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The Impact of Information Feedback on Group Decision Making When Applying System Dynamics Models

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Abstract

The present paper addresses the development of a methodology for group decision support by applying system dynamics models. The methodology is based on the system approach, a control paradigm applying simulation and system dynamics. A system enabling the active cooperation of decision subjects was developed. The system developed is user friendly, with regards to visualization and transparency of simulation results. A reference model of the business system was developed and several experiments were conducted with the model. The experiments considered the task of strategy determination with an explicitly defined criteria function. The criteria function was explicitly defined in order to increase the level of experimental control. Experiments were conducted under different conditions, which differed in model application and group information feedback. Qualitative judgment of the business strategy parameters, application of a simulator and application of a simulator with group information feedback were considered. 105 subjects, senior students, participated in the experiments. The analysis of the results, as well as hypotheses testing was conducted using statistical methods. The research treats the influence of group feedback information on the group decision process in detail. The hypothesis that positive group feedback information influences the convergence of the decision process was proven. The proposed system introduces an improvement in classical decision support systems and provides better results in terms of the criteria function value.

Key words: decision process, system dynamics, multicriteria group decision making, decision support system, modeling, simulation methodology

1. Introduction

Simulation models developed by System Dynamics (SD) methodology are important tools for strategy development and decision support. The methods of scenario creation and selection applying multicriteria decision functions were developed in recent research (Kljajic et al., 2000a; Kljajic et al., 1996; Larsen et al., 1997). The present paper is also the continuation of research conducted in the field of exploration of SD models, which was presented at the SDS conference in Bergen (Kljajic et al., 2000b). A significant finding is that every important organizational decision requires the cooperation of many decision-makers and therefore, management relies on decision groups. The new approach addressing the development of organizational strategy considers collective understanding of organizational processes (Isaacs 1999). In comparison to other methods, dynamical analysis of a considered system behavior is the main advantage of testing the strategy with the aid of simulation scenarios. Simulation scenarios allow us to consider incomplete, unreliable and subjective information. The ideal of learning organization can therefore be approached with the models of SD. Planning with simulation scenarios differs from other decision methods mostly in its dynamical analysis of uncertain situations and support of man (decision maker) – machine interaction. Scenarios represent the unified language for mediating new ideas and improving business decision analysis (Heijden 1996). The implementation of the group support systems as a tool for strategic decision-making results in positive business outcomes (Dennis et al., 1997) and therefore, improves the decision process.

Decisions in organizational systems generally rely not only on the individual but also on the group of experts working in a specific field (Beach 1997; Tung 1987), where knowledge elicitation is a main concern (Ford and Sterman 1998). Decisions made in the groups are supported with a larger knowledge base, more experience and many different views on account of their nature. The research in the field of group decision support systems covers different technical and organizational fields (Briggs et al., 1998; Fjermestad 1998). The group as a whole understands the considered system better and provides synergetic effects (Hale 1997). The group support system improves group work and reduces the number of conflicts (Caouette and O'Connor 1998). Nevertheless, all characteristics of the group decision process must be carefully considered (Bohlmann 1996). A higher level of knowledge and coordination between group members is indicated in the groups. However, concurrent reception of information and interaction between group members is of great importance (Tubbs 1998), and is considered in the presented research.

Convergence of the criteria function for solving different decision problems with SD models in the groups was analyzed in detail. Experiments under different conditions were conducted in order to analyze the influence of information feedback and different methods of work in the decision process. The goal of the conducted experiments was to acquire knowledge of the group decision process supported with the SD model and the influence of feedback information on the decision process. The hypothesis of the influence of group feedback information on the decision process was formulated as the starting point of the research. The objective of the research was to determine the methodology, which would improve decision processes based on SD models and verify methodology with experiments. The hypothesis was tested on the model of production where complexity was not too high in order to prevent the influence of high complexity on the experimental performance. The appropriate level of complexity was experimentally confirmed with a statistical test. The criteria function was explicitly determined to concisely define the target of the system.

The present research connects many research fields, such as: SD, multicriteria decison making and group support systems. Although the fields differ they have a common point, which is the support of the decision-maker. Nevertheless, the developed methodology should be applicative on an arbitrary dynamical model.

Analysis of the results of different modes of implementation of SD models should contribute to the development of more efficient group decision support systems. The main concern in the present paper focuses on the experiments, where the criteria function and the model are both explicitly stated. The results of the experiments show that implementation of feedback information in the decision support system significantly influences decision processes.

Two experiments were conducted on two different SD models. The first experiment was described in Kljajic et al. (2000b) and was the starting point for further research. This experiment showed positive results in cases where feedback information was applied (Skraba 2000). Since the level of complexity in previous research was relatively high, which could have confused decision-makers, it was decided to carry out a new, less complex experiment. This reduced the influence of possible poor understanding of the problem or experimental results. The second experiment, which is described later in the paper, included the following activities: Decision makers in the experiment created a business strategy based on the explicitly stated criteria functions, which enabled more accurate analysis of decision process dynamics. The business strategy was defined as a set of values of user settable model parameters. There were three blocks of experiments conducted under different conditions. The criteria function was stated in the form of linearly sum.

Similar problems of interconnecting SD methodology and group decision support systems can be found in Richardson and Andersen (1995), where group support at the modeling process is described. The impact of a group support system on the formation of knowledge is described in Kwok and Khalifa (1998). Results of the study show that the application of a group support system contributes to a higher level of understanding of problem states compared to other methods, and contributes to the knowledge of group process research and analysis (Andersen et al., 1996). Better understanding improves individual contributions to the final result of the decision process through the application of group techniques in the process of model building (Vennix 1996). Nevertheless, the problem of reality in the design of the research is present and should be seriously considered (Chun and Park 1998).

The influence of informational feedback on the decision process, as described in previous researches, was not experimentally verified. The present research describes the analysis of feedback information influence on the decision process and forms a new view of the design of modern decision support systems based on SD models.

2. Methodology

The model of the present task can be described with sets *M*, *J* and *L*, where *M* is the mathematical model, *J* is the set of criteria, and *L* is the set of limitations. The main task of efficient management is to develop methods to determine optimal control based on the known *M*, J and *L*. Figure 1 shows the model of production as the black box with input parameters u_1, u_2, u_3, u_4 (where u_1 is Product Price, u_2 is Salary, u_3 are Marketing Costs and u_4 Desired Inventory) and three different experimental conditions a_1, a_2, a_3. Model M of the system represents object representation in the form of the state equation:

$$x(k+1) = f(x(k), u(k), a) \qquad (1)$$

where $x(k)$ represents the state of the system, $u(k)$ the control vector or alternative strategy and a the experimental conditions. Model M represents the system on which the decision experiment was conducted.

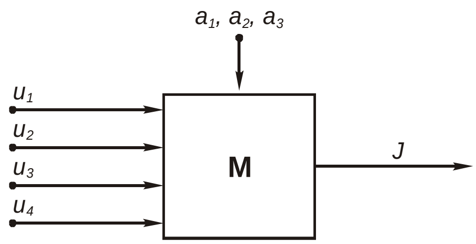

Figure 1: Model with Input Parameters at Different Experimental Conditions

Criteria function J is stated in the form of the linearly weighted sum:

$\max_{u \in U} J = \sum_{i=1}^{4} w_i J_i(a_j)$, where the sum of weights equals $\sum_{i=1}^{4} w_i = 1$.

The efficiency of the selected strategy was determined according to the results of the decision task, which was stated as:

Find the appropriate strategy $u \in U$ with model M to achieve the maximum possible value of criteria function J, by setting the values of parameters of the strategy $u \in U$ within the parameter limitations at different experimental conditions a_i.

The experiment was conducted in three different experimental situations: a_1) determining the business strategy according to individual perception of the problem statement, where the decision-maker is not supported by the result of the model simulation, a_2) determining the strategy with the aid of a simulation model, and a_3) determining the business strategy with the aid of a simulation model and continuous group feedback information.

The following hypothesis is stated for the conducted experiments:

> The results of the decision-making process conducted by experimental condition a_3 are better than the results gathered by experimental condition a_2, and these are better than the results of experimental condition a_1 in terms of criteria function values and decision process convergence. Stated differently, the best results of the decision process are gathered when group feedback information is introduced. These results are better than in cases where the decision is based only on individual experience with a simulation model. The lowest values of results are indicated for the case where only the qualitative knowledge of the problem is used, thus the formal model contributes to better decision making in comparison to the process where no formal model is used.

The stated hypothesis determines the goal of research and will be statistically analyzed. Business strategy determination is one of the common decision tasks in real systems, therefore the problem addressed is of great importance for applying SD models.

2.1 Implementation of Feedback Information

Different simulation scenarios, which in our case represent business strategies, are designed by the variations of the set of the parameter values. These strategies were evaluated with the linearly weighted sum of a muticriteria decision function. The group decision process supported with the SD models is shown in Figure 2. Subjects participating in the decision process (S_1, S_2, ... S_n), used individual decision support systems (IS_{n1}, IS_{n2}, ... IS_n), that enabled testing of business strategies on the model. Information about results of individual systems were fed back into the group support system through the feedback loop I_f that provided the group's view of the decision problem. GS represents the system for providing feedback information to participants in the form of aggregation of the results.

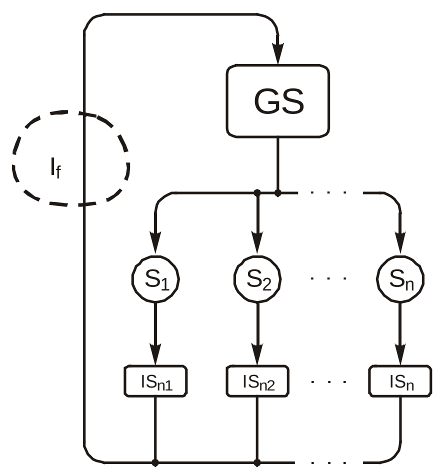

Figure 2: Expert Group Decision Support System Applying SD Models –Simulators

All members of the expert group involved were able to test the different alternatives, in order to gain a better insight into the problem stated. Decision group members were also able to use feedback information from the group in its raw or aggregated form.

2.2 Subjects

One hundred and five senior graduate students (47 females and 58 males) from the University of Maribor participated in the research in order to satisfy the requirements of their regular study program. The students were randomly assigned to six groups, which were then assigned to work under one of the three experimental conditions a_1, a_2, or a_3.

2.3 SD Model of Production with the Model of Multicriteria Decision Function

The Causal Loop Diagram (CLD) in Figure 3 shows the structure of the production model, which was used in the experiment of business strategy determination. The model consists of classical sub models of SD (Forrester 1973; Sterman 2000; Hines 1996). The model of production implements the structure production – workforce – product life cycle. CLD shows that the Product Price positively influences the Income. However, as the prices increase, the Demand decreases below the level it would otherwise have been. If the Marketing Costs increase, the Demand increases above what it would have been. The production system must provide the proper inventory level to cover the demand, which is achieved with the proper Desired Inventory. Surplus inventory causes unwanted costs due to warehousing. The workforce is dependent on the production volume and its productivity, which are stimulated through Salaries. The model is controlled with a user-friendly interface in the form of a business simulator.

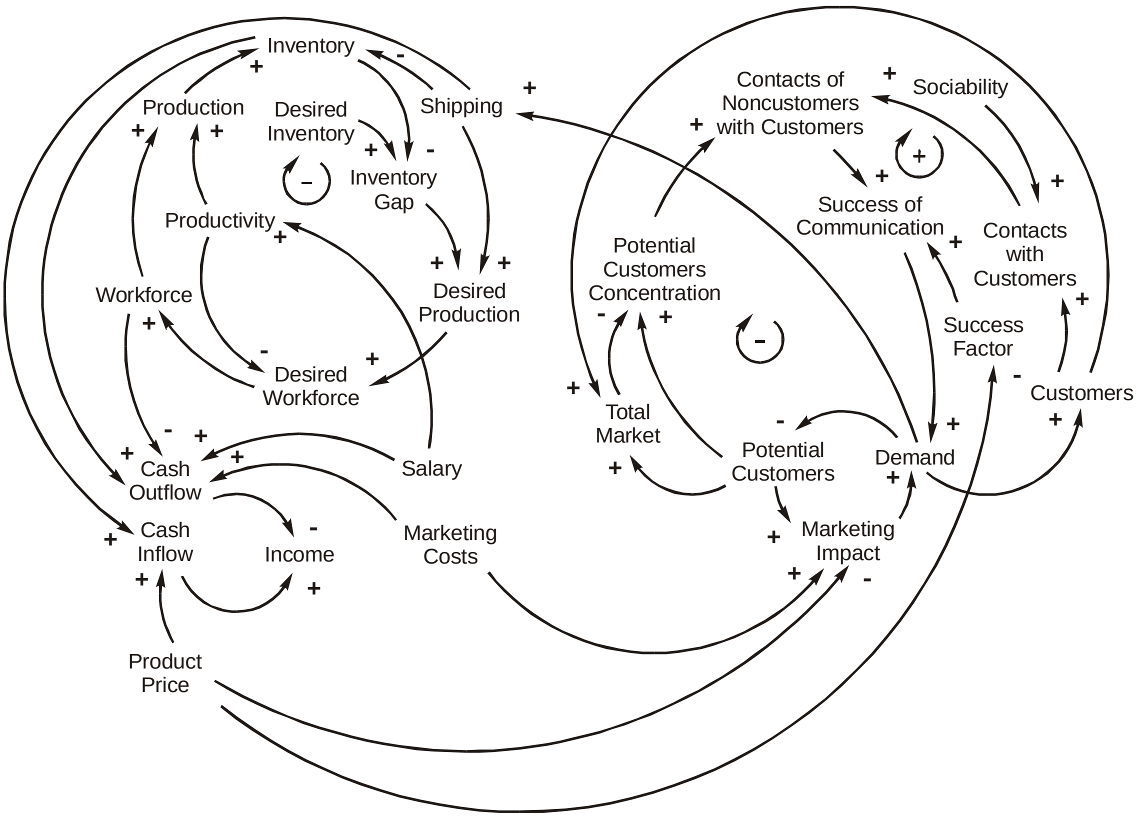

Figure 3: Causal Loop Diagram of Production Model

The component of the model was also the sub model of the multicriteria decision function, which was used for strategy evaluation. The criteria function in the expanded form of equation (1) is stated as:

$$J = \frac{d_0 + \sum_{i=0}^{t_k} d(t_i)}{c} w_1 + \frac{p_0 + \sum_{i=0}^{t_k} p(t_i)}{o_0 + \sum_{i=0}^{t_k} o(t_i)} w_2 - \frac{s_0 + \sum_{i=0}^{t_k} s(t_i)}{p_0 + \sum_{i=0}^{t_k} p(t_i)} w_3 - \frac{v_0 + \sum_{i=0}^{t_k} v(t_i)}{p_0 + \sum_{i=0}^{t_k} p(t_i)} w_4 \, , \qquad (2)$$

where d_0 is the initial value of Income, $d(t)$ is the Income function where $d(t) = p(t) - o(t)$ where $p(t)$ is the Revenue function, $o(t)$ is the Expenses function, t_k is the final time of observation, c is the Capital, w_1, w_2, w_3 and w_4 are the weights values, p_0 is the initial value of Revenues, o_0 are the initial Expenses, s_0 are the initial workforce expenses, $s(t)$ is the workforce expense function, v_0 are the initial inventory costs, and $v(t)$ the inventory costs function.

Actual values of weights were determined as the constant factors. The criterion description and weight values are shown in Table 1.

Criterion	Description	Weight	Value of Weight
J_1	*Capital Return Ratio*	w_1	0.50
J_2	*Overall Effectiveness Ratio*	w_2	0.35
J_3	*Workforce Effectiveness Ratio*	w_3	0.10
J_4	*Inventory Income Ratio*	w_4	0.05

Table 1: Criterions and Weights

The block diagram of the multicriteria evaluation function used at the simulation scenario evaluation is shown in Figure 4. The model incorporates cumulative values of Income, Cash Outflow, Costs of Workforce, and Warehousing Costs, as well as the values of the Overall Effectiveness Ratio, Workforce Effectiveness Ratio, Inventory Income Ratio and Capital Return Ratio.

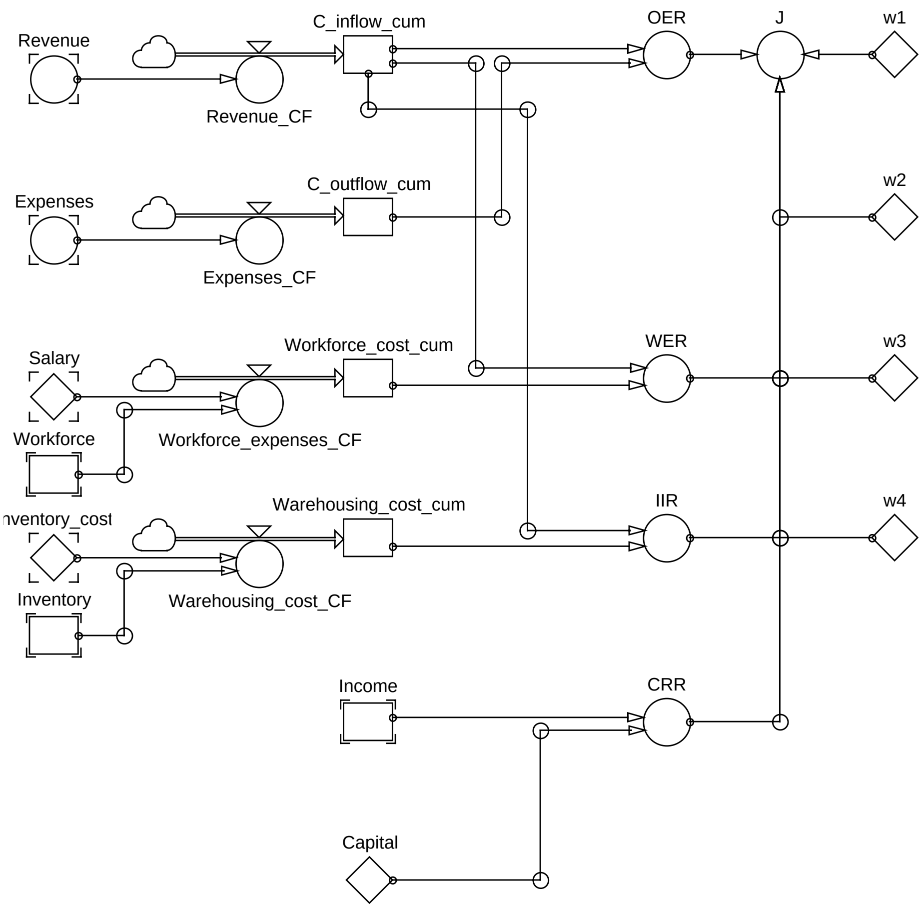

Figure 4: The Model of Multicriteria Decision Function in Powersim

The maximum value of the criteria function was determined in order to analyze the results of the experiments. Optimization of the model was conducted with Powersim Solver. Optimization was completed using two methods: incremental and genetic algorithms. The maximum value of the criteria function was determined as $J = 1.5$. The procedure of searching for the maximum value of the criteria function was time consuming and not operational (several hours) where on the other hand, the search for the best strategy with the proposed system yielded a better end result in only ½ hour. This was probably only a coincidence but speaks for the potential power of the proposed system.

2.4 Description of the Experimental Task

The experiment was conducted under three different experimental conditions. The experimental conditions can be briefly described as follows:

Experimental condition a_1 assumes the individual assessment of the decision-maker at the determination of the business strategy. The decision is made without a formal model. Only the "mental models" are applied i.e. the subject has to select the best alternative according to the perception of the subjective problem. After the experiment was completed, the simulation with the chosen set of parameter values was run on model M in order to obtain the value of criteria function J for each subject.

Experimental condition a_2 assumes the individual application of the SD model at the determination of the business strategy. The decision-maker forms the strategy according to the developed SD model.

Experimental condition a_3 assumes the application of the SD model with group feedback information. Decision-makers get feedback on the defined strategies of all the participants in group $S_s = \{u_1, u_2, u_3, u_4\}; s = 1,2,...n$ as well as the aggregated values of the decisions in the form

of average values of parameters $\overline{S} = \left\{ \frac{\sum_{i=1}^{n} u_{1_i}}{n}, \frac{\sum_{i=1}^{n} u_{2_i}}{n}, \frac{\sum_{i=1}^{n} u_{3_i}}{n}, \frac{\sum_{i=1}^{n} u_{4_i}}{n} \right\}$.

The time of conducting the experiment was ½ hour for all three experimental conditions. The efficiency of the decision process was determined according to the multicriteria function, which was explicitly stated.

Decision-makers were introduced to the experimental problem of determining a business strategy according to the stated criteria function. The presentation of the decision problem was prepared in the form of an electronic presentation. The structure of the considered system was presented and the main parameters in the model were explained. The evaluation criteria for the business strategies were also considered. The work with the simulator was explained. The participating subjects were familiar with SD simulators, therefore working with the simulator was not a technical problem. Every decision-maker formed a strategy according to the stated problem.

Decision-makers stated their business strategy in the form of values with the following parameters: Product Price, Salary, Marketing Costs and Desired Inventory. Certain limitations of parameter values had to be met, as for example, the maximum warehousing capacity. Criteria function J was stated in the form of a linearly, weighted sum. The criterions considered in the strategy statement were: Overall Effectiveness Ratio, Workforce Effectiveness Ratio, Inventory Income Ratio, and Capital Return Ratio.

The proposed experiment was based on the model, which was not very complex but also not trivial from the decision point of view. The decision problem addressed, consisted of main elements, which were representative for real decision processes: input parameters, limitations, criteria function, set of output values, and dynamics provided by the SD model.

3. Results

The results of the decision process conducted under experimental conditions a_1 (ten participants, N$_1$=10; the group marked G_1), a_2 (fifty-two participants in three groups, N$_2$=52; the groups marked G_2, G_3 and G_4), and a_3 (forty-participants in two groups, N$_3$=40; the groups marked G_5 and G_6) are shown in Figure 5. The values of criteria function J in Figure 5 are ordered from highest to lowest (Y-axis). The X-axis shows the relative number of participating subjects (value 1 means 10 for the group of results gathered under experimental condition a_1, 52 for experimental condition a_2 and 40 for a_3). Results gathered from experimental condition a_1 are the lowest; their average is $\bar{J}_{a_1} = 0.588$. Average results gathered under experimental condition a_2 are higher than the results gathered under experimental condition a_1 ($\bar{J}_{a_2} = 1.076$), while the standard deviation is smaller ($\sigma_{a_2} = 0.317$ for a_2 and $\sigma_{a_1} = 0.412$ for a_1). The highest values for criteria function were gathered under experimental condition a_3 ($\bar{J}_{a_3} = 1.386$), while the deviation was the smallest ($\sigma_{a_3} = 0.073$). Maximum values of the criteria function were similar for experimental conditions a_2 and a_3. Nevertheless, values declined more rapidly for experimental condition a_2 with a larger relative number of participants.

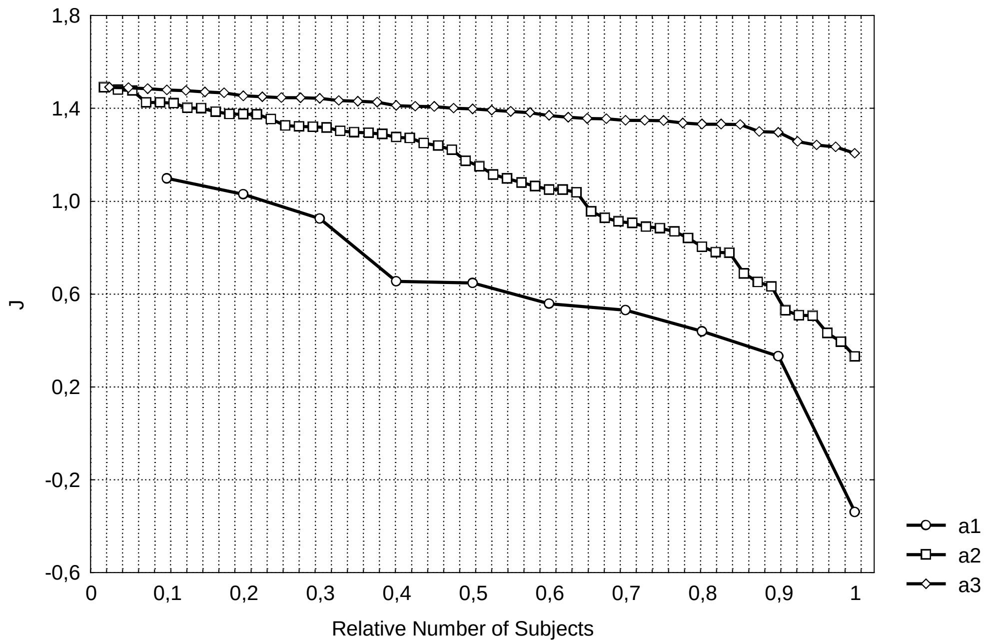

Figure 5: Values of Criteria Function J for Different Experimental Conditions a_1 (N$_1$=10), a_2 (N$_2$=52), and a_3 (N$_3$=40). The lowest values of criteria function were gained under the experimental condition a_1 where qualitative assessment was applied. Results marked a_2 were gathered with the aid of an SD model, and the results marked with a_3 were gathered under experimental conditions where group information feedback was applied.

In order to analyze the obtained results, the contrast analysis ANOVA (Winer 1970), the following statistical hypotheses were tested:

a) There is no significant difference in the results of the decision process conducted under experimental condition a_2 (individual application of SD model at the determination of the business strategy; groups G_2, G_3 and G_4), and experimental condition a_1 (individual assessment of the decision-maker at the business strategy determination with no formal model; group G_1), which is expressed with contrast ψ_1 ; $H_0 : \bar{J}_{G_1 a_1} = \frac{\bar{J}_{G_2 a_2} + \bar{J}_{G_3 a_2} + \bar{J}_{G_4 a_2}}{3}$

b) There is no significant difference between the results of the decision process conducted under experimental conditions a_2 and a_3 (application of the SD model with group feedback information; groups G_5 and G_6), which is expressed with contrast ψ_2 ; $H_0 : \frac{\bar{J}_{G_2 a_2} + \bar{J}_{G_3 a_2} + \bar{J}_{G_4 a_2}}{3} = \frac{\bar{J}_{G_5 a_4} + \bar{J}_{G_6 a_4}}{2}$.

c) There is no significant difference between the results of the decision process conducted under experimental conditions a_1 and a_3, which is expressed with contrast ψ_3 ; $H_0 : \bar{J}_{G_1 a_1} = \frac{\bar{J}_{G_5 a_4} + \bar{J}_{G_6 a_4}}{2}$.

The critical value for rejecting the null hypotheses is $F_c(1,99) = 11.502$, with a risk of $\alpha = 0.001$. Calculated values of F – statistics for three determined contrasts ψ_1, ψ_2 and ψ_3 were larger than the critical value ($F_{\psi_1} = 28.972$, $F_{\psi_2} = 34.207$ in $F_{\psi_3} = 75.435$). Therefore, the null hypotheses were rejected.

According to the tested hypotheses, it can be concluded that significant differences exist between the results of the decision process conducted under different experimental conditions a_1, a_2, and a_3. The comparison of means shows the following order of criteria functions value: $\bar{J}_{a_1} < \bar{J}_{a_2} < \bar{J}_{a_3}$. The experimental condition where the individual assessment of the decision-maker at the business strategy determination without a formal model was applied, experimental condition a_1, resulted in the lowest average value of criteria function. A higher average value was obtained with the experimental condition of individual application of the SD model at the determination of the business strategy a_2. The highest value of criteria function was gained under the experimental condition a_3, where SD models were supported by group information feedback.

The Mann-Whitney nonparametric U-test was also used for the comparison of a groups' results (experimental conditions a_1, a_2 and a_3). The Mann-Whitney U test is a nonparametric alternative to the t-test for independent samples. The Mann-Whitney U test assumes that the variable under consideration was measured on at least an ordinal (rank order).

The following null hypotheses and corresponding working hypotheses for comparisons between values of criteria functions J gained under experimental conditions a_1, a_2, and a_3 were tested: $H_{0_{(12)}}: \bar{J}_{a_1} = \bar{J}_{a_2}$, $H_{1_{(12)}}: \bar{J}_{a_1} \neq \bar{J}_{a_2}$, $H_{0_{(13)}}: \bar{J}_{a_1} = \bar{J}_{a_3}$, $H_{1_{(13)}}: \bar{J}_{a_1} \neq \bar{J}_{a_3}$ and $H_{0_{(23)}}: \bar{J}_{a_2} = \bar{J}_{a_3}$, $H_{1_{(23)}}: \bar{J}_{a_2} \neq \bar{J}_{a_3}$.

The results of three tests for average criteria function values J, with the nonparametric Mann-Whitney U-test for different experimental conditions a_1, a_2, and a_3 rejected all three null hypotheses with the risk level $\alpha = 0.01$.

According to the results of the Mann-Whitney nonparametric U-test for differences in the means between values of criteria function J gained under experimental conditions a_1, a_2, and a_3, the working hypotheses of significant differences between experimental conditions can be accepted. The main emphasis is on the difference between experimental conditions a_2 and a_3, where SD models are used without and with group informational feedback. These two groups have the same technical means to address the stated decision problem. Nevertheless, the small improvement in the decision support system, such as the implementation of feedback significantly improved the efficiency of the decision process. The comparison of the means indicates the following order of criteria functions value: $\bar{J}_{a_1} < \bar{J}_{a_2} < \bar{J}_{a_3}$.

4. Conclusion

The article describes estimation of information impact on the decision process based on SD models, where group feedback information is implemented. The hypotheses of system effectiveness were tested in an experimental environment on interactive simulation models with experimental groups. The hypothesis of effective human – decision support system connection was confirmed. The criterion of complexity was considered at the design of the experiment since this is one of the important factors in such experimental designs.

The decision support system incorporating SD models was developed with the goal of analyzing the impact of group feedback information on the decision process. The impact of informational feedback was analyzed with statistical tools. Results indicate significant differences between different experimental conditions of conducting the decision process. The advantage of the group decision process supported with group feedback information is shown in the convergence of the decision process, which is higher when feedback information is applied.

A reference SD model was developed with the purpose of providing an appropriate complexity model for solving decision tasks. The multicriteria decision function was used at the phase of business strategy determination, which enabled the structured solving of the stated decision problem. Preceding research showed that an explicitly stated criteria function is needed for proper experiment design. This is also the crucial point for quantitative analysis of experimental results, which, in our case, gave the insight of dynamics, or decision process, which is dependent on different experimental conditions of conducting the decision process.

In the experiment, 105 subjects divided into six groups participated. They worked under different experimental conditions for conducting the decision process. Differences between the results gained under the experimental condition a_1 (individual assessment of the decision-maker without the formal model) and experimental condition a_2 (individual application of the SD model) and a_3 (applied SD model with group feedback information) were statistically significant at the significance level $\alpha = 0.001$, which was tested with ANOVA contrast analysis. The comparison of average values showed that the largest values of criteria function J were obtained when group feedback information was applied – experimental condition a_3, and the lowest values were obtained in the case where no formal model was applied (a_1).

The Mann-Whitney nonparametric U-test was used for the comparison of the groups' results (experimental conditions a_1, a_2, and a_3) as an additional test to increase analysis confidence. The hypotheses of difference between experimental conditions were accepted at risk level $\alpha = 0.01$. Statistical analyses indicate that group feedback information significantly impacts on the group decision process supported by the SD model. The influence of information feedback results in higher convergence of the decision process i.e. the consensus of the group at the process of determination of the business strategy. Feedback information is therefore the main component in the efficient decision support system based on the SD model. Experimental results show that implementation of SD models at decision-making improves the decision process, while introduced feedback information contributes to further improvements of the process. The effect of increasing system efficiency can be explained with the introduction of additional information into the system, which is the main component of learning and the system's control.

The developed system, promises better results with regard to criteria function values. As the best principle of controlling the decision process, experimental condition a_3 was selected (group information feedback). Further development of similar systems should consider the findings of the impact of informational feedback. The proposed methodology based on SD models, which incorporates group feedback information, contribute to improvements of the group decision process. The methodology was experimentally tested and proves the effectiveness of the system. Nevertheless, the application on real cases is needed for further development and experimentation.

5. Acknowledgement

This research was supported by the Ministry of Science and Technology of the Republic of Slovenia (Program No. PP-0586-501).

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