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Effects of planning on the garbage-can decision processes: a reformulation and extension

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Abstract. A computer simulation, based on the garbage-can decisionmaking process, is presented in order to investigate effects of making plans and of two other organizational characteristics — namely, decision cost and problem disutility — on the behavior of complex systems. In this simulation a three-factor factorial design was implemented where decision cost, problem disutility, and planning investment were considered in terms of combinations of six levels of these factors. The results suggest that all three factors have statistically significant effects on the behavior of the complex system. In particular, decision cost and problem disutility tended to have effects counter to each other, whereas planning resulted in more efficient decisionmaking, but at the cost of resolving fewer problems.

1 Introduction

Though faced with a bewildering set of decisions, planners are confident in many cases that planning affects not only behaviors of organizations, but also outcomes. There is, however, little backing for this confidence; this is particularly true in urban planning. Organizations and cities are both complex systems and we are just beginning to understand their properties. We know surprisingly little about planning processes and how they affect organizations and urban development (Hopkins, 2001). One approach to gaining understanding of planning in organizations and urban development, or of complex systems in general, is to develop and analyze simulation models. The simulation presented here builds on the garbage-can model of organizational choice behavior presented by Cohen et al (1972), because that model describes realistically "an environment characterized by complex interactions among actors, solutions, problems, and choice opportunities" (March, 1994, page 198) and can be extended to represent real planning situations (Hopkins, 2001). My objective in this paper is to develop simulations with which to investigate the implications of introducing planning behaviors into complex systems evolving in time, but not space. The primary focus is on devising simulations from which we might discover general principles about the effects of planning phenomena on systems behavior. Though I could construct from scratch new, simpler, models than the garbage-can model in order to examine the effects of planning specifically, such models might lack the internal and external validity of complex environments which the garbage-can model seems to possess. I discuss in section 5 how such a dilemma can be resolved.

I consider, therefore, this paper as a sequel of my previous work on planning effects of garbage-can decisionmaking processes by reporting the results from a simulation proposed in that work (Lai, 1998, pages 100 – 101). In contrast to that work on organizational choice behavior, where decisionmaking and implementation incur no cost and problems do no harm, my approach here is to relax that assumption by simulating the same garbage-can model, but with some modifications and different interpretations. In the next section I depict conceptually the working of the garbage-can model. For detailed descriptions of how the garbage-can model works, and how planning can be incorporated in that model, the reader is recommended to consult

Cohen et al's original article (1972) and my previous work (Lai, 1998), respectively. I then introduce the simulation design for the present purposes and report the results, as well as discussing some implications in the next three sections.

2 The garbage-can model

The garbage-can model was originally designed to describe organizational choice behavior under three conditions: problematic preferences, unclear technology, and fluid participants (Cohen et al, 1972). Put simply, four streams of elements flow into the organizational system in a relatively independent way with problems, decisionmakers, and solutions thrown into choice opportunities, or 'garbage cans', and decisions are made. No cost or harm, as measured by disutility, are incurred by decisions and problems in the original formulation. Figure 1 shows a simplified, conceptual diagram of the garbage-can model.

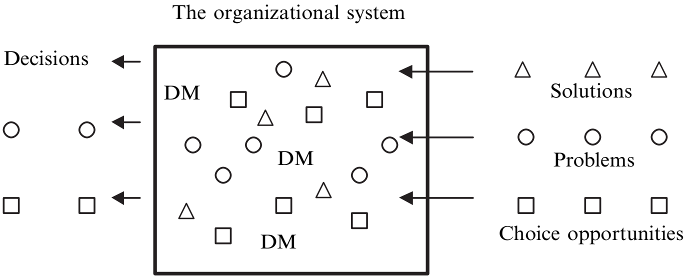

Figure 1. A conceptual diagram of the garbage-can decisionmaking process (DM are decisionmakers).

In the simplified diagram, the inputs of the model are the sequences of problems, solutions, and choice opportunities; the outputs are decisions. A system of organization composed of decisionmakers is facing incoming problems, solutions, and choice opportunities in time. When the three streams of elements flow into the system in an unpredictable, random way, decisionmakers, solutions, and problems are thrown into garbage cans where decisions may or may not be made. If a decision is made in a garbage can as an output of the system, the problems and choice opportunities attached to the garbage can disappear and leave the system.

In the original garbage-can model, decisions and problems incur no cost or harm. This is not the case in real-world situations. The making and implementation of decisions are costly, and problems reduce people's levels of satisfaction. Making decisions to build highways and infrastructures costs, among other things, time, money, and energy; floods may kill households or render them homeless. However, if we incorporate some cost indices into these elements, the garbage-can model captures, at least partially if not completely, some characteristics of the realistic complex planning processes.

3 Simulation design

As in my previous work (Lai, 1998), I define planning narrowly here, in part to control entry times of choice opportunities into the garbage-can model. But, instead of ignoring decision cost and problem disutility, as in the original garbage-can model, these are both considered in the present simulation. In addition to the four internal variables originally considered in Cohen et al's (1972) formulation (that is, net energy load, access structure, decision structure, and energy distribution—which are explained below) forming eighty-one ($3 \times 3 \times 3 \times 3$) stereotypes of simulation runs, in the present simulation I add three control factors to investigate their effects on the system—decision cost, problem disutility, and planning investment—forming a three-factor factorial design with the observation number equal to one for each combination of the six levels of the three factors. The terms 'garbage can', 'choice opportunity', and 'decision situation' are used interchangeably in the following depiction.

'Energy load' implies the amount of resources measured as energy required to solve a problem. There are three types of energy load: light, medium, and heavy. 'Access structure' describes which problem could be solved in which decision situation. 'Decision structure' regulates which decisionmaker is able to participate in which decision situation. There are three types of access structure and of decision structure: hierarchical, unsegmented, and specialized. 'Energy distribution' prescribes how resources are allocated to decisionmakers. Three types of energy distribution available to decisionmakers are considered: more important people with more energy (that is, the energy available decreases from the first to the last decisionmaker), less important people with more energy (that is energy available increases from the first to the last decisionmaker), and equal energy (that is all decisionmakers have the same amount of energy). The combination of the levels of the internal variables is reminiscent of the typology of various organizations with different characteristics. For example, problems may be more easily solved in one organization, such as a university, than in another, such as a construction firm. Sampling across these various types of organizations, as in the present simulation, may yield explanations which can be generalized.

The logic of the simulation design is equivalent to that of the design of factorial experiments with three factors, each combination of the control factors having only one observation, which can be found in any experimental-design text (see, for example, Kirk, 1982; Winer, 1971). Hence the validity of the experimental design and the associated analyses applies here (see, for example, Scheffé, 1959, pages 98–106). Instead of using real subjects, in the simulation design for each combination of the levels of the three factors each set of the eighty-one stereotypes of the simulation are run once, given a predetermined sequence of problems and choice opportunities. The values of eleven statistics, which are discussed below, are recorded across the eighty-one stereotypes, forming one set of observations concerning the characteristics of the organization. A three-way analysis of variance (ANOVA) can be carried out for each statistic to examine the main effect of each factor. Note, however, that the interaction term is neglected in the model for simplicity; "hence all sources of variation other than main effects are considered to be part of the experimental error" (Winer, 1971, page 394). Thus the conclusions obtained from the simulation can be generalized.

More specifically, let us assume that each decision made in a garbage can incurs some cost, between zero and one, associated with that garbage can. These costs are assigned randomly a priori to the ten choice opportunities, each arriving in one of the first ten time steps. Assume also that each problem is associated with an amount of disutility between zero and one, which is also assigned randomly a priori. The ten randomly generated decision costs are 0.70, 0.84, 0.72, 0.31, 0.16, 0.33, 0.47, 0.25, 0.83, and 0.28; whereas the twenty disutilities are 0.23, 0.03, 0.86, 0.20, 0.27, 0.67, 0.32, 0.16, 0.37, 0.43, 0.08, 0.48, 0.07, 0.84, 0.06, 0.29, 0.92, 0.37, 0.78, and 0.33. One might argue that the random assignment of costs and utilities can best be characterized by a Monte Carlo simulation. I suspect that this would make the simulation more complicated without producing any more useful insights, given the validity of the experimental design as just depicted.

Planning investment is represented as the number of time periods and choice opportunities considered for comparisons. In particular, choice opportunities that have neither been activated nor arisen, but are within the time horizon of the prediction, are compared based on a criterion of energy deficit to be activated or enacted for each time period. Thus some degree of interdependence among decisions is reached through this formulation. Energy deficit is the difference between the amount of energy required to make a decision and that available from the associated decisionmakers in the previous time step.

Following my previous work (Lai, 1998), in the present simulation there are in total ten choice opportunities each occurring in one of the first ten time steps. Five levels of planning investment are considered in the present simulation: 0, 2, 4, 6, 8; and ten time step decision horizons in which choice opportunities entering the system are compared. 'Decision horizon' is defined here as the number of time steps over which the planner can look ahead from the current time step. In order to evaluate, as a control, how the variations of focus on the two additional factors of decision cost and problem disutility would affect the behavior of the system, different weights are assigned to decision cost and to problem disutility. These weights can also be considered as the relative importance of the two factors to the planner, and set to real numbers between zero and one, with increments of 0.2. Thus we have decision weights and problem weights set to 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0.

There are in total 216 (6 × 6 × 6) combinations of different levels of the three factors (six decision horizons or planning investments, six decision weights, and six problem weights). Each of the 216 combinations represents a set of particular levels of planning investment, decision-cost weight, and problem-significance weight. Statistics are recorded by summing across all 81 stereotypes of simulations for all 216 combinations of the factorial levels. Table 1 summarizes the simulation design.

Table 1. The factors and variables of the simulation design.

Controlling factors	Internal variables	Number of levels	Total number of observations
Planning investment Decision horizons	net energy loads (three types) access structures (three types) decision structures (three types) energy distributions (three types)	six: 0, 2, 4, 6, 8, and 10 (across all 81 combinations of values of internal variables)	216 (6 × 6 × 6) combinations of levels (across all 81 combinations of values of internal variables
Decision-cost weights	net energy loads (three types) access structures (three types) decision structures (three types) energy distributions (three types)	six: 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 (across all 81 combinations of values of internal variables)	
Problem-disutility weights	net energy loads (three types) access structures (three types) decision structures (three types) energy distributions (three types)	six: 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 (across all 81 combinations of values of internal variables)	

4 Simulation results

Following Cohen et al (1972), in the analysis of the results I focus on four sets of statistics that characterize the garbage-can decision processes: problem activity, problem latency, decisionmaker activity, and decision difficulty. These statistics are necessary to provide an overview of how the organizational systems perform. 'Problem activity' measures the degree to which problems are active within the organization, and reflects the degree of conflict within the organization or the degree

Table 2. The statistics and variable names used in the simulation.

Statistic	Variable[a]	Interpretation
Problem persistence	KT	The total number of time periods a problem is activated and attached to a choice, summed over all problems.
Problem latency	KU	The total number of time periods a problem is activated, but not attached to a choice, summed over all problems.
Problem velocity	KV	The total number of times any problem shifts from one choice opportunity to another.
Problem failures	KW	The total number of problems not solved at the end of twenty time periods.
Decisionmaker velocity	KX	The total number of times any decisionmaker shifts from one choice to another.
Decisionmaker inactivity	KS	The total number of time periods a decisionmaker is not attached to a choice, summed over all decisionmakers
Choice persistence	KY	The total number of time periods a choice opportunity is activated, summed over all choice opportunities.
Choice failures	KZ	The total number of choice opportunities not made by the end of the twenty time periods.
Energy reserve	XR	The total amount of effective energy available to the system but not used because decisionmakers are not attached to any choice opportunity.
Energy wastage	XS	The total effective energy used on choice opportunities in excess of that required to make them at the time they are made.
Disutility removal	XT	The total amount of disutility removed at the end of the twenty time steps.

[a] Except for disutility removal (XT), these variables were used originally by Cohen et al (1972).

of articulation of problems. As shown in table 2, four statistics are used for this measure: disutility removal (XT), problem failures (KW), problem velocity (KV), and problem persistence (KT). 'Problem latency' measures the degree to which problems are active, but not attached to any choice opportunities. The measure is reflected by KU in table 2. The decisionmaker-activity measure is reflected by decisionmaker inactivity (KS), decisionmaker velocity (KX), energy reserve (XR), and energy wastage (XS). Decision difficulty is measured by choice failures (KZ) and choice persistence (KY). A statistic of the total amount of problem disutility removed (XT) is considered here in addition to the original ten statistics proposed in the original model.

Based on the simulation design, a three-way ANOVA analysis was conducted for the 216 simulation runs for each statistic as shown in table A1 in the appendix. Because of limitation of space, the simulated data are not reported here. Because each combination of the levels of the three factors is composed of one simulation run, that is, one set of data, the confounding effect or the interaction term of the model is ignored for simplicity. We can, however, test the main effects of the three control factors on the organizational behavior for the eleven statistics. According to the results from table A1, except for the main effect of problem disutility for KX—namely, decisionmaker velocity—all other main effects on the system behavior of the three factors with respect to all the eleven statistics were statistically significant at $p = 0.05$.

A closer examination of the simulated data showed the following findings. In terms of problem activity, the focus on decision cost and that on problem disutility yielded similar tendencies. The heavier the weight placed on decision cost or problem disutility, the more disutility was removed. But increase in planning investment had the reverse effect: more planning investment tended to result in a smaller amount of problem disutility removed. Increase in the weight on problem disutility resulted in more problems resolved, but increase in planning investment and decision cost led to fewer problems solved. Different tendencies were found in problem velocity and problem persistence in that these measures increased with increase in the weight of decision cost and decreased with increase in the weight of problem disutility. Planning tended to decrease problem velocity and problem persistence.

In terms of problem latency, the focus on decision cost and that on problem disutility yielded tendencies counter to each other. The heavier the weight was placed on decision cost, the smaller the number of latent problems; and the heavier the weight on problem disutility, the larger the number of latent problems. Planning tended to increase the number of latent problems.

The measures of decisionmaker activity indicated profound effects of decision cost and problem disutility. In terms of decisionmaker velocity, the focus on decision cost increased the degree to which decisionmakers shifted from one choice to another, whereas planning investment had the reverse effect in that increase in planning investment decreased decisionmaker velocity. But for decisionmaker inactivity, the measure yielded tendencies counter to each other for the focus on decision cost and that on problem disutility. Increase in the weight of decision cost tended to decrease the number of decisionmakers not attached to choice opportunities; increase in the weight of problem disutility tended to increase the number of decisionmakers not attached to choice opportunities. Increase in planning investment resulted in more such decisionmakers. As a result, the total energy not used for decisionmaking presented the same pattern. Increase in the weights of decision cost and problem disutility resulted in increase in energy wastage, whereas increase in planning investment decreased energy wastage.

Regarding the measures for decision difficulty: for choice failures, the focus on decision cost tended to increase the number of choice opportunities in which no decisions were made; focus on problem disutility tended to decrease the number of choice opportunities in which no decisions were made. Planning investment had similar effect in that increase in planning investment resulted in increase in decision difficulty. Choice persistence showed a similar pattern in relation to decision cost and problem disutility. Increase in planning investment resulted in decrease in choice persistence.

On the face of it, the effects of decision cost and problem disutility seemed counter to each other. Increase in the weight of decision cost tended to increase problem activity, decrease problem latency, increase decisionmaker activity, and increase decision difficulty; increase in the weight of problem disutility tended to decrease problem activity, increase problem latency, decrease decisionmaker activity, and decrease decision difficulty. However, increase in either decision-cost weight or problem-disutility weight would remove more problem disutility. Planning rendered a smaller amount of problem disutility removed, but increased decisionmaking efficiency. Compared with the results of the earlier simulation, the effects of planning remained the same in the present simulation, regardless of whether decisions were costly and whether problems caused harm. The three factors all affected organizational choice behavior independently.

5 Some implications

From the results derived in the previous and present simulations concerning the effects of planning on complex systems, we can conclude that making plans matters in complex systems. Planning imposes some degree of order on the seemingly chaotic garbage-can decision processes in that problems and decisionmakers tend to stick to the same decision situations. On the other hand, planning tends to solve fewer problems. The question of immediate interest is that of how much planning should be invested to gain better outcomes? The conventional wisdom of the idealized, rational, comprehensive, planning paradigm implies that the planner should acquire all the information and evaluate all the alternatives to seek the actions that bring about optimal outcomes. This approach is equivalent to an attempt to control the dynamic processes of a complex system fully. Regardless of whether one can accomplish this objective, the simulations presented here and earlier suggest that neither zero planning investment nor making plans with a complete scope is desirable. There might be an optimal level of planning investment between the two extremes. How much planning investment a planner should make in a particular situation is a question of theoretical and practical importance, and needs further rigorous investigation.

In the present simulation, there are two interpretations of weights associated with decision cost and problem disutility. The first interpretation is that they represent the planner's trade-off judgments between the two factors. The more weight that is imposed on problem disutility, the more attention is focused on solving these problems. The more weight that is given to decision cost, the more attention is focused on making these decisions. Decisions made may not, however, solve problems. Depending on the planner's preferences, whether the organization is to solve problems without worrying about how resources are spent or is to make efficient decisions is a subjective judgment. The simulation implies that the two objectives seem in conflict. The second interpretation is that they represent the hypothesized change in the amount of cost and disutility. Regardless of which interpretation is adopted, decision cost and problem disutility seem to have countereffects on the garbage-can decision processes. More focus on or increase in decision cost results in more problems, and decisionmakers shifting among decision situations, and thus makes decisionmaking more difficult, whereas problem disutility has the opposite effects. There is a need to achieve a balance between how much emphasis should be put on problem solving and on decisionmaking to promote the overall performance of the garbage-can organization.

The present simulation suggests that planning investment, decision cost, and problem disutility all matter: that is, they all affect how the garbage-can decision processes evolve. Planning seems, however, quite distinct from the other factors because decision cost and problem disutility seem correlated in terms of their effects on the statistics. I suspect that though all three factors matter, planning affects the dynamics processes through control whereas the other two factors have only partial impacts on these processes. Making plans is only one way of affecting outcomes. Other characteristics of organizations, such as their design and objectives, may also affect how the organizations perform. How to make effective use of different organizational factors collectively to gain what we want is a challenging task.

One might argue that in order to test the effects of planning directly, a totally different, simpler, simulation should be designed and run by addressing patterns of interdependence among decision situations and the resulting effects. This simple design can then focus solely on how cost and disutility of decisions and problems affect the behavior of the system, without referring to seemingly irrelevant variables such as decision structure and energy load. These variables may digress from the research objectives. Though simplicity is, of course, desired in modeling, it is sometimes at the cost of realism. The garbage-can model is at least simple enough to understand conceptually. That model is a descriptive one for complex decision environments with plausible internal and external validity. Simulating that model would result in useful conclusions. One way to resolve this dilemma, however, is to conduct another, simpler, Monte Carlo simulation taking into account different streams of decision situations with respect to different patterns of interdependences, and comparing effects of various amounts of cost, disutility, and planning investment. We can then apply the 'alignment of computational models' approach, as suggested by Axtell et al (1997), to examine whether the two simulations produce the same results. Such a comparison is beyond my scope in the present paper and begs future work.

6 Conclusions

I have shown a simulation based on the garbage-can model to consider planning, decision cost, and problem disutility. The simulation results suggest that the three factors all affect the behavior of the system in a statistically significant way. The main effects of the three factors with respect to almost all the statistics under consideration were significant. Each factor matters in affecting organizational choice behavior, with planning effects being quite distinct from the other two factors.

The simulation results showed that neither decision cost nor problem disutility had all the attributes desired from the planner's point of view of increasing organizational performance in the garbage-can decision processes. Though focusing on the decision cost tended to reduce problem latency and increase decisionmaker activity, it also tended to increase problem activity and decision difficulty. The focus on problem disutility tended to have the reverse effects. The effects of planning were similar to those derived from the previous simulation in that a focus on planning resulted in fewer problem resolutions, but more efficient decisionmaking. An organization emphasizing decision cost but ignoring problem disutility might not perform better than the one taking an opposite position. It might be that, from a normative point of view, the organization needs to balance or make value trade-offs between the two so that the overall performance of the organization can be improved and that planning has its claim to be effective. We may not be sure under what conditions planning may yield better outcomes, but one thing we can be sure of, based on the simulation results, is that making plans and acting accordingly in the narrow sense defined here does matter in a complex system characterized partially by chaotic interactions of components. Insights into the characterizations of a normative theory of planning could be derived from a more rigorous axiomatic analysis based on the result, such as the '4 Is' conditions for planning argued by Hopkins (2001).(1) Additional work will be necessary to determine the external validity of these simulations, that is, to interpret concrete situations in terms of such principles.

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(1) Hopkins (2001) argues that the urban development processes can be characterized by four conditions among decisions under which making plans can gain benefits, that is to seek actions that result in better outcomes: interdependence, indivisibility, irreversibility, and imperfect foresight, or the '4 Is'. Interdependence means that the outcome of one decision affects that of another; indivisibility requires that increments of a physical investment cannot be made in arbitrary amounts; irreversibility implies that decisions, once made, are costly to change; and imperfect foresight simply recognizes the fact that prediction is not complete. Under these conditions which defy iterative adjustments assumed in the economic literature, making plans by considering related decisions may yield better outcomes. It is worth proving axiomatically, however, that Hopkins's argument is true.

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Appendix

Table A1. The ANOVA (analysis of variance) tables.

Factor	DF	SS	MS	*F*	*P*
Problem persistence (KT)					
Decision cost	5	54 906 684	10 981 336	384.03	0.000
Problem disutility	5	42 038 900	8 407 780	294.03	0.000
Planning investment	5	53 307 428	10 661 485	372.85	0.000
Error	200	5 718 930	28 595		
Total	215	155 971 936			
Problem latency (KU)					
Decision cost	5	81 092 960	16 218 592	293.96	0.000
Problem disutility	5	650 187	130 037	2.36	0.042
Planning investment	5	113 282 776	22 656 556	410.65	0.000
Error	200	11 034 384	55 172		
Total	215	206 060 304			
Problem velocity (KV)					
Decision cost	5	100 208 640	20 041 728	503.05	0.000
Problem disutility	5	527 966	105 593	2.65	0.024
Planning investment	5	28 492 375	569 848	14.30	0.000
Error	200	7 968 026	39 840		
Total	215	111 553 872			
Problem failures (KW)					
Decision cost	5	28 485	5 697	4.83	0.000
Problem disutility	5	262 006	52 401	44.42	0.000
Planning investment	5	272 294	54 459	46.16	0.000
Error	200	235 951	1 180		
Total	215	798 736			
Decisionmaker velocity (KX)					
Decision cost	5	17 122 228	3 424 445	127.12	0.000
Problem disutility	5	21 291	4 258	0.16	0.977
Planning investment	5	4 921 405	984 281	36.54	0.000
Error	200	5 387 909	26 940		
Total	215	27 452 832			
Decisionmaker inactivity (KS)					
Decision cost	5	38 717 772	7 743 155	212.42	0.000
Problem disutility	5	6 535 899	1 307 180	35.86	0.000
Planning investment	5	36 378 568	7 275 713	199.60	0.000
Error	200	7 290 435	36 452		
Total	215	88 920 672			
Choice persistence (KY)					
Decision cost	5	51 406 300	10 281 260	1 678.98	0.000
Problem disutility	5	2 057 397	411 479	67.20	0.000
Planning investment	5	5 836 151	1 167 230	190.61	0.000
Error	200	1 224 704	6 124		
Total	215	60 524 552			

Table A (continued).

Factor	DF	SS	MS	*F*	*P*
Choice failures (KZ)					
Decision cost	5	41 094.2	8 218.8	574.09	0.000
Problem disutility	5	9 031.6	1 806.3	126.17	0.000
Planning investment	5	4 608.2	921.6	64.38	0.000
Error	200	2 863.3	14.3		
Total	215	57 597.3			
Energy Reserve (XR)					
Decision cost	5	2 155 737	431 147	176.75	0.000
Problem disutility	5	701 772	140 354	57.54	0.000
Planning investment	5	3 486 094	697 219	285.82	0.000
Error	200	487 869	2 439		
Total	215	6 831 471			
Energy wastage (XS)					
Decision cost	5	254 593	50 919	66.04	0.000
Problem disutility	5	61 132	12 226	15.86	0.000
Planning investment	5	1 312 748	262 550	340.52	0.000
Error	200	154 207	771		
Total	215	1 782 680			
Problem disutility removal (XT)					
Decision cost	5	2 471.0	494.2	2.31	0.045
Problem disutility	5	47 579.7	9 515.9	44.55	0.000
Planning investment	5	35 241.3	7 048.3	33.00	0.000
Error	200	42 721.5	213.6		
Total	215	128 013.5			

Note. DF degrees of freedom, SS sum of squares, MS mean squares.