costs have to be considered as well. The number of workers employed is dependent on the gap between required production volume and actual production volume as well as workforce productivity, which is stimulated through Salaries (u_2). Proper stimulation should provide reasonable productivity. There is one negative loop in the CLD that represents the production system dependent on market demand. The desired inventory level controls this part of the model. The decision problem was stated as a business plan determination for the next 12-month period.

A business model was constructed in Powersim™ in the form of a user-friendly business simulator. The user interface of the simulator comprised of a control panel with sliders and input fields for the user adjustable input parameters and an output window containing output graphs that represented the dynamic response of the model for the next 12 months. The output graphs presented the economic entities (y_1 = Capital Return Ratio, y_2 = Overall Effectiveness Ratio, y_3 = Workforce Effectiveness Ratio, y_4 = Inventory/Income ratio) that formed the criteria function and are described in detail later in the text. After setting the decision parameters (u_1, u_2, u_3, u_4), the online simulation could be processed for the next 12-month period.

Criteria Function and Task

Criteria function represented the goal of our system and was explicitly stated for the purpose of controlling and analyzing the results of the experiment. Criteria function was stated as a linearly weighted sum of several ratios presented to the participants in the form of output graphs (y_1 = Capital Return Ratio (CRR), y_2 = Overall Effectiveness Ratio (OER), y_3 = Workforce Effectiveness Ratio (WER), y_4 = Inventory/Income ratio (IIR)):

$$\max_{u_i \in U} J = \mathrm{CRR} \cdot w_1 + \mathrm{OER} \cdot w_2 - \mathrm{WER} \cdot w_3 - \mathrm{IIR} \cdot w_4 \tag{1}$$

The weight values were prescribed as: $w_1 = 0.5$, $w_2 = 0.35$, $w_3 = 0.1$ and $w_4 = 0.05$ and were known to the participants. The particular output in Equation 1 is defined by:

$$\mathrm{CRR} = \frac{d_0 + \sum_{i=0}^{t_k} d(t_i)}{c}, \qquad \mathrm{OER} = \frac{p_0 + \sum_{i=0}^{t_k} p(t_i)}{o_0 + \sum_{i=0}^{t_k} o(t_i)},$$
$$\mathrm{WER} = \frac{s_0 + \sum_{i=0}^{t_k} s(t_i)}{p_0 + \sum_{i=0}^{t_k} p(t_i)}, \qquad \mathrm{IIR} = \frac{v_0 + \sum_{i=0}^{t_k} v(t_i)}{p_0 + \sum_{i=0}^{t_k} p(t_i)}, \tag{2}$$

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 initial Expenses, s_0 initial workforce expenses, $s(t_i)$ the workforce expense function, v_0 initial inventory costs, and $v(t_i)$ the inventory costs function. Criteria Function was optimized by Powersim Solver$^{\text{TM}}$ for the purpose of controlling and analyzing the experiment. The optimum value of Criteria Function was $J = 1.5$.

The goal of the participants was to maximize the criteria function in Equation 1. It was assumed that Capital Return Ratio (CRR) and Overall Effectiveness Ratio (OER) should be maximized at minimal Workforce and Inventory costs determined by Workforce Effectiveness Ratio (WER) and Inventory/Income Ratio (IIR). The participants in the experiment had to find the appropriate values of Product Price, Salary, Marketing Costs and Desired Inventory Level in order to achieve the maximum value of Equation 1.

In the presented research the assumption has been made that the defined model is accepted as validated by the users, which is subsequently applied in their business decision. However, in reality, this is hard to achieve on account of many obstacles during model implementation. On the other hand, it is assumed that if such models are applied in strategic decision-making, enforcement in the feedback loop of the decision group should provide better results of the criteria function.

It was not our intention to address model building or validation of the SD model. This was provided by implementing the classical SD structure and properly instructing the subjects to understand the case addressed. These are certainly important issues. However, addressing these questions would significantly expand research. The value of the model and its application in the form of a business simulator depend on the subjects' knowledge of the problem that the model addresses (Warren 2002).

Experimental Design

As we wanted to compare the performance differences due to three experimental conditions for the decision process we selected a post test only experimental design with three treatment groups: a_1, a_2 and a_3. The time of conducting the experiment was 30 minutes for all three conditions. The appropriate experiment time was determined in our preliminary experiments, where we tested the time needed to accomplish the task of this complexity. In the preliminary experiments the majority of the participants were able to solve the task of the described complexity within 30 minutes. Additionally the repeated measurements were employed for the groups a_2 and a_3 in order to compare the dynamics of the decision process supported by the simulation model. Repeated measurements were performed after predefined time intervals that equalled 30 minutes of total experimental time (time intervals: 8+8+8+6 minutes). After each predefined time interval the participants had to send their "best achieved business strategies" to the network server. The participants of group a_1 registered their selected parameter values on the paper form only at the end of the experiment. Parameter values registered by the participants under condition a_1 were later entered into the simulation model to calculate the Criteria Function values for each subject. The value of the Criteria Function was the observed variable of the experiment, measuring the quality of the decisions achieved by the participants. The application running over the computer network enabled us to record every action (occurrence of simulation run) of each participant who had worked with the simulation model. The frequency of simulation runs was thus observed under conditions a_2 and a_3 in order to monitor the dynamics during the decision process.

In order to confirm the performance differences due to the three conditions in the decision process we stated the following hypotheses:

Hypothesis 1. Individual decision-making supported by the simulation model yields higher values of criteria function than individual decision-making without the simulation model.
Hypothesis 2. 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.
Hypothesis 3. Values of Criteria Function monotony increase with time (time intervals 8+8+8+6 minutes) of the experiment under conditions a_2 and a_3.

All the hypotheses were tested at the $\alpha = .05$ level of importance.

Participants

The participants were 174 University of Maribor senior undergraduate management science students who attended the 180 hour courses of "Modelling and System Simulation" and "Systems Theory". Each subject was trained with hands-on experience with the SD tool Powersim™, covering all three sub-models: a) production, b) workforce, and c) marketing. Participation in the experiment was specified as part of their regular syllabus. There were 73 male and 101 female participants. All of them received the same theoretical and practical training as part of the course. They were well accustomed with the SD methodology for decision support in organizational systems based on the stated goal (in our case the Criteria Function). Practical training assured that the participants had the technical knowledge to use the main experiment tool – Powersim™. The subjects of all three experimental groups were aware of the interconnections of the model components and the impact of feedback loops in the system.

The experiment was carried out at the end of the course, so the knowledge they acquired was fresh and their motivation for creative participation was high. The participants were not told what experimental condition they would be part of until they entered the laboratory.

The criteria function value and the anonymous index number of each participant were reported via the internet after the experiment. The participants were motivated to find proper parameter values which would provide the best results. Participation in the experiment was also one of the study requirements in the course covering the field of business simulator implementation.

Equipment and Materials

The experiment was conducted in laboratories equipped with 16 computers and one server, all connected to a star-shaped network. The participants under condition a_1 were equipped with only a paper and pen, whereas the participants under conditions a_2 and a_3 were equipped with personal computers. However, all of them received a common written and oral presentation of the business model by the CLD, the problem and the task. The use of a business simulator and group feedback information was demonstrated to the participants who worked under conditions a_2 and a_3. Since the participants were used to working with computers, the use of a business simulator did not present any technical difficulty. During the experiment the participants were not allowed to communicate other than via the controlled channels. Four experimenters equipped with stop-watches and four technical coordinators had supervised the performance of the experiment (controlling time and offering technical support to the participants).

Procedure

We randomly assigned 174 students into 12 experimental groups. Each group contained 14 to 16 students. Four groups were assigned to work under condition a_1: decision-making without a simulator; four groups were assigned to work under condition a_2: individual decision-making supported by individual feedback information (provided by a simulator); and four groups were assigned to work under condition a_3: decision-making supported by both individual and group feedback information. After a common oral presentation of the business model by the CLD, the problem and the task to all participants, the groups were taken into the laboratories. At the beginning of the experiment each participant had received a written presentation as well. In the laboratory the experimenters explained the specific experimental condition the group participated in. The experimenters also explained the use of the business simulator and group feedback information to the groups that had used it. Once the experimenters and technical coordinator assessed that the application was properly running on each participants' computer the experiment began.

Results

Figure 4 shows the values of Criteria Function achieved by the participants under conditions a_1 (four groups; $N_{a1} = 58$), a_2 (four groups; $N_{a2} = 58$) and a_3 (four groups; $N_{a3} = 58$) at the end of the experiment. The values are arranged in descending order on the y-axis while subjects are presented on the x-axis.

From Figure 4 we can observe that Criteria Function values achieved by the participants under condition a_1 are distributed at interval [–1.42, 1.28], values achieved by the participants under condition a_2 are distributed at interval [–0.29, 1.48], and values achieved by the participants under condition a_3 were distributed at interval [0.01, 1.49]. Only 7 subjects (12%) under condition a_1 achieved values of Criteria Function greater than 1, while as many as 13 subjects (22%) determined the negative value of Criteria Function. Under condition a_2 only one subject reached a negative value of Criteria Function and 28 subjects (48%) achieved values greater than 1, whereas 43 subjects (74%) under condition a_3 achieved

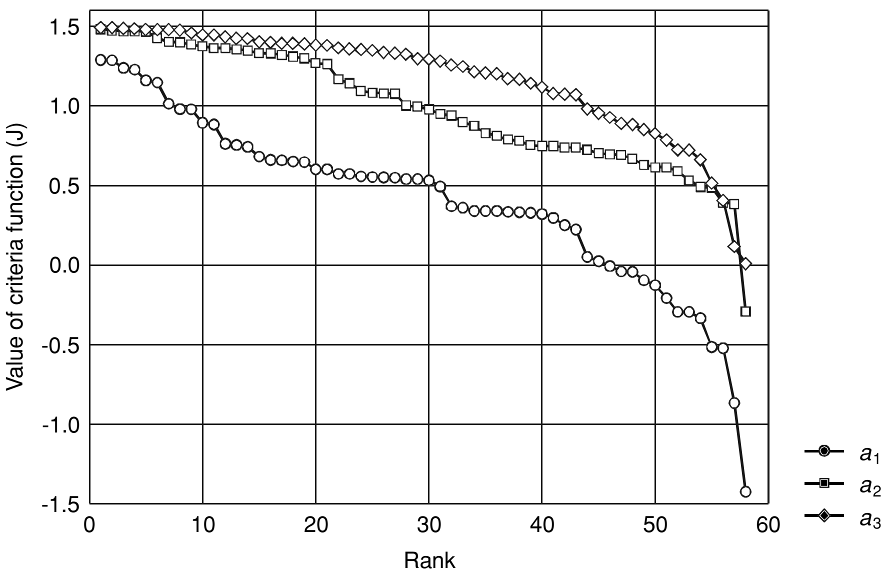

Figure 4. Values of Criteria Function (J) sorted from highest to lowest achieved by the participants under the experimental conditions a_1 (individual decision-making without the use of the simulation model), a_2 (individual decision-making supported by the simulation model), and a_3 (decision-making supported by the individual use of the simulation model and group feedback information).

values greater than 1. Criteria Function values achieved by the participants in group a_1 were the lowest; with an average of $M_{a1} = 0.40$ and deviation of $SD_{a1} = 0.54$. Average results achieved by the participants under experimental condition a_2 were higher than the results of group a_1 with an average of $M_{a2} = 0.98$ and standard deviation of $SD_{a2} = 0.37$. The highest values of Criteria Function were achieved under experimental condition a_3, with an average of $M_{a3} = 1.17$, while the deviation was the smallest ($SD_{a3} = 0.34$). The convergence of the decision process can also be presented with the coefficient of variation: $CV_{a1} = 1.33$, $CV_{a2} = 0.37$ and $CV_{a3} = 0.29$ for experimental conditions a_1, a_2 and a_3, respectively. The smaller value of the coefficient of variation indicates a higher convergence of the decision process under a particular treatment. The lowest value of the coefficient of variation is observed under condition a_3, where the process is supported by the simulation model and employment of group feedback information. The highest value of the coefficient of variation is observed under experimental condition a_1.

The hypotheses (H1 and H2) were tested with the non-parametric Mann Whitney *U*-test because of the one-way determination of Criteria Function ($J_{opt} = 1.5$) and non-normally distributed samples. The Mann Whitney *U*-test assumes that the variable under consideration was measured on at least an ordinal (rank order) and does not assume normality of the data. It is therefore more robust than the parametric t-test. A hypothesis (H1) of the significant differences between the results gained under conditions a_1 and a_2 was accepted according to the results of the *U*-test [$U(N_1 = 58, N_2 = 58) = 563, p < .000$]. The hypothesis (H2) of significant differences between the results gained under conditions a_2 and a_3 was accepted according to the results of the *U*-test [$U (N_1 = 58, N_2 = 58) = 1134, p < .002$].

Figures 5 and 6 show the values of Criteria Function J sampled under conditions a_2 and a_3 at different time intervals. The values of Criteria Function are arranged in descending order on the *y*-axis while participants are presented on the *x*-axis for a particular phase. The decision process phases are represented by curves marked a_{i1} for the first phase (at the 8th minute), a_{i2}, the second phase (at the 16th minute), a_{i3}, the third phase (at the 24th minute), and a_{i4} the fourth phase of the experiment (at the 30th minute).

In Figures 5 and 6 we can observe the convergence of Criteria Function values towards the optimum value of Criteria Function (1.5) in each sequential phase for both experimental conditions. The hypotheses that differences exist between experimental phases within condition a_2 and within condition a_3 were tested with the non-parametric test for repeated measures, Friedman ANOVA. We report the results of Friedman ANOVA tests in Tables 1 and 2 for experimental conditions a_2 and a_3, respectively, where values of mean rank, sum of ranks, mean and standard deviation of a particular phase are presented.

Based on the Friedman ANOVA test the hypothesis that Criteria Function values sampled in four phases of the experiment under condition a_2 significantly differ [$\chi^2(3, N = 58) = 47.16, p < .000$] can be accepted.

Based on the Friedman ANOVA test the hypothesis that Criteria Function values sampled in four phases of the experiment under condition a_3 significantly differ [$\chi^2(3, N = 58) = 41.42, p < .000$] can be accepted.

For the purpose of comparing the convergence of the decision process between experimental conditions a_2 and a_3 at each parallel phase the nonparametric Mann Whitney *U*-test was performed. On the basis of the Mann Whitney *U*-tests the hypothesis that significant

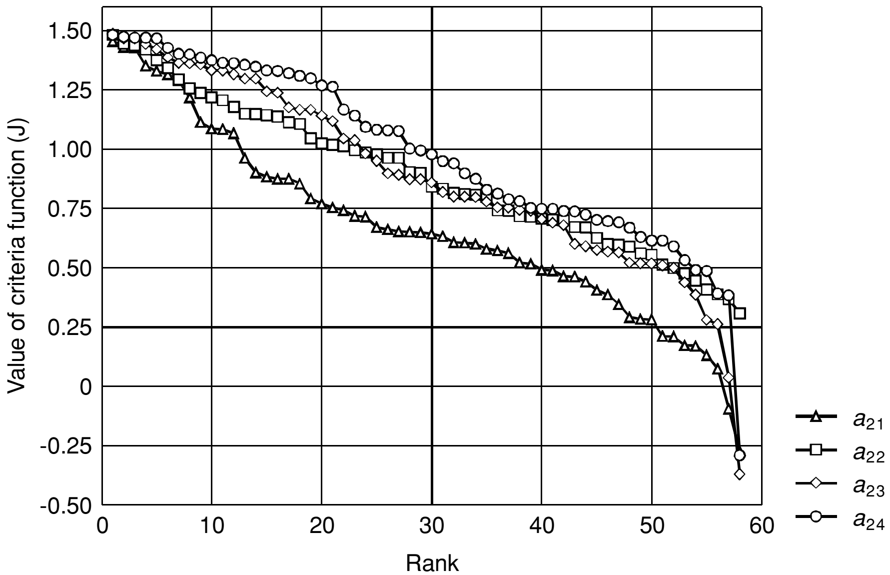

Figure 5. Values of Criteria Function sampled at the 8th, 16th, 24th and 30th minute under experimental condition a_2 where participants were supported by the simulation model.

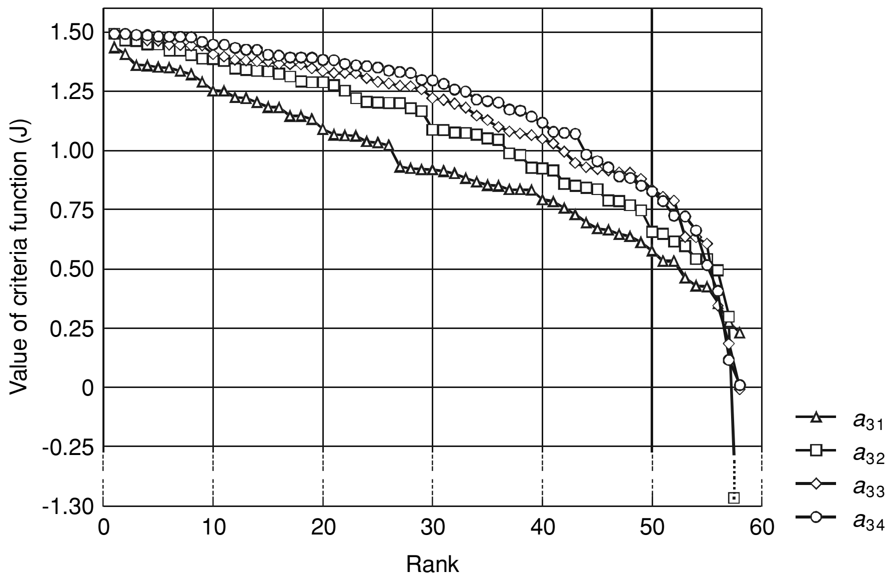

Figure 6. Values of Criteria Function sampled at the 8th, 16th, 24th and 30th minute under experimental condition a_3 where participants were supported by the simulation model and group feedback information.

Table 1. Friedman ANOVA test; Criteria Function values sampled in four phases of the decision process supported by the simulator (a_2)

Phase	Mean rank	Sum of ranks	*M*	SD
a_{21}	1.66	96.50	0.67	0.39
a_{22}	2.39	138.50	0.89	0.31
a_{23}	2.67	155.00	0.89	0.39
a_{24}	3.27	190.00	0.98	0.37

Table 2. Friedman ANOVA test; Criteria Function values sampled in four phases of the decision process supported by the simulator and group feedback information (a_3)

Phase	Mean rank	Sum of ranks	*M*	SD
a_{31}	1.69	98.00	0.93	0.31
a_{32}	2.34	136.00	1.04	0.43
a_{33}	2.87	166.50	1.13	0.33
a_{34}	3.09	179.50	1.17	0.34

differences exist between the values of Criteria Function achieved by the participants under conditions a_2 and a_3 in the first phase (after 8 minutes) $[N_1 = 58, N_2 = 58) = 1021, p < .0002]$, in the second phase (after 16 minutes) $[U(N_1 = 58, N_2 = 58) = 1134, p < .002]$, and in the third phase (after 24 minutes) $[U(N_1 = 58, N_2 = 58) = 1027, p < .0002]$ can be accepted.

Furthermore, we wanted to gain an insight into the dynamics of the decision process supported by the simulation model. Network application enabled us to record every simulation run on the business simulator for each individual participant. The data of participant parameter values, index number and start time of each simulation run with millisecond precision was recorded in the database on the network server for each participant. During the whole experiment 8,120 records of participant parameters were recorded in the server database. Figure 7 shows the frequency of simulation runs (testing) on the simulator in the timeframe of the experiment for experimental conditions a_2 and a_3. The x-axis represents four time intervals of the experiment (8+8+8+6 minutes) marked as Phase 1, 2, 3 and 4. The number of simulation runs performed by the participants is shown on the y-axis.

Figure 7 presents the frequency of simulation runs (testing of the decision parameters) on the business simulator (under conditions a_2 and a_3). It shows that group a_3 had performed more simulation runs in the first 8 minutes of the experiment, while the intensity of decision parameter testing of group a_2 was low during the first 8 minutes. The number of simulation runs performed by group a_2 had increased in the continuation of the experiment (Phases 2, 3 and 4, see Figure 7). Group a_2 had performed more testing on the business simulator in the second, third and fourth phase of the experiment compared to group a_3. However, the cumulative frequency of simulation runs at the end of the observed time (30 minutes) was similar for both groups a_2 and a_3 ($f_{\text{cum}}a_2 = 2{,}925$; $f_{\text{cum}}a_3 = 2{,}930$).

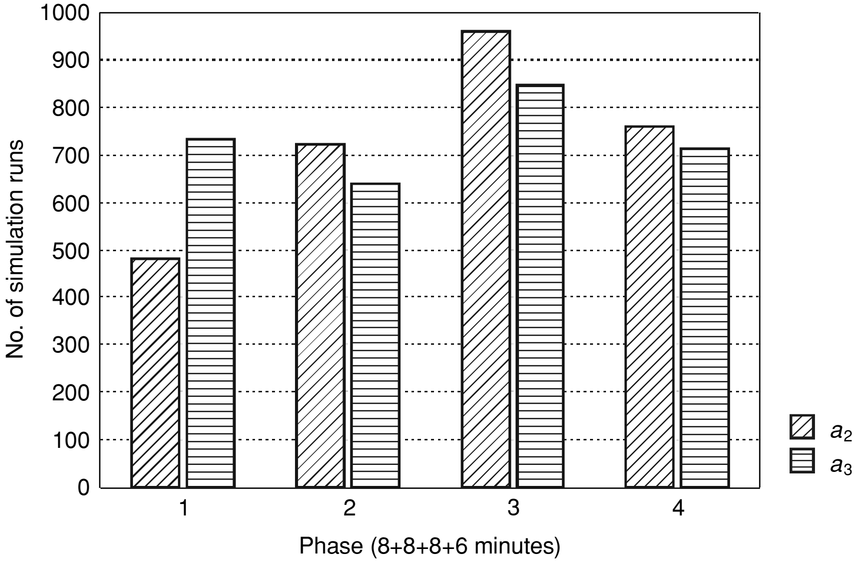

Figure 7. Frequency of simulation runs on the simulator under experimental conditions a_2 and a_3 in the timeframe of the experiment divided into four phases (8+8+8+6 minutes).

Discussion

The development of information and computer technology has a strong impact on intensive research in the field of GDSS and their application in complex problem solving. A significant number of works, as reported by Rouwette et al. (2002), are devoted to the topic of a group approach to problem solving and the organizational learning process based on SD models. However, no study has treated the experimental design such as that described here, which would rigorously consider the impact of SD model application and group feedback on the convergence of Criteria Function value.

The main goal of the presented research was therefore two-fold:

(a) To show the usefulness of the simulation model as a part of GDSS in the solution of the decision problem.
(b) To prove the positive influence of group feedback information on the convergence of Criteria Function value.

The study examined the role of feedback information in the decision process supported by the SD model. The motive for conducting the present experiment was to confirm our previous findings that the application of the simulation model with group feedback information significantly improves the quality and convergence of the decision process compared to when only the simulation model is applied (Škraba et al. 2003). In the present study we performed an experiment with three treatment groups in order to assess the utilization of the simulation model and group feedback information. Furthermore, we recorded the particular values of the observed variable J (Criteria Function) in time intervals and frequency of simulation runs performed on the simulation model for treatment groups a_2 and a_3 in order to compare the dynamics of the decision process.

The results of the study suggest that the simulation model and group feedback information does have a positive impact on the decision process in increasing the criteria function (performance of the participants) and unity of the group. A comparison of mean values of Criteria Function showed that the highest values of criteria function J were achieved under condition a_3 (where the simulation model with group feedback were applied), and the lowest values were achieved under condition a_1 (where the participants solved the decision problem individually without the simulation model). Convergence of the decision process is best presented by the coefficient of variation. The largest convergence of Criteria Function values is observed under condition a_3, followed by the results of condition a_2 and the smallest convergence is observed in the results of decision-making under condition a_1. The experimental results support our first hypothesis that higher values of Criteria Function were achieved by the participants using the simulation model for decision support compared to values of Criteria Function achieved by the participants relying only on the presented CLD. These results signify that the simulation model is an efficient tool in decision support, especially for providing the decision knowledge for strategy evaluation where most decisions are made without such tools. However, one should be aware that the value of many minds is at least partly offset by the costs of group work (Nunamaker et al. 2002), therefore the right balance between group and individual information processing should be considered.

Our second hypothesis that the participants supported by the simulation model and group feedback information achieved higher Criteria Function values than the participants who were supported by the simulation model was confirmed. Convergence of the criteria function demonstrates that a better quality of the decision process in terms of group unity had been achieved under condition a_3 compared to condition a_2. An important observation is that group feedback information influences the change of individual strategies, which also contributes to the learning process. The results show that the participants of the decision group have a definite ability to determine the best among all of the proposed strategies, which were fed back under experimental condition a_3. The observation mentioned is similar to the work of Henry et al. (1996) where a group's ability to evaluate the relative quality of the participating subjects' contributions was indicated. An important attribute of the developed system is the monitoring of individual decisions and an interactive analysis of group activity. The Criteria Function provided support for subjects to determine the best business strategy. This was also important for an experimental design where the goal has to be unambiguously set in order to provide the basis for structural problem solving. The presented methodology complements the group model-building paradigm as described in Vennix (1996). When groups share information in the course of discussion, this is inevitably an active cognitive process (Paulus 1989, p. 9). This comment supports the application of SD environments for the analysis of complex decision tasks. Different strategies, which were tested by the participants, generate different organizational perspectives. Every member of a decision group is allowed to test different alternatives in order to gain a better insight of the problem state. The results achieved verify the cost-benefit of a group decision process using an enterprise simulation model in real business decision processes.

The findings of the repeated sampling confirmed our expectations of convergence of the observed variable towards the optimum value in time. The convergence of Criteria Function values is more evident and consistent under condition a_3, when group feedback information was applied. In fact the average value of Criteria Function observed under condition a_2 is lower at the end of the third phase than at the end of the second phase. This supports our hypothesis that group feedback provides an orientation for the participants in addition to information in the search for the optimum decision parameters set. The simulation run frequencies show that both groups (a_2 and a_3) had performed almost the same number of tests on the simulation model during the experimental time. The fact that both groups performed a similar number of simulation runs would suggest that they both could have arrived at a similar quality of decisions (values of Criteria Function) if the conditions had been the same. The two conditions had been comparable only in the first 8 minutes, and even then the groups had achieved significantly different results. We presume that group a_3, who anticipated sharing their results after the first 8 minutes for the purpose of achieving the common goal, was more motivated. The number of simulation runs performed by group a_3 in the first 8 minutes suggests that the participants were motivated to reach a certain solution by the end of the first phase. On the other hand, the participants of group a_2 had to submit their results after the first 8 minutes and resume with their own individual search and exploration of the simulation model. In the continuation of the experiment group a_3 performed fewer tests on the simulation model than group a_2, which can be explained by the processing of group feedback information. The final decision submitted by group a_3 indicates that the sharing of results during the search for an optimum set of decision parameters influences the cognitive processes of the participants, resulting in higher values of Criteria Function determination.

The results of the current research are important for the development of environments where simulation models are applied for decision assessment. SD models contribute to the enhancement of mental models, which are often the only base for real decision-making. Once SD models are applied in the decision-making process, one should be aware that applied feedback could contribute to a higher probability so that the chosen strategy yields better business results. Implementation of feedback in such decision processes is often obstructed in the real world due to interpersonal relationships which hinder such interaction. The results of the present research therefore provide an important message about the SD models application and feedback role in the group decision process, which should have an impact on the development of tools for supporting the group decision process.

The findings of this study relate to the experimental environment, but nevertheless have important theoretical and practical implications. An understanding of the role of feedback information should contribute to the development of the decision support systems that employ SD models. The proposed methodology has been partially applied in real cases where it proves to be suitable and efficient for decision process support (Kljajić et al. 2000). The knowledge captured in the structure of the model is additionally structured through the search of proper strategies and represents a transformation of the group perception of the process considered and its anticipated behaviour. An understanding of the model and its validity rely on the knowledge of all the participants involved in a particular organizational process, therefore group modelling and business strategy determination exemplify a method which improves the quality of the decision process regarding the criteria function value. It is expected that by implementing the decision support systems using the proposed methodology similar responses should be observed as in an experimental environment, which should result in better economic efficiency of the decision process as well as the process of organizational learning.

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