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Individual Versus Group Resource-Allocation Performance

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INDIVIDUAL VERSUS GROUP RESOURCE-ALLOCATION PERFORMANCE

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I would like to dedicate this thesis to the memory of Mrs. Christine Robbins whose life was tragically cut short. She opened my eyes to the world of research and for that I am forever grateful.

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ABSTRACT

Decisions about resource-allocation are faced by us daily, but only recently has published research explored how people make resource-allocation decisions. Previous studies examined how individuals make resource-allocation decisions when the goal was to maximize payoff with a limited amount of resources. In the present study, the literature was extended by examining how groups of varying sizes allocate resources in maximization problems and how their performance is comparable to individuals' resource-allocation performance. Individuals and groups of varying sizes scheduled two helicopters that differed in the number of personnel and fuel requirements and were asked to maximize the number of flight hours under conditions of certainty, risk, and uncertainty. Results indicated that groups were more effective than individuals in the number and quality of solutions acquired, but individuals were more efficient than groups with respects to productivity per person under Risk and Uncertainty but not Certainty.

INDIVIDUAL VERSUS GROUP RESOURCE-ALLOCATION PERFORMANCE

Introduction

Most of our waking hours are spent in, and the bulk of our work-related productivity occurs within, settings consisting of two or more persons. Given the importance of groups in society, social scientists have long been interested in how group members interact with each other and with members of other groups to produce various commodities or decisions. Two relatively independent lines of research on groups evolved within social psychology during the first three decades of the 1900s. The earliest of these, which was instigated by Triplett (1898), examined the effects of the presence of other persons on facilitating the performance of individuals across a variety of tasks. This work later resulted in research on social facilitation/impairment (Zajonc, 1965) and has been continued in research on social loafing (e.g., Harkins & Petty, 1982). The second line of research, which was instigated by Watson (1928), examined individuals versus groups on problem-solving and decision-making tasks. It is this second line of research that this thesis will expound upon.

Individual versus Group Problem-Solving Research

One of the first studies on individual versus group problem-solving was conducted by Watson (1928) who tested the efficiency of groups as compared with the efficiency of the same individuals working by themselves on a word-construction task. Beginning with a given word, the participants were asked to construct as many new words as possible from the letters in the stimulus word. The participants first worked individually for 10 minutes, then in groups ranging from three to 10 persons for another 10 minutes, followed by a third period in groups, and finally a fourth period as individuals. Results indicated that the number of words constructed in the 10 minutes by the poorest individual was 18 words; the average individual was 32 words; the best individual was 49 words; whereas, the number of words constructed in the 10 minutes by the group in a cooperating environment was 75 words. Watson concluded that groups are superior to individuals and that the variability among groups depends more upon the ability of the best member than upon others in the group. This was based upon the observation that the performance of the group corresponded more closely to that of the best group member than to the performance of others in the group.

Shaw's (1932) study was the first systematic attempt to investigate how small group processes affect a group's performance on problem-solving tasks. She tested individuals and small groups of four cooperating individuals on a series of complex intellectual puzzles. For example, three married couples (i.e., three jealous husbands and three beautiful wives) are trying to cross a river in a boat holding just three at a time under the constraint that only the husbands can row and no husband will allow his wife to be in the presence of any of the other husbands unless he is also present. The "husbands and wives" problem (known historically as the Tartaglia) turned out to be fairly difficult for individuals in Shaw's study with only three out of the 21 individuals able to solve the problem correctly. However, the majority of the four-person groups (i.e., three out of the five) solved the problem. Shaw obtained similar results for the other puzzles (i.e., the historical Alcuin or the "cannibals and missionaries" problem and the historical Tower of Hanoi or the disk transfer problem) that she examined. Shaw's results indicated that groups produced more correct solutions, but often at a cost in time. In addition, Shaw noted that there was an unequal amount of participation by group members and in erroneous solutions, groups did not err as early in the process as did the average individual. The relative superiority of groups with respect to accuracy was interpreted by Shaw to be due to the rejection of incorrect suggestions and the checking of errors in the group. She also found that in the group more incorrect suggestions were recognized and rejected by someone other than the one who had made the error.

Thorndike (1938) hypothesized that Shaw's (1932) results could be limited by the problem type. In Shaw's study, participants were only presented with complex intellectual puzzles. Thorndike investigated the hypothesis that as the range of responses increased, the superiority of the group over individuals will increase. Thorndike presented individuals and groups problems with a "limited" number of responses or problems with an "unlimited" number of responses. Results confirmed once again that groups were superior to individuals on both types of problems, but the difference between individuals and groups was greatest in problems with an unlimited number of responses. Thorndike agreed with Shaw that group superiority results more from members pooling information by rejecting incorrect options than by contributing options for consideration. Thorndike's problems differed so much from those of Shaw as to suggest that generalizations about group superiority in problem-solving tasks could be made.

A similar study was undertaken by Husband (1940) by contrasting individuals and groups in terms of the number of person-minutes required to arrive at a solution and the quality of the solution. He stated that it must be shown that two persons can do a task in less than one half of the time, or three persons in less than one third of the time, four in less than a quarter of the time, etc., as compared with an individual. The problems presented to the participants (i.e., individuals and pairs) included arithmetic problems, a jigsaw puzzle, and code deciphering. Husband found that pairs were significantly better on the deciphering task and the jigsaw puzzle, but there was no significant difference between pairs and individuals on the arithmetic problems. This finding is consistent with Watson (1928) and Shaw (1932). However, Husband noted that the time saved by pairs was never more than one-third, rather than the one-half needed to equate individuals and groups in terms of the number of person-minutes required for the solution. He concluded that pairs are relatively less efficient than individuals.

Up to this point in the individual versus group performance research, the samples only consisted of college students. Klugman (1944) hypothesized that the superiority of groups over individuals would be different in another type of sample. In the study, Klugman examined individual versus group problem-solving in children to determine whether two heads are better than one in the solution of 20 arithmetic problems that graduated in difficulty. Results showed that children working together solved more problems correctly but took more time. Klugman concluded that the high number of correct solutions from the pairs and the longer time needed to solve the problems were both due to the presentation, discussion, rejection, and acceptance of a large number of possible answers which occurred more when the children were working together than when working independently.

After a long interval following Klugman's (1944) work, Taylor and Faust (1952) compared individuals with groups of two and four persons on a modified version of "twenty questions". Participants were told only whether the object they were to attempt to find was animal, vegetable, or mineral. In searching for the object, they asked a series of questions, each of which could be answered "yes" or "no". To find the solution most economically, the participants had to use a high order of conceptualization, gradually increasing the specificity of the concepts employed until they arrived at the particular object. They found that group performance was superior to individual performance in terms of the number of questions, number of failures, and elapsed time per problem; but the performance of groups of four was not superior to that of groups of two, except in terms of the number of failures to reach the solution. The performance of individuals was superior to that of either size group in terms of the number of person-minutes required for solution.

Taylor (1954) proposed an alternate method that suggested that there are circumstances under which groups could be expected to be more productive than individuals who work alone even if no cooperative or facilitative effects are assumed to occur in groups. For example, when the experimental task is of the "Eureka" type, such as those used in Shaw's (1932) study, the presence in a group of a single individual who can solve the problem may be sufficient to enable the group to solve it. Under such conditions, it may be hypothesized that groups will function at the level of their most competent members, rather than at the level of their "average" members.

Taylor's (1954) alternative method for testing individual and group performance has individuals randomly assigned to work either individually or in groups. After the experiment is completed, those who had actually worked alone are arranged by a random procedure into so-called "nominal" groups of the same size as the real groups. The performances of nominal groups are then scored as though the individuals had actually worked together. If any individual in the nominal group had solved the problem, the group is scored as having solved it. In order to use nominal group performance as a baseline against which to compare real group performance, the assumption must be made that if one, or more than one person in the group solves the problem, they will be able to convince the others that the solution is correct. It is possible that the group effect may stimulate a solution in a member who might have failed if he or she was working alone; however, this person may not be able to persuade the others, and the group as a whole may fail to decide on the correct answer.

Marquart (1955) repeated and expanded Shaw's (1932) study using eight complex intellectual puzzles of various kinds. All the participants worked on all problems, both as individuals and as members of groups of three. Using the method that Shaw used, groups were found to be superior to individuals. Marquart criticized the validity of such an interpretation in which an individual working alone is counted as equal to one group and in which no allowance is made for the fact that a group solution might be the result of any one of the members (perhaps the ablest) rather than the cooperative effort of the group as a whole. As a result, Marquart used Taylor's (1954) nominal method and found that the groups working as groups (i.e., the "real" groups) were no better than groups working as individuals (i.e., the "nominal" groups). Marquart then used the nominal method to reanalyze Shaw's data and found no difference between nominal and real groups.

Despite the development of Taylor's (1954) alternative method and Marquart's (1955) findings, the past 30 years of individual versus group research strongly supported the conclusion that groups produce more and better solutions to problems than do individuals, but that groups were typically inferior to individuals in the productivity per person with respects to the amount of person-minutes required (for reviews, see Davis, 1969; Duncan, 1959; Lorge, Fox, Davitz, & Brenner, 1958). In summary, groups were generally more effective than individuals, while individuals were generally more efficient than groups.

After the initial studies on individual versus group performance on problem-solving behavior, the individual-group research shifted in focus. Lorge and Solomon (1955) reanalyzed a portion of Shaw's (1932) data using a mathematical modeling technique and discovered that when the amount of available resources was taken into account, the groups really did not perform very well. In fact, the groups could actually be described as having been quite inefficient, in that the members did not make good use of their resources. The Lorge-Solomon finding was quickly replicated (Steiner & Rajaratnam, 1961), and the notion that groups are inefficient problem-solving units has since become one of the most widely accepted in the groups field.

As a result, a new era in groups research came about with the development of Steiner's (1972) group process and productivity model, Davis' (1973) social decision schemes model, and Hackman and Morris' (1975) group process-performance model. These models led group researchers away from the conceptions of groups as input-output devices (i.e., put information in and a decision comes out) and towards a focus on the process by which groups solve problems and reach decisions.

Obviously, it would be of valuable interest to study group processes to ascertain how members of a group facilitate or inhibit the development of a group product. But, it is just as important to ascertain the quantity and quality of the product produced by groups in contrast to quantity and quality of the product produced by individuals. Thus, this thesis will not address the group processes area since an initial analysis of how groups allocate resources in resource-allocation problems and how their performance compares to that of individuals must be done first in order to build the foundation of understanding group resource-allocation behavior.

Resource-Allocation Research

Operations research, or management science, is the scientific and mathematical approach to problem-solving. The successful application of linear programming (LP) to operations research has had its largest impact in the research of the attainment of an optimal solution in resource-allocation decisions. LP is a mathematical method for determining the optimal allocation of resources given known resource constraints and payoffs (Dantzig, 1963). When a decision maker knows the quantity of available resources, as well as how these resources combine to produce payoffs, it is possible to calculate the exact allocation strategy that will provide the optimal solution of the problem. Even though LP has been commonly used in economics and business settings, the examination of how people approach these resource-allocation decisions has only received recent attention in the psychological literature.

Gingrich and Soli (1984) were the first to incorporate LP into the context of understanding resource-allocation behavior. In their study, participants were asked to define their goals, conduct a cost-benefit analysis, and were required to maximize the goal of physical fitness while allocating a limited amount of time and money to two sports that they chose when they initially defined their goals. In this two-dimensional, one-time resource-allocation task under certainty, it was found that participants attained solutions of at least 90% of the optimal LP solution.

Busemeyer, Swenson, and Lazate (1986) used a hill-climbing model in order to examine learning in a resource-allocation problem when the objective function is initially unknown. Results indicated that when there was no local maximum, the majority of participants achieved the learning criterion, but when a maximum was present, participants were stuck and failed to achieve the learning criterion. Overall, they found that participants quickly discovered the maximum payoff when there was only one optimum, but when the participants were presented with more than one optimum (i.e., suboptimal maxima), performance dropped.

In three studies, Langholtz, Gettys, and Foote (1993, 1994, 1995) extended the initial research of Gingrich and Soli (1984) and Busemeyer et al. (1986) by examining people's behavior in several resource-allocation tasks. Langholtz et al. (1993) examined resource-allocation behavior under certainty, risk, and uncertainty. In a series of eight four-day trials, members of the Coast Guard were asked to schedule two helicopters that differed in the amount of personnel and fuel required in order to maximize the number of flight hours with a limited amount of personnel and fuel. Participants were randomly assigned to one of three problem environments: certainty, where resources do not fluctuate over the course of the trial; risk, where resources can be gained or lost and the probabilities are known, and uncertainty, where resources can be gained or lost and neither the possible outcomes nor their probabilities are known.

Results indicated that after the first trial participants attained solutions of at least 80% of the optimal LP solution, whereas after eight trials all three groups (i.e., certainty, risk, and uncertainty) learned to attain at least 90% of the optimal LP solution without any formal training or knowledge of LP. Specifically, participants performed best under certainty with consistent performance of at least 90% of the optimal LP solution after only three trials. Participants were slightly worse under risk with performance initially hovering around at least 75% of the optimal LP solution, but learned to improve to at least 90% of the optimal LP solution over successive trials; and participants were worst under uncertainty with performance consistently hovering around 85% of the optimal LP solution over the eight trials. In general, participants appeared to be able to solve the linear program intuitively under certainty and, after some time, risk, but found it more difficult to adapt under uncertainty.

Langholtz, Gettys, and Foote (1994) extended the analysis of resource-allocation behavior by adding the component of harsh environments where essential resources are scarce and multiple losses are possible. Members of the Coast Guard were required to schedule two patrol boats in order to maximize the total number of underway operating hours attainable with a limited amount of personnel and fuel. Two sessions of eight three-day trials were presented to the participants and were randomly assigned to three varying degrees of harshness: low difficulty (LD) or the benign environment, where a minimum patrol of 3.5 hours per day was required; middle difficulty (MD), where a minimum patrol of 4.5 hours per day was required; and high difficultly (HD), or the harshest environment, where a minimum patrol of 5.5 hours per day was required. In addition to the daily minimums, participants experienced personnel loss, where the participant was either faced with zero, one, or two losses in personnel hours, which further increased the difficulty of the task.

It was found that all three groups (i.e., LD, MD, and HD) were able to attain solutions of at least 91.3% of the optimal LP solution with each group individually performing at 88.8% of the optimal LP solution for LD, 92.8% of the optimal LP solution for MD, and 92.3% of the optimal LP solution for HD. In addition, it was also shown that

77.8% of the participants in the LD condition, 67.5% of the participants in the MD condition, and 52% of the participants in the HD condition were able to complete the cycle. When the difficulty was high and there were multiple losses, completion rates ranged from 53% of the participants in the LD, 30% of the participants in the MD, and participants in the HD were unable to complete the cycle. This inability to complete the cycle is due to the participants' lack of planning in anticipation of possible losses. Despite the increase in performance as a result of the higher minimums, participants continued to obtain solutions of at least 90% of the optimal LP solution. These results indicated that minimum standards can increase performance, but just as high minimums force higher performance, high minimums also set higher requirements for survival.

Langholtz, Gettys, and Foote's third study (1995) examined resource-allocation performance over time under conditions of both loss and gain of resources. A problem similar to the three-day scheduling problem used in the Langholtz et al. (1994) study was used in order to replicate the previous findings about loss situations, but with modifications to examine how people allocate resources in gain situations.

It was found that participants were able to achieve 90% of the optimal LP solution in gain, as well as in loss situations, and it was confirmed that not only do participants not plan for losses, but they also do not plan for gains. Participants did not plan for probable changes, did not pre-position themselves to deal with gains or losses, and did not respond immediately when gains or losses occurred. Instead, they reacted after the fact and waited until the last possible opportunity. In all eight trials, participants performed better with gains than with losses. It was found that the asymmetry between gains and losses are due to the equal-scheduling tendency rather than the intrinsic difference between gains and losses.

In a fourth study, Langholtz, Ball, Sopchak, and Auble (1997) investigated the study of resource-allocation behavior by creating both two- and three-dimensional commonplace problems modeled with Integer Programming (IP). College students were asked to schedule an optimum number of meals over a seven-day period given a limited amount of time and money. Participants were randomly assigned to one of three groups: symmetrical, where resources are allocated equally to each alternative; skewed, where resources are allocated in a two-thirds ratio; and all-or-nothing, where resources are allocated to one alternative neglecting the other. In addition to the participants being presented with one of the three two-dimensional problems, all the participants were presented with an identical three-dimensional problem.

Results confirmed prior research that participants were able to attain solutions of at least 80-90% of the optimal LP solution despite the introduction of IP resource-allocation problems. In addition when comparing the results between two-dimensional and three-dimensional problems, participants were able to obtain similar levels in terms of percent of optimality, distribution along a constraint, squandering or hoarding of resources, and equal scheduling tendency.

Ball, Langholtz, Auble, and Sopchak (1998) expanded the literature by examining the cognitive strategies used by participants in resource-allocation tasks. The same meal scheduling problem as the Langholtz et al. (1997) study was used with the addition of the use of verbal protocols to analyze participants' self-reported thought processes. Two strategies were hypothesized to be utilized by the participants. The first is a solve-and-schedule (SAS) strategy, where a decision maker searches the problem space in advance to determine the solution and, once solved, schedules the same allocation strategy each time the problem is repeated. The second strategy found by Ball et al. (1998) was a consume-and-check (CAC) strategy, where a decision maker does not formulate any planned approach to guide their allocation strategy, but rather consumes resources on a day-by-day approach, making allocation decisions in response to events as they unfold. Results indicated that 21% of the participants were defined as SAS strategists, while the predominant strategy, CAC, was used by 79% of the participants.

In all the previous studies, Langholtz and his colleagues have only analyzed the performance of individuals and how they make resource-allocation decisions. However, resource-allocation decisions are not always made by individuals. Many times groups of varying sizes are faced with making resource-allocation decisions on a daily basis.

This thesis, which has a threefold purpose, will expand on the earlier resource-allocation literature that only examined how individuals solve resource-allocation problems. This thesis will use the Langholtz et al. (1993) Coast Guard law enforcement deployment scenario as the resource-allocation problem presented to the individuals and groups of varying sizes. Hence, the first purpose is to replicate the previous findings found with individuals in the Langholtz et al. (1993) study. The second purpose is to analyze how groups of varying sizes allocate resources in maximization problems when the goal is to maximize payoff with a limited amount of resources. The third purpose is to determine how the resource-allocation performance of individuals compares to the resource-allocation performance of groups of varying sizes. Underlying these three purposes, resource-allocation behavior of individuals and groups of varying sizes will be examined under the conditions of (a) certainty, where the decision maker knows exactly what to expect; (b) risk, where the decision maker does not know what resources will be available, but is aware of the probabilities of possible gains or losses of the resources; and (c) uncertainty, where the decision maker does not know about possible gains or losses and is unaware of the associated probabilities.

Some Plausible Explanations for Group Performance in Resource-Allocation Problems

First, are groups capable of functioning as linear programmers when solving maximization problems? Previous research has demonstrated that individuals are capable of functioning as intuitive linear programmers when solving maximization problems under varying conditions (Langholtz et al., 1993, 1994, 1995, 1997). Regardless of the size of the group (i.e., the two-person, three-person, and four-person groups), the capability of the groups to function as intuitive linear programmers should also be demonstrated.

Second, will groups of varying sizes (i.e., the two-person, three-person, and four-person groups) be able to obtain the same percent of optimality (i.e., 80-90% of the optimal LP solution) that has been found in previous research involving maximization problems solved by individuals? As previous research has shown, groups produce not only a higher number of correct solutions, but also a higher quality in the solutions (for reviews, see Davis, 1969; Duncan, 1959; Lorge, Fox, Davitz, & Brenner, 1958). The ranges in the percent of the optimal LP solution of the groups (i.e., the two-person, three-person, and four-person groups) should be higher than what has been found in the previous resource-allocation research that examined performance of individuals because of the ability for groups to produce a higher quality of the solution (i.e., a higher percent of the optimal LP solution).

Third, what type of learning will take place in the groups of varying sizes (i.e., the two-person, three-person, and four-person groups) with practice over the course of the problem cycles? Groups in the certainty condition should begin to demonstrate a learning pattern in the first few problem cycles as a result of the group knowing exactly what to expect. The groups in the risk condition should also demonstrate a learning pattern, but at a slower pace than the groups in the certainty condition due to the necessary adjustments encountered in dealing with the probabilities and outcomes that are part of the risk problem. Groups in the uncertainty condition should demonstrate the slowest learning due to their not knowing in advance what the possible outcomes are.

Fourth, how do groups of varying sizes (i.e., the two-person, three-person, and four-person groups) handle a mid-course adjustment when something unexpected comes up? Will groups realize the structure of the scenario has changed and that an alternate strategy is needed? Groups in the risk and uncertainty conditions should both be responsive by changing their allocation strategy when an unexpected event occurs. A difference in the performance level should be exhibited between the risk and uncertainty conditions. The groups in the risk condition should be able to adjust more quickly to the correct allocation strategy when an unexpected event occurs due to their knowledge of the probabilities of subsequent changes in the problem than the groups in the uncertainty condition who are unaware of the probabilities.

Fifth, what behavior will groups of varying sizes (i.e., the two-person, three-person, and four-person groups) exhibit when faced with different environmental manipulations? Since groups in the certainty condition know exactly what to expect, their performance should yield a higher level of success in obtaining the optimal LP solution. In the risk condition, groups should also exhibit success in obtaining the optimum; yet they should begin to understand how to appropriately adjust to unexpected changes towards the middle of the problem cycles. In the uncertainty condition, groups should not exhibit high levels of success throughout all the problem cycles due to their lack of advanced knowledge of the changes to expect.

Sixth, how much variation is there in the resource-allocation behavior of groups of varying sizes (i.e., the two-person, three-person, and four-person groups)? Are the performances of groups predictable? How variable are the differences of groups? Groups in the certainty condition should exhibit the least amount of variability due to their knowing exactly what to expect. In the risk condition, groups should display a greater amount of variability early in the first few problem cycles, but the variability should diminish once groups have learned to adjust to the unexpected changes, whereas in the uncertainty condition, groups should exhibit the most variability due to their diminished ability to predict or anticipate changes in the problem.

Seventh, what cognitive strategy or strategies might groups of varying sizes (i.e., the two-person, three-person, and four-person groups) use when solving maximization problems? As found in the Ball et al. (1998) study, there are two types of strategies decision makers use to solve maximization resource-allocation problems. Specifically, they found that 21% of the individuals were defined as solve-and-schedule (SAS) strategists, whereas 79% of the individuals were defined as consume-and-check (CAC) strategists. A majority of the groups should use the cognitively less demanding CAC strategy as opposed to the more cognitively demanding SAS strategy because the members of the groups will settle for an easier, less demanding strategy because of social loafing where members of the group taking part in a cognitive task (i.e., the resource-allocation problem) will put forth less effort.

Some Plausible Explanations for Individual Versus Group Performance in Resource-Allocation Behavior

Eighth, are groups superior to individuals when solving a resource-allocation problem? When analyzing the data as the majority of the individual versus group performance studies did (i.e., comparing the number of correct solutions of individuals to the number of correct solutions of groups), the groups' performance should be superior to that of the individuals irrespective of the treatment condition (i.e., certainty, risk, and uncertainty) because members of the groups perform their task cooperatively and have positive, facilitative effects upon one another that individuals do not benefit from. However, when analyzing the data using the "nominal" group technique (Taylor, 1954), groups should not be superior to individuals because the group solution might be the result of any one of the members (e.g., the most competent member), rather than the cooperative effort of the group as a whole.

Finally, will individuals be superior in the amount of person-minutes used to solve the resource-allocation problem as opposed to the groups of varying sizes (i.e., the two-person, three-person, and four-person groups)? Previous research has shown that individuals are more efficient than groups with respects to the amount of person-minutes used to solve problem-solving tasks (Husband, 1940; Taylor & Faust, 1952; Watson, 1928). Groups should not demonstrate a meaningful savings of person-minutes when solving the resource-allocation problem as compared to the individuals irrespective of the treatment condition (i.e., certainty, risk, and uncertainty) because groups must deal with such issues as coordination losses (e.g., members of the group having to communicate with each other what allocation strategy to use) which will affect (i.e., increase) the amount of time taken to solve the problem.

Method

Participants

Seventy-five males and 105 females participated in this study. Their ages ranged from 18 to 23 years with a mean age of 19. All the participants were undergraduate students from The College of William & Mary and received course credit for their involvement.

Apparatus

A resource-allocation problem was presented to the individuals and groups individually on a PC computer. A C++ program was used to execute the problem, check for faulty input from the individuals and groups, and record the individuals' and groups' responses. The program began by providing the individuals and groups with the instructions for performing the resource-allocation problem including the starting resources, the resource requirements for each helicopter, and the daily constraints. Once the individuals and groups understood the resource-allocation problem, a new screen with a reminder box of the resource requirements for each helicopter, starting resources, and the minimum flying constraint was displayed. In addition, after making resource-allocation decisions for a day, a summary display of the following information was shown: the amount of hours flown by each helicopter, the amount of resources consumed, and the amount of resources left to consume for the remaining days of the deployment. The screen was cleared at the end of each individual four-day deployment cycle.

Task

Individuals and groups were presented with a resource-allocation problem that required them to schedule two Coast Guard helicopters, the H-65 and the H-52, with differing personnel and fuel requirements. Individuals and groups attempted to find the most efficient way to schedule these two helicopters in order to maximize the total number of flight hours over the specified patrol area during a four-day law enforcement deployment in the Caribbean Islands. They were told that they would be required to fly both helicopters for a combined minimum of at least 1.5 flight hours per day. Individuals and groups were also told that the they would have a total of 90 personnel operating or supporting hours and a total of 1125 gallons of fuel that they would have to allocate over the four-day deployment (see Appendix A).

Once individuals and groups completed the four-day resource-allocation problem, or deployment cycle, the helicopters were returned to their parent station taking any remaining personnel hours and gallons of fuel with them. Individuals and groups were told that the resources (i.e., the personnel hours and gallons of fuel) would not be carried over from one four-day deployment to another four-day deployment. Once the first four-day deployment was completed, individuals and groups were presented with a second four-day problem, followed by six more, for a total of eight four-day deployment cycles.

Design

The 180 participants were randomly assigned to one of four group conditions (i.e., individuals, two-person groups, three-person groups, or four-person groups). The individuals and groups were then randomly assigned to one of three treatment conditions: Certainty, Risk, or Uncertainty. Therefore, this was a 4 x 3 level design (see Table 1).

Individuals and groups in the Certainty, Risk, and Uncertainty conditions were informed during the introductory display that the H-65 required 6 personnel hours for each hour of flight and 50 gallons of fuel for each hour of flight, whereas the H-52 required 4 personnel hours for each hour of flight and 75 gallons of fuel for each hour of flight. In addition, they were notified that they were to schedule a minimum of 1.5 total hours of flight per day. They were told that their starting amount of resources would be 90 personnel operating or supporting hours and 1125 gallons of fuel that needed to be allocated over the four-day deployment.

The individuals and groups in the Certainty condition were provided the same personnel and fuel requirements in the amounts indicated in the introductory display and as the problem progressed, the requirements did not change.

In addition to the introductory information presented to all three treatment conditions, the individuals and groups in the Risk condition were given an additional paragraph. The paragraph indicated a warning to the individuals and groups about previous law enforcement deployments. Specifically, individuals and groups were advised about unforeseen events such as sickness and injury that had caused a decrease in the number of personnel operating or supporting hours available. They were advised of a 25% chance that these events could occur on any day during the four-day deployment. In addition, they were informed that when these events have occurred, they would deplete the available amount of personnel hours to X – 12, where X is the amount of personnel hours that the individuals and groups had remaining at the time the personnel loss occurred. The individuals and groups were told that the loss in personnel hours could occur only once during each four-day law enforcement deployment because additional personnel would be brought in to prevent any loss beyond 12 personnel hours. The remaining amount of fuel at the time of the personnel loss was not affected. The loss of personnel hours remained constant for the remainder of the four-day law enforcement deployment. As the experiment progressed, individuals and groups in the Risk condition experienced the personnel loss situation at the start of the 2nd, 3rd, or 4th day of the four-day deployment cycle as shown in Table 2. The personnel loss situation was never introduced on the first day because this would have defined a different beginning for the LP problem

Individuals and groups in the Uncertainty condition were shown an identical introductory display screen as were the individuals and groups in the Certainty condition. However, as the experiment progressed, the individuals and groups in the Uncertainty condition experienced the same series of personnel losses as the individuals and groups in the Risk condition (see Table 2). The individuals and groups in the Uncertainty condition were never given any information regarding the personnel loss in the introductory display. The personnel loss situations simply occurred and the individuals and groups in the Uncertainty condition were required to make their own inferences regarding the probabilities of future losses in personnel hours.

Procedure

Participants were randomly assigned to one of four group conditions (i.e., individuals, two-person groups, three-person groups, or four-person groups). In addition, the individuals and groups were randomly assigned to one of the three treatment conditions (i.e., Certainty, Risk, or Uncertainty). They were seated at a computer terminal and given an overview of the task to be completed. Specifically, individuals and groups were told that they would be scheduling two helicopters, the H-65 and the H-52, during a four-day law enforcement deployment at the Caribbean Islands. They were told that they would have 90 personnel hours and 1125 gallons of fuel to allocate over a four-day deployment and that a minimum 1.5 hours of flight must be scheduled per day. In addition, they were told that they would have to repeat this four-day law enforcement deployment eight times.

Individuals and groups were informed how the computer program functioned, what each display consisted of, and how to input their data. They were told that they had as much time as they needed to complete the problem. Individuals and groups were then asked if they understood the experiment and, if they responded affirmatively, they were told to begin the experiment.

Once the individuals and groups understood the introductory display, they were instructed to record the amount of time it took them to read the introduction by looking at the timer on the bottom of the display. Once the time had been recorded, the individuals and groups would press the "continue" button and proceed to the next display where they began allocating resources for day one in deployment cycle one. Individuals and groups then entered the number of flight hours they wished to fly one or both of the helicopters and pressed the "allocate" button. If the individuals and groups either over allocated or flew under the 1.5 minimum flying requirement an error message popped up to notify the individuals and groups that they had entered an invalid answer. They were then instructed to change their answer and enter a new answer. When a feasible solution was entered, a summary display indicated to the individuals and groups the day of the four-day deployment they were on, how many hours the helicopter(s) flew, the amount of personnel hours and gallons of fuel they had utilized thus far, and the amount of personnel hours and gallons of fuel they had left to allocate for the remaining days in the four-day deployment.

Once the individuals and groups were satisfied with the allocation strategy for the first day, they pressed the "next day" button and proceeded to the next day and repeated allocating resources until the end of the 4th day. At the end of the four-day deployment cycle, the program displayed a summary of the total hours of flight each helicopter had flown over the four-day deployment and the total amount of personnel hours and gallons of fuel that was utilized. The individuals and groups were then instructed to record the amount of time it took the them to complete the four-day deployment by looking at the timer on the bottom of the display. Once the time had been recorded and they pressed the "ok" button, the program reset for the next four-day deployment cycle.

When the individuals and groups in the Risk and Uncertainty conditions pressed the "next day" button to move to a new day that had a personnel loss situation, a display popped up describing the loss situation by informing the individuals and groups that due to the flu, a decrease in personnel hours (i.e., X –12, where X was the amount of personnel hours that they had remaining at the time this personnel loss occurred) had occurred. In addition, they were told that the loss in personnel hours did not affect the amount of available fuel and the daily flying requirement.

Eight four-day deployment cycles were completed in total. Objective functions, personnel and fuel constraints, and minimum flying constraint are found in the Appendix B. Graphical representations of the scenario under Certainty, Risk, and Uncertainty are found in Figure 1, Panels A-B.

Linear Programming

Before proceeding, a mini-tutorial should be given in order to clarify LP concepts in relation to the resource-allocation problem in this study. To analyze a problem using

LP, it must be structured in a format that can be broken down into the following components: an objective, activities or decision variables, and constraints (Pannell, 1997).

LP is designed to find the best, or "optimal" solution, to a problem. In most cases, the optimal solution is the solution that maximizes or minimizes the objective (i.e., the goal of the problem). For example, the objective of this scenario discussed in this study is to maximize the number of flight hours of a four-day law enforcement deployment. When devising a plan or strategy, the decision maker is typically faced with deciding what to do, how to do it, and how much of it to do. Each of the available alternatives, when deciding what to do and how to do it, are called activity or decision variables. For this study, the decision maker needed to determine what combination of flight hours is needed in order to obtain the objective. Hence, each helicopter (i.e., the H-65 and the H-52) is considered a decision variable. In addition, an LP problem includes a number of restrictions, or constraints, on which a combination of activities can be selected. These constraints ensure the solution is realistic, logical, and achievable, hence forming a feasible region in which a number of activities can be selected, but only the extreme point of the feasible region will be the optimal LP solution. For example, the constraints in this study are the personnel and fuel constraints and the minimum flying constraint.

There are two different linear programming approaches that can be used when solving resource-allocation problems: the graphical solution method and the simplex method. The graphical solution method, which is used for two- or three-variable problems, uses a coordinate graph to display the constraints and feasible region of the specific problem in order to determine the optimal LP solution. On the other hand, the simplex method is a mathematical algorithm that systematically examines basic feasible solutions for the optimal LP solution.

The current study will use the graphical solution method to solve the two-variable maximization resource-allocation problem. When using the graphical solution method, the first step is to construct the graph. The resource-allocation problem is represented in two dimensions with one dimension, for example, representing the number of hours flown by the H-65 (i.e., the x axis) and the other dimension, for example, representing the number of hours flown by the H-52 (i.e., the y axis). The next step is to plot the constraints. This can be done by obtaining the horizontal and vertical intercepts of each constraint line found in equations 2 and 3 in Appendix B (see Figure 2, Panel A). When the constraint lines have been drawn, the valid side of the constraint lines must be determined in order to establish where the feasible region (i.e., the solution points where all the constraints are satisfied) is located. This is done by picking any point that is not on the constraint line and determining if the point satisfies the constraint. The origin is often convenient for this purpose. If the "test" point satisfies the constraint, then all the points on the same side will satisfy that constraint. The final step is determining the optimal solution. In most resource-allocation problems, the optimal solution, or most attractive corner, will be a corner point, or extreme point, of the feasible region (i.e., at the intersection of the constraint lines), which is the case for this resource-allocation problem (see Figure 2, Panel B). The optimal solution can be confirmed by finding the intersection of the two constraint equations by simultaneous equations and then plugging the answers into the objective function. See Lapin (1981) for a detailed step-by-step procedure of the graphical solution method.

When a decision maker is faced with a resource-allocation problem under Risk or Uncertainty, the structure (e.g., the size of the feasible region and the slope of the objective function) of the resource-allocation problem changes. In this maximization problem, under Risk or Uncertainty, the available amount of personnel hours has decreased due to an unforeseen event (i.e., the flu). As a result of the change in the amount of personnel resources available, the personnel constraint line shifts in accordance with the change in the x and y intercepts (see equation 6 in Appendix B). As can been seen in Figure 2, Panel C, the size of the feasible region and the slope of the objective function has changed due to the personnel loss, hence changing the location of the optimal LP solution.

Results

Overall Performance

Individuals

None of the individuals under Certainty, Risk, and Uncertainty were able to find the optimal LP solution in all eight deployments. The mean solution for all the individuals under Certainty, Risk, and Uncertainty by the eighth cycle was 92% of z* where the correct solution was z*, or 100% of the optimal LP solution, and anything less than z* (e.g., 95% of z*) is considered under-consumption of resources and therefore suboptimal.

The behavior of the individuals in all three treatment conditions across the eight deployment cycles is shown in Figure 3, Panel A. Overall, it can be seen that the individuals in the Certainty condition consistently improved and continued to progress closer to z* as the eight deployment cycles progressed and achieved 96% of z* on the eighth cycle. Individuals in the Risk condition displayed unsuccessful attempts to progress towards z* for the first and second cycles where they went from 89% of z* to 78% of z*, respectively. It was not until the third cycle when the individuals began to consistently progress up towards z*. On the eighth cycle, the individuals finally achieved 95% of z*. Unlike the individuals under Certainty and Risk, the individuals in the Uncertainty condition can be seen displaying the most erratic behavior where they never achieved a group mean higher than 85% of z* on any of the eight deployment cycles.

Two-Person Groups

Two of the two-person groups (i.e., two two-person groups in the Certainty condition) were able to find the optimal LP solution in all eight deployments. The mean solution for all the two-person groups under Certainty, Risk, and Uncertainty by the eighth cycle was 95% of z*.

The behavior of the two-person groups in all three treatment conditions across the eight deployment cycles is shown in Figure 3, Panel B. Overall, it can be seen that the two-person groups in the Certainty condition after the first cycle consistently stayed at 99% of z* across the remaining seven deployment cycles. Two-person groups in the Risk condition displayed the best performance (i.e., 99% of z*) on the first and fifth deployment cycles when there was no personnel loss, whereas the two-person groups displayed inconsistent behavior during the other deployment cycles when there was a personnel loss. On the eighth cycle, the two-person groups finally achieved 98% of z*. The two-person groups in the Uncertainty condition can be seen displaying a consistent but suboptimal behavior across the eight deployment cycles (i.e., the two-person groups hovered around 95% of z*).

Three-Person Groups

Three of the three-person groups (i.e., three three-person groups in the Certainty condition) were able to find the optimal LP solution in all eight deployments. The mean solution for all the three-person groups under Certainty, Risk, and Uncertainty by the eighth cycle was 97% of z*.

The behavior of the three-person groups in all three treatment conditions across the eight deployment cycles is shown in Figure 3, Panel C. Overall, it can be seen that the three-person groups in the Certainty condition after the first cycle consistently stayed at 99% of z* across the remaining seven deployment cycles. After the first deployment cycle where the three-person groups' mean in the Risk condition was 99% of z*, three-person groups displayed a consistent but suboptimal performance for the remaining deployment cycles (i.e., the three-person groups hovered around 95% of z*). Three-person groups in the Uncertainty condition can be seen displaying the most success with the first and fifth deployment cycles (i.e., 97% and 99% of z*, respectively) when there was no personnel loss, whereas the three-person groups displayed inconsistent behavior during the other deployment cycles when there was a personnel loss.

Four-Person Groups

Three of the four-person groups (i.e., three four-person groups in the Certainty condition) were able to find the optimal LP solution in all eight deployments. The mean solution for all the four-person groups under Certainty, Risk, and Uncertainty by the eighth cycle was 94% of z*.

The behavior of the four-person groups in all three treatment conditions across the eight deployment cycles is shown in Figure 3, Panel D. Overall, it can be seen that the four-person groups in the Certainty condition after the first cycle consistently stayed at 99% of z* across the remaining seven deployment cycles. After displaying a group mean of 99% of z* during the first deployment cycle, four-person groups in the Risk condition moved down to 88% of z* on the second deployment cycle due to the personnel loss. On the subsequent deployment cycles, the four-person groups progressed back towards z* where on the eighth cycle, the four-person groups finally achieved 95% of z*. Four-person groups in the Uncertainty condition can be seen displaying the most success with the first and fifth deployments (i.e., 99% and 96% of z*, respectively) when there was no personnel loss, whereas the four-person groups displayed a consistent but suboptimal performance (i.e., the four-person groups hovered around 88% of z*) for the other deployment cycles when there was a personnel loss.

Certainty, Risk, and Uncertainty Effects

Individuals

There was a significant treatment effect with performance collapsed across cycles, $F(2,21) = 18.76$, $p < .001$. A Tukey HSD shows performance was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $p < .002$), while performance in the Risk and Uncertainty conditions were not significantly different from each other. Tests for interaction between treatment and cycle were not significant. However, cycle was a significant predictor of performance for the individuals in the Certainty condition, $R^2(1,6) = .81$, $p < .001$, demonstrating a learning effect. Cycle was not a predictor of performance for the individuals in the Risk and Uncertainty conditions.

Two-Person Groups

There was a significant treatment effect with performance collapsed across cycles, $F(2,21) = 8.49$, $p < .002$. A Tukey HSD shows performance was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $p < .005$), while performance in the Risk and Uncertainty conditions were not significantly different from each other. Tests for interaction between treatment and cycle were not significant. However, cycle was a marginally significant predictor of performance for the two-person groups in the Certainty condition, $R^2(1,6) = .36$, $p < .067$, demonstrating a learning effect. Cycle was not a predictor of performance for the two-person groups in the Risk and Uncertainty conditions.

Three-Person Groups

There was a significant treatment effect with performance collapsed across cycles, $F(2,21) = 11.22$, $p < .001$. A Tukey HSD shows performance was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $p < .003$), while performance in the Risk and Uncertainty conditions were not significantly different from each other. Tests for interaction between treatment and cycle were not significant. However, cycle was a marginally significant predictor of performance for the three-person groups in the Certainty condition, $R^2(1,6) = .38$, $p < .06$, demonstrating a learning effect. Cycle was not a predictor of performance for the three-person groups in the Risk and Uncertainty conditions.

Four-Person Groups

There was a significant treatment effect with performance collapsed across cycles, $F(2,21) = 12.72$, $p < .001$. A Tukey HSD shows performance was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $p < .003$), while performance in the Risk and Uncertainty conditions were not significantly different from each other. Tests for interaction between treatment and cycle were not significant. However, cycle was a marginally significant predictor of performance for the four-person groups in the Certainty condition, $R^2(1,6) = .36$, $p < .06$, demonstrating a learning effect. Cycle was not a predictor of performance for the four-person groups in the Risk and Uncertainty conditions.

Overall Comparison of the Four Different Groups

Comparing the three treatment conditions across individuals and groups (i.e., the two-person, three-person, and four-person groups), there was a significant effect in the

Certainty condition, $F(3,28) = 20.60$, $p < .001$ (Figure 4, Panel A). A Tukey HSD shows that performance from individuals was significantly different from the two-person, three-person, and four-person groups (HSD, $p < .001$), while performance from the two-person, three-person, and the four-person groups were not significantly different from each other.

There was a significant effect in the Risk condition when comparing the three treatment conditions across individuals and groups (i.e., the two-person, three-person, and four-person groups), $F(3,28) = 4.13$, $p < .015$ (Figure 4, Panel B). A Tukey HSD shows that performance from individuals was significantly different from the two-person, three-person, and four-person groups (HSD, $p < .03$), while performance from the two-person, three-person, and the four-person groups were not significantly different from each other.

There was a significant effect in the Uncertainty condition when comparing the three treatment conditions across individuals and groups (i.e., the two-person, three-person, and four-person groups), $F(3,28) = 8.21$, $p < .001$ (Figure 4, Panel C). A Tukey HSD shows that performance from individuals was significantly different from the two-person, three-person, and four-person groups (HSD, $p < .001$), while performance from the two-person, three-person, and the four-person groups were not significantly different from each other.

Individual Performance

Individuals

Panel A of Figure 5 depicts the six individuals' performances under Certainty. All but two of the six individuals improved between the first and second cycles. The greatest improvement was seen between the fifth and six cycles where only three individuals, averaging 94% of z*, had not achieved the optimal LP solution. From the sixth cycle on, there were never more than three individuals that had not achieved the optimal LP solution. By the eighth cycle, all but two individuals acquired z*.

None of the six individuals in the Risk condition improved between the first and second cycles (see Panel 5B). Unlike the individuals in the Certainty condition, there was never a consistent increase in the number of individuals acquiring the optimal LP solution in the remaining deployment cycles. The greatest improvement was seen between the fifth and sixth cycles where all but one individual was above 90% of z*. By the eighth cycle, only two individuals were below 90% of z*.

Only one of the six individuals in the Uncertainty condition improved between the first and second cycles (see Panel 5C). Like the individuals in the Risk condition, yet to a larger degree, there was never a consistent increase in the number of individuals acquiring the optimal LP solution in subsequent cycles. On the fifth cycle, only one individual achieved z*, while the other five individuals were below 90% of z*.

Two-Person Groups

Panel A of Figure 6 depicts the six two-person groups' performances under Certainty. All but one two-person group improved between the first and second cycles. After the third cycle, only one two-person group did not achieve the optimal LP solution. This suboptimal two-person group obtained 98% of z* for the remaining five cycles.

Of the six two-person groups in the Risk condition, only one two-person group improved between the first and second cycles (see Panel 6B). The greatest improvement was seen between the fourth and fifth cycles where only two two-person groups, averaging 95% of z*, had not achieved the optimal LP solution. After the fifth cycle, performance dropped for all the two-person groups. By the eighth cycle, none of the two-person groups acquired less than 92% of z*.

All but one of the six two-person groups in the Uncertainty condition improved between the first and second cycles (see Panel 6C). Like the two-person groups in the Risk condition, the greatest improvement was between the fourth and fifth cycles where only two two-person groups, averaging 92% of z*, had not achieved the optimal LP solution. Performance dropped after the fifth cycle and by the eighth cycle, only one two-person group was below 90% of the optimal LP solution.

Three-Person Groups

Panel A of Figure 7 depicts the six three-person groups' performances under Certainty. Only one of the three-person groups improved between the first and second cycles. After the second cycle, only one three-person group did not achieve the optimal LP solution. This suboptimal three-person group's performance was variable across the remaining cycles with the three-person group never achieving lower than 92% of z*.

Of the six three-person groups in the Risk condition, none improved between the first and second cycles (see Panel 7B). The greatest improvement was seen between the fourth and fifth cycles where only one three-person group, 87% of z*, had not achieved the optimal LP solution. After the fifth cycle, performance dropped for all the three-person groups. By the eighth cycle, none of the three-person groups acquired less than 94% of z*.

The three three-person groups in the Uncertainty condition improved between the first and second cycles (see Panel 7C). Like the three-person groups in the Risk condition, the greatest improvement was between the fourth and fifth cycles where only one three-person group, 92% of z*, had not achieved the optimal LP solution. After the fifth cycle, performance dropped for all the three-person groups and by the eighth cycle, only one three-person group was below 90% of the optimal LP solution.

Four-Person Groups

Panel A of Figure 8 depicts the six four-person groups' performances under Certainty. Only two four-person groups improved between the first and second cycles. From the second cycle to the sixth cycle, only two four-person groups did not achieve the optimal LP solution. After the sixth cycle, only one four-person group did not achieve the optimal LP solution.

Of the six four-person groups in the Risk condition, only one four-person group improved between the first and second cycles (see Panel 8B). The greatest improvement was seen between the fourth and fifth cycles where only one four-person group, 62% of z*, had not achieved the optimal LP solution. After the fifth cycle, performance dropped for all the four-person groups. By the eighth cycle, none of the four-person groups acquired less than 92% of z*.

None of the six four-person groups in the Uncertainty condition improved between the first and second cycles (see Panel 8C). Like the four-person groups in the Risk condition, the greatest improvement was between the fourth and fifth cycles where only one four-person group did not achieve the optimal LP solution (i.e., they were at 75% of z*). Performance dropped after the fifth cycle and by the eighth cycle, four four-person groups were below 90% of the optimal LP solution.

Behavior on the Day of a Loss and Subsequent Days

Individuals

Figure 9, Panel A shows that before a loss occurred, the individuals in all three treatment conditions allocated more hours of flight towards the personnel-hungry H-65, but after the personnel loss occurred, all individuals under Risk and Uncertainty changed their strategy and allocated more hours of flight towards the personnel-efficient H-52.

In order to clearly represent the immediate shift in allocation of hours when a loss had occurred, Figure 10, Panel A has been adjusted so that all loss days are averaged across individuals and cycles under the Risk and Uncertainty conditions with individuals in the Certainty condition shown for comparison only. As shown in Figure 10, Panel A, individuals in the Certainty condition scheduled the two helicopters for approximately equal hours, yielding a slope of approximately 1, where the optimal slope was 1 (i.e., 9 hours of flight for the H-65/9 hours of flight for the H-52). In the Risk and Uncertainty conditions, individuals produced a slightly higher slope of approximately 1.2 when there was no personnel loss. When the personnel loss occurred, it can be seen that the individuals under Risk and Uncertainty revised their strategy with an average slope of 2 for the Risk and Uncertainty conditions, where the optimal slope was 2.1 (i.e., 5.4 hours of flight for the H-65/11.4 hours of flight for the H-52). Day-before-loss behavior and day-of-loss behavior were significantly different, $\underline{F}(5,18) = 10.56$, $\underline{p} < .001$. Individuals in the Risk and Uncertainty conditions continued to average slopes of approximately 2.5 and 2.1 respectively, while individuals in the Certainty condition continued to average a slope of about 1, thus producing a significant interaction between treatment and day, $\underline{F}(10,18) = 3.58$, $\underline{p} < .009$.

Two-Person Groups

Figure 9, Panel B shows that before a loss occurred, the two-person groups in all three treatment conditions allocated more hours of flight towards the personnel-hungry H-65, but after the personnel loss occurred, all two-person groups under Risk and Uncertainty changed their strategy and allocated more hours of flight towards the personnel-efficient H-52.

In Figure 10, Panel B, two-person groups in the Certainty condition scheduled the two helicopters for approximately equal hours, yielding a slope of approximately 1, where the optimal slope was 1. In the Risk and Uncertainty conditions, two-person groups produced a slightly higher slope of approximately 1.1 and 1.3, respectively, when there was no personnel loss. When the personnel loss occurred, it can be seen that the two-person groups in Risk and Uncertainty revised their strategy with an average slope of 2.6 for the Risk condition and 2.2 for the Uncertainty condition, where the optimal slope was 2.1. Day-before-loss behavior and day-of-loss behavior were significantly different, $F(5,18) = 23.86$, $p < .001$. Two-person groups in the Risk and Uncertainty conditions continued to average slopes of approximately 2.5 and 2.3, respectively, while two-person groups in the Certainty condition continued to average a slope of about 1, thus producing a significant interaction between treatment and day, $F(10,18) = 6.99$, $p < .001$.

Three-Person Groups

Figure 9, Panel C shows that before a loss occurred, the three-person groups in all three treatment conditions allocated more hours of flight towards the personnel-hungry H-65, but after the personnel loss occurred, all three-person groups under Risk and

Uncertainty changed their strategy and allocated more hours of flight towards the personnel-efficient H-52.

In Figure 10, Panel C, three-person groups in the Certainty condition scheduled the two helicopters for approximately equal hours, yielding a slope of approximately 1.1, where the optimal slope was 1. In the Risk and Uncertainty conditions, three-person groups produced a slightly higher slope of approximately 1.1 when there was no personnel loss. When the personnel loss occurred, it can be seen that the three-person groups in Risk and Uncertainty revised their strategy with an average slope of 2.3 for the Risk condition and 2.6 for the Uncertainty condition, where the optimal slope was 2.1. Day-before-loss behavior and day-of-loss behavior were significantly different, $\underline{F}(5,18) = 13.26$, $\underline{p} < .001$. Three-person groups in the Risk and Uncertainty conditions continued to average slopes of approximately 2.5 and 2.7 respectively, while three-person groups in the Certainty condition continued to average a slope of about 1, thus producing a significant interaction between treatment and day, $\underline{F}(10,18) = 3.01$, $\underline{p} < .02$.

Four-Person Groups

Figure 9, Panel D shows that before a loss occurred, the four-person groups in all three treatment conditions allocated more hours of flight towards the personnel-hungry H-65, but after the personnel loss occurred, all four-person groups under Risk and Uncertainty changed their strategy and allocated more hours of flight towards the personnel-efficient H-52.

In Figure 10, Panel D, four-person groups in the Certainty condition scheduled the two helicopters for approximately equal hours, yielding a slope of approximately 1.1, where the optimal slope was 1. In the Risk and Uncertainty conditions, four-person groups produced a slightly higher slope of approximately 1.1 and 1.2, respectively, when there was no personnel loss. When the personnel loss occurred, it can be seen that the four-person groups in Risk and Uncertainty revised their strategy with an average slope of 2.3 for the Risk condition and 2.1 for the Uncertainty condition, where the optimal slope was 2.1. Day-before-loss behavior and day-of-loss behavior were significantly different, $F(5,18) = 30.17$, $p < .001$. Four-person groups in the Risk and Uncertainty conditions continued to average slopes of approximately 2.4 and 2.2, respectively, while four-person groups in the Certainty condition continued to average a slope of about 1, thus producing a significant interaction between treatment and day, $F(10,18) = 10.17$, $p < .001$.

Allocation of Resources by Day

Individuals

As shown in Figure 11, Panel A, individuals in all three treatment conditions flew the largest portion of flight hours on the first day of the cycle (i.e., 32% under Certainty, 33% under Risk, and 34% under Uncertainty). The percent of hours flown on subsequent days dropped by approximately 8% from day 1 to day 2, 3% from day 2 to day 3, and 2% from day 3 to day 4 thus producing a significant difference in the number of hours flown on each subsequent day, $F(3,8) = 273.18$, $p < .001$. A Tukey HSD shows the number of flight hours per each day were significantly different from each other (HSD, $p < .001$). The Certainty, Risk, and Uncertainty conditions, taken separately, each showed day of cycle to be significant ($p < .001$).

Two-Person Groups

As shown in Figure 11, Panel B, two-person groups in all three treatment conditions flew the largest portion of flight hours on the first day of the cycle (i.e., 29% under Certainty, 28% under Risk, 29% under Uncertainty). The percent of hours flown on subsequent days dropped by approximately 3% per day thus producing a significant difference in the number of hours flown on each subsequent day, $F(3,8) = 119.08$, $p < .001$. A Tukey HSD shows the number of flight hours per each day were significantly different from each other (HSD, $p < .001$). The Certainty, Risk, and Uncertainty conditions, taken separately, each showed day of cycle to be significant ($p < .001$).

Three-Person Groups

As shown in Figure 11, Panel C, three-person groups in all three treatment conditions flew the largest portion of flight hours on the first day of the cycle (i.e., 28% under Certainty, 27% under Risk, 26% under Uncertainty). The percent of hours flown on subsequent days dropped by approximately 3% from day 1 to day 2 and from day 2 to day 3, and 2% from day 3 to day 4 thus producing a significant difference in the number of hours flown on each subsequent day, $F(3,8) = 54.89$, $p < .000$. A Tukey HSD shows the number of flight hours per each day were significantly different from each other (HSD, $p < .004$). The Certainty, Risk, and Uncertainty conditions, taken separately, each showed day of cycle to be significant ($p < .001$).

Four-Person Groups

As shown in Figure 11, Panel D, four-person groups in all three treatment conditions flew the largest portion of flight hours on the first day of the cycle (i.e., 30% under Certainty, 28% under Risk, 29% under Uncertainty). The percent of hours flown on subsequent days dropped by approximately 4% from day 1 to day 2, 2% from day 2 to day 3 and from day 3 to day 4 thus producing a significant difference in the number of hours flown on each subsequent day, $F(3,8) = 87.48$, $p < .001$. A Tukey HSD shows the number of flight hours per each day were significantly different from each other (HSD, $p < .001$). The Certainty, Risk, and Uncertainty conditions, taken separately, each showed day of cycle to be significant ($p < .001$).

Allocation of Resources by Cycle

Individuals

As shown in Figure 12, the individuals in all three treatment conditions left substantial amounts of resources unallocated during the early cycles, but the individuals under Certainty were able to detect the waste early and minimize additional waste. By the fifth cycle, individuals allocated 93% of personnel and 94% of fuel. For the remainder of the deployment cycles, the amount of resources allocated for the individuals generally remained between 90% and 95%. By the eighth cycle, individuals returned with 7% of unused personnel and 6% of unused fuel (Figure 12, Panel A).

Individuals in the Risk condition did not learn efficient resource-allocation as quickly as did the individuals under Certainty. Although the individuals in the Certainty and Risk conditions started with approximately the same percentage of resources allocated, the individuals' performance under Risk actually decreased over the first four cycles and then showed steady improvement. Individuals were able to allocate a mean of 94% of personnel and 98% of fuel by the eighth cycle (Figure 12, Panel B). The comparative underutilization of fuel is caused by the individual's tendency to schedule the fuel-hungry H-52 for less than the optimal number of hours.

The individuals under Uncertainty did not improve over the eight cycles (Figure 12, Panel C). The individuals tended to underallocate fuel in the same way as did the individuals under Risk. However, individuals in the Uncertainty condition can be seen not showing any steady improvement across the eight deployment cycles.

Two-Person Groups

In the Certainty condition, two-person groups were able to detect the waste immediately and minimize additional waste. By the third cycle, two-person groups allocated 98% of personnel and fuel and by the eighth cycle, two-person groups returned with only 2% of unused personnel and fuel (Figure 13, Panel A).

Two-person groups in the Risk condition did not learn efficient resource-allocation as quickly as did the two-person groups under Certainty. Efficient resource-allocation can be seen in the first and fifth cycle where two-person groups allocated 98% of personnel and fuel (Figure 13, Panel B). Unlike the minimization in waste of resources during the first and fifth cycle, when a personnel loss occurred, an increase in unused resources occurred. By the eighth cycle, two-person groups allocated 97% of personnel and 98% of fuel.

The two-person groups under Uncertainty were at a higher percent of resources consumed than the two-person groups under Risk. The two-person groups did not show any steady improvement across the eight deployment cycles, but remained above 93% of consumed resources (Figure 13, Panel C).

Three-Person Groups

In the Certainty condition, three-person groups were able to detect the waste immediately and minimize additional waste. By the fifth cycle, three-person groups allocated 98% of personnel and fuel and by the eighth cycle, three-person groups returned with 2% of unused personnel and fuel (Figure 14, Panel A).

Three-person groups in the Risk condition did not learn efficient resource-allocation as quickly as did the three-person groups under Certainty. Although the three-person groups under Certainty and Risk started with approximately the same percentage of resources allocated, the three-person groups' performance under Risk actually decreased initially and then remained constant across the remaining deployment cycles. Three-person groups were able to allocate a mean of 96% of personnel and fuel by the eighth cycle (Figure 14, Panel B).

The three-person groups under Uncertainty were at approximately the same percent of resources consumed as the three-person groups under Certainty and Risk. The three-person groups did not show any steady improvement across the eight deployment cycles, but the best performance was in the fifth cycle where the three-person groups allocated 98% of personnel and fuel (Panel 14, Panel C).

Four-Person Groups

In the Certainty condition, four-person groups were able to detect the waste immediately and minimize additional waste. By the second cycle, four-person groups allocated 98% of personnel and fuel and by the eighth cycle, four-person groups returned with 2% of unused personnel and fuel (Figure 15, Panel A).

Four-person groups in the Risk condition did not learn efficient resource-allocation as quickly as did the four-person groups under Certainty. Although the four-person groups under Certainty and Risk started with approximately the same percentage of resources allocated, the four-person groups' performance under Risk decreased over the first four cycles and never showed any steady improvement. Four-person groups were able to allocate a mean of 93% of personnel and 98% of fuel by the eighth cycle (Figure 15, Panel B).

Except for the first cycle, the four-person groups under Uncertainty tended to underallocate fuel and personnel (Figure 15, Panel C). There was no improvement in performance across the remaining seven deployments cycles.

Cognitive Strategies

Despite the lack of verbal protocol data, we can still assess the day-to-day and deployment-to-deployment allocation strategies that individuals and groups used in order to determine the predominant cognitive strategy used in solving maximization problems. When an individual or group uses a SAS strategy, their allocation strategy is characterized by solving the resource-allocation problem with math and then repeating the same solution over and over across all the days and the deployments. When an individual or group uses a CAC strategy, their allocations strategy is characterized by solving the resource-allocation problem on a day-to-day basis by "consuming" resources and displaying varying solutions across all the days and the deployments. Using these two definitions of a SAS strategist and CAC strategist, the allocation strategies of individuals and groups were analyzed.

Individuals

In the Certainty, Risk, and Uncertainty conditions, none of the individuals (0%) utilized a SAS strategy where they attempted to determine the maximum amount of flight hours of the four-day deployment before scheduling on a daily basis. Rather, all the individuals (100%) in the Certainty, Risk, and Uncertainty conditions utilized a CAC strategy where they focused first on making daily allocations with the expectation that this would lead to the maximum amount of flight hours for the four-day deployment.

Two-Person Groups

In the Certainty condition, four of the two-person groups (67%) utilized a SAS strategy. Of the four two-person groups, two of them found z* on all eight cycles, whereas the other two two-person groups did not find z* on any of the eight deployment cycles but demonstrated a SAS strategy by allocating 9 hours of flight for the H-65 and 8 hours of flight for the H-52 consistently across the eight cycles, which is 94% of z*. The other two two-person groups (33%) in the Certainty condition utilized a CAC strategy.

In the Risk condition, one of the two-person groups (17%) utilized a SAS strategy while the remaining five two-person groups (83%) utilized a CAC strategy. The one two-person group that used the SAS strategy did not find z* on any of the eight deployment cycles but demonstrated a SAS strategy by allocating 9 hours of flight for the H-65 and 8 hours of flight for the H-52 consistently across the eight cycles, which is 94% of z*. In the Uncertainty condition, all the two-person groups (100%) used the CAC strategy.

Overall, five two-person groups (28%) across all three treatment conditions utilized the SAS strategy, whereas 13 two-person groups (72%) utilized the CAC strategy.

Three-Person Groups

In the Certainty condition, four of the three-person groups (67%) utilized a SAS strategy. Of the four three-person groups, three of them found z* on all eight cycles, whereas the other three-person group did not find z* on any of the eight deployment cycles but demonstrated a SAS strategy by allocating 9 hours of flight for the H-65 and 8 hours of flight for the H-52 consistently across the eight cycles, which is 94% of z*. The other two three-person groups (33%) in the Certainty condition utilized a CAC strategy.

In the Risk condition, one of the three-person groups (17%) utilized a SAS strategy while the remaining five three-person groups (83%) utilized a CAC strategy. The one three-person group that used the SAS strategy did not find z* on any of the eight deployment cycles but demonstrated a SAS strategy by allocating 9 hours of flight for the H-65 and 8 hours of flight for the H-52 consistently across the eight cycles, which is 94% of z*. In the Uncertainty condition, all the three-person groups (100%) used the CAC strategy.

Overall, five three-person groups (28%) across all three treatment conditions utilized the SAS strategy, whereas 13 three-person groups (72%) utilized the CAC strategy.

Four-Person Groups

In the Certainty condition, three of the four-person groups (50%) utilized a SAS strategy where all three four-person groups found z* on all eight cycles. The other three four-person groups (50%) in the Certainty condition utilized a CAC strategy.

In the Risk and Uncertainty conditions, none of the six four-person groups (0%) utilized a SAS strategy, all of the four-person groups (100%) utilized a CAC strategy.

Overall, three four-person groups (17%) across all three treatment conditions utilized the SAS strategy, whereas 15 four-person groups (83%) utilized the CAC strategy.

The Number of Correct Solutions for Individuals and Groups

Irrespective of the treatment condition, groups acquired a higher number of correct solutions, or z*, than individuals when using Shaw's (1932) method of comparing the number of correct solutions produced by individuals to the number of correct solutions produced by groups. Specifically, none of the individuals acquired z*, whereas eight of the groups acquired z*.

Irrespective of the treatment condition, groups acquired a higher number of correct solutions than individuals when using Taylor's (1954) method of comparing the number of correct solutions from "nominal" groups to the number of correct solutions from "real" groups. Specifically, none of the individuals acquired z* so when individuals were randomly assigned to "nominal" groups of two-, three-, and four-person groups, none of the groups were scored as having found z* since none of the individuals acquired z*. Eight "real" groups acquired z*.

Amount of Time Taken for the Introduction and Deployment

Individuals

There was no significant treatment effect with the amount of time taken to read the introduction collapsed across cycles, but there was a significant treatment effect with the amount of time taken to solve the problem collapsed across cycles, $F(2,21) = 5.88$, $p < .009$ (Figure 16, Panel A). A Tukey HSD shows the amount of time taken to solve the problem was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $p < .007$), while the amount of time taken to solve the problem in the Risk and Uncertainty conditions were not significantly different from each other.

Cycle was not a significant predictor of the amount of time taken to read the introduction under Certainty, Risk, and Uncertainty. Cycle was not a significant predictor of the amount of time taken to solve the problem under Certainty, but was marginally significant under Risk ($\underline{R}^2(1,6) = .36$, $\underline{p} < .068$) and Uncertainty ($\underline{R}^2(1,6) = .39$, $\underline{p} < .055$), demonstrating a decrease in the amount of time taken to solve the problem as the deployment cycles progressed.

Two-Person Groups

There was no significant treatment effect with the amount of time taken to read the introduction collapsed across cycles, but there was a significant treatment effect with the amount of time taken to solve the problem collapsed across cycles, $\underline{F}(2,21) = 4.13$, $\underline{p} < .031$ (Figure 16, Panel B). A Tukey HSD shows the amount of time taken to solve the problem was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $\underline{p} < .04$), while the amount of time taken to solve the problem in the Risk and Uncertainty conditions were not significantly different from each other.

Cycle was not a significant predictor of the amount of time taken to read the introduction. Cycle was not a significant predictor of the amount of time taken to solve the problem under Certainty and Uncertainty, but was significant under Risk ($\underline{R}^2(1,6) = .41$, $\underline{p} < .05$), demonstrating a decrease in the amount of time taken to solve the problem as the deployment cycles progressed.

Three-Person Groups

There was no significant treatment effect with the amount of time taken to read the introduction and the amount of time taken to solve the problem collapsed across cycles (Figure 16, Panel C).

Cycle was not a significant predictor of the amount of time taken to read the introduction. Cycle was a significant predictor of the amount of time taken to solve the problem under Certainty ($R^2(1,6) = .62$, $p < .021$), demonstrating a decrease in the amount of time taken to solve the problem as the deployment cycles progressed. Cycle was not a significant predictor of the amount of time take to solve the problem under Risk and Uncertainty.

Four-Person Groups

There was no significant treatment effect with the amount of time taken to read the introduction collapsed across cycles, but there was a significant treatment effect with the amount of time taken to solve the problem collapsed across cycles, $F(2,21) = 4.34$, $p < .026$ (Figure 16, Panel D). A Tukey HSD shows the amount of time taken to solve the problem was significantly different in the Certainty condition than in the Risk and Uncertainty conditions (HSD, $p < .032$), while the amount of time taken to solve the problem in the Risk and Uncertainty conditions were not significantly different from each other.

Cycle was not a significant predictor of the amount of time taken to read the introduction. Cycle was not a significant predictor of the amount of time taken to solve the problem under Risk, but was significant under Certainty ($R^2(1,6) = .45$, $p < .04$) and

Uncertainty ($R^2(1,6) = .51$, $p < .028$), demonstrating a decrease in the amount of time taken to solve the problem as the deployment cycles progressed.

Overall Comparison of the Four Different Groups

Comparing the amount of time taken to read the introduction across individuals and groups (i.e., the two-person, three-person, and four-person groups), there was no significant effect in the Certainty, Risk, and Uncertainty conditions (Figure 17, Panels A-C). Comparing the amount of time taken to solve the problem across individuals and groups (i.e., the two-person, three-person, and four-person groups), there was a significant effect in the Certainty condition, $F(3,28) = 10.95$, $p < .001$ (Figure 18, Panel A). A Tukey HSD shows the amount of time taken to solve the problem was significantly different for the individuals than the two-person, three-person, and four-person groups (HSD, $p < .032$), while the amount of time taken to solve the problem in the two-person, three-person, and the four-person groups were not significantly different from each other. There was no significant treatment effect across individuals and groups (i.e., the two-person, three-person, and four-person groups) in the Risk and Uncertainty conditions (Figure 18, Panels B-C).

Discussion

The first purpose of the thesis was to replicate the findings from the Langholtz et al., (1993) study. Results showed that individuals under Certainty and Risk showed patterns of learning as the deployment cycles progressed as opposed to the individuals under Uncertainty. When presented with a change in resources, individuals under Risk and Uncertainty responded with an appropriate revision of behavior, but the amount was not sufficient to achieve the same level of performance as when no changes in resources was introduced. Individuals in all three treatment conditions chose to allocate more resources during the early days of each cycle and individuals under Certainty and Risk left less unused resources by the eighth cycle as opposed to individuals under Uncertainty.

Overall, individuals were able to obtain at least 81-96% of the optimal LP solution confirming once again that decision makers can solve linear programming problems intuitively in resource-allocation problems. The best performance was seen in the Certainty condition, and after some practice, in the Risk condition, whereas the worst performance was in the Uncertainty condition. These results are consistent with the Langholtz et al. (1993) study.

Some Plausible Explanations for Group Performance in Resource-Allocation Problems

The second purpose of the thesis is to analyze how groups of varying sizes (i.e., the two-person, three-person, and four-person groups) allocate resources in maximization problems when the goal is to maximize payoff with a limited amount of resources.

Groups as Functioning Linear Programmers

The first question in this research was to see if groups are capable of solving resource-allocation problems intuitively when faced with a maximization resource-allocation problem. These data demonstrate that groups can solve linear programming problems intuitively in resource-allocation problems. The best performance was seen in the Certainty condition, and after some practice, in the Risk and Uncertainty conditions. Two-person, three-person, and four-person groups in the Certainty condition started at 94%, 96%, and 95% of z*, respectively, on the first cycle and immediately progressed to 99% of z* on the second cycle. All the groups remained at that percent of z* for the remaining seven deployments.

Two-person, three-person, and four-person groups in the Risk condition, unlike those in the Certainty condition, did not immediately progress to 99% of z* by the second cycle. Instead, the two-person, three-person, and four-person groups moved away from the most attractive corner by going as low as 86%, 94%, and 88% of z*, respectively, in the second cycle due to the adjustments needed when the personnel loss occurred. On the fifth cycle (i.e., when no personnel loss occurred), the two-person and three-person groups achieved 99% of z* and the four-person groups achieved 94% of z*, but after the fifth cycle, the groups again moved away from the most attractive corner due to the reoccurrence of the personnel loss. By the eighth cycle, the groups finally achieved 98% of z* for the two-person groups and 97% of z* for the three-person and four-person groups.

Like the groups in the Risk condition, the groups in the Uncertainty condition did not immediately progress to 99% of z* as did the groups in the Certainty condition.

Instead, the two-person, three-person, and four-person groups moved away from the most attractive corner by going as low as 95%, 89%, and 88% of z*, respectively, in the second cycle due to the adjustments needed when the personnel loss occurred. On the fifth cycle (i.e., when no personnel loss occurred), the two-person, three-person, and four-person groups achieved 98%, 99%, and 96% of z*, respectively, but after the fifth cycle, all the groups again moved away from the most attractive corner due to the reoccurrence of the personnel loss. By the eighth cycle, the two-person, three-person, and four-person groups finally achieved 91%, 94%, and 88% of z*, respectively.

<u>Percent of Z*</u>

The second question in this research was to see what level of success would be obtained when solving maximization problems by two-person, three-person, and four-person groups. The Langholtz et al. studies (1993, 1994, 1995, 1997) that examined people's resource-allocation behavior in maximization problems found that participants were obtaining solutions of at least 80-90% of the optimal LP solution. All the groups in the present study, even under Uncertainty, demonstrated a higher level of success at approaching the optimal LP solution. In the first cycle, the average performance for the two-person, three-person, and four-person groups in all three treatment conditions was at 98%, 97%, and 98% of z*, respectively, and by the eighth cycle, the groups' average performance was at 96% of z* for the two-person and three-person groups and 95% of z* for the four-person groups.

Overall, in maximization problems where the objective is to maximize payoff with a limited amount of resources, the two-person, three-person, and four-person groups obtained solutions of at least 95% of z* or higher. The percent of z* that the groups acquired in all three treatment conditions in the study was significantly higher than the percent of z* that the individuals acquired. The groups' ability to acquire a higher percent of z* in the current study is consistent with the individual versus group performance literature that states that groups produce higher quality solutions (for reviews, see Davis, 1969; Duncan, 1959; Lorge, Fox, Davitz, & Brenner, 1958).

Learning Across Deployment Cycles

The third question in this research was to see the type of learning that would take place with practice over the course of the problem cycles. Without knowing the formal LP model, all the groups (i.e., the two-person, three-person, and four-person groups) in the Certainty condition immediately improved their resource-allocation skills, whereas in the Risk and Uncertainty conditions, all the groups' resource-allocation behavior was variable during deployment cycles when a personnel loss occurred as opposed to deployment cycles when there was no personnel loss.

On the first cycle, the two-person, three-person, and four-person groups in the Certainty condition averaged 94%, 96%, and 95% of z*, respectively. From the second cycle on, all the groups (i.e., two-person, three-person, and four-person groups) moved to 99% of z* and remained there for the remaining seven deployment cycles.

After the first cycle, where the two-person, three-person, and four-person groups in the Risk condition obtained 99% of z*, their performance wavered across the remaining deployment cycles until the eighth cycle, where they finally achieved 98%, 97%, and 97% of z*, respectively. The two-person, three-person, and four-person groups in the Uncertainty condition obtained 98%, 97%, and 99% of z*, respectively, on the first cycle. Like the groups in the Risk condition, all the groups wavered in their performance throughout the subsequent deployment cycles, but unlike the groups in the Risk condition, all the groups under Uncertainty did not acquire as high a percent of the optimal LP solution by the eighth cycle. In the eighth cycle, the two-person, three-person, and four-person groups obtained 92%, 94%, and 87% of z*, respectively.

Mid-Course Adjustments

The fourth question in this research was to see how the decision maker handles a mid-course adjustment when something unexpected occurs. These data demonstrate that all the groups (i.e., the two-person, three-person, and four-person groups) were cognizant of when they needed to revise their allocation strategy as a response to the personnel loss during a current deployment cycle and as a result of experience over several deployment cycles. All the groups in the Risk and Uncertainty conditions recognized when a change in the allocation of hours to the helicopter was needed in order for them to achieve optimal results.

The behavior of switching their strategy of flying more flight hours with the personnel-hungry H-65 to the personnel-efficient H-52 when the personnel loss occurred is depicted by all the groups in the Risk and Uncertainty conditions in Figures 9 and 10. All the groups in the Risk and Uncertainty conditions continued to maintain this newly adopted strategy throughout the rest of the deployment, demonstrating their consistent efforts to achieve or maintain the optimal result (i.e., the maximum amount of flight hours). In addition, another clear representation of the ability for all the groups in the Risk and Uncertainty conditions to revise their strategies when faced with a personnel loss is demonstrated in Figure 3, Panels B-D where all the group performances improved over the deployment cycles.

Performance under Certainty, Risk, and Uncertainty

The fifth question in this research was to see the behavior that the groups exhibited when faced with different environmental manipulations (i.e., Certainty, Risk, and Uncertainty). The results of this study demonstrate that in resource-allocation problems that requires participants to maximize payoff with a limited amount of resources, the two-person, three-person, and four-person groups were best under Certainty, and after some practice Risk and Uncertainty. This is contrary to previous findings in Langholtz et al. (1993) study where participants were best under Certainty, after some practice Risk, and worst under Uncertainty demonstrating that the performance of individuals were significantly different in each treatment condition. However, in the current study, the performance of all the groups under Certainty was significantly different from Risk and Uncertainty, but the performance of all the groups under Risk and Uncertainty were not significantly different from each other.

Individual Differences

The sixth question of this research was to see how much variation there is among groups' resource-allocation behavior. There was a wide variability of allocation performance among all the groups (i.e., the two-person, three-person, and four-person groups), especially under Risk and Uncertainty. After the second cycle, all the groups in the Certainty condition remained at 99% of z* for the remaining seven deployment cycles. In the Risk condition, the variability of all the groups was higher than in the Certainty condition. The variability was greatest during the deployment cycles when there was a personnel loss. This variability did not diminish as the deployment cycles progressed unless it was a deployment cycle when there was no personnel loss. In the

Uncertainty condition, all the groups displayed slightly more variability when there was a personnel loss and like the groups in the Risk conditions, the variability did not diminish as the cycles progressed unless it was a deployment cycle when there was no personnel loss.

Plausible Cognitive Strategies

The seventh question in this research was to see what type of cognitive strategy or strategies groups use when solving maximization problems. An analysis of the allocation strategies of the groups can be used to assess whether the groups displayed no variability in the allocation strategies from day-to-day and deployment-to-deployment, which is consistent with a SAS strategy, or whether groups displayed variability in the allocation strategies from day-to-day and deployment-to-deployment, which is consistent with a CAC strategy. Results show that 28% of the groups (i.e., two-person and three-person groups) used SAS strategies (i.e., five groups) and 72% of the groups (i.e., two-person and three-person groups) were CAC strategies (i.e., 13 groups) irrespective of the treatment condition. For the four-person groups, results show that 17% of the groups were SAS strategists (i.e., three groups) and 83% of the groups used CAC strategists (i.e., 15 groups) irrespective of treatment condition.

Some Plausible Explanations for Individual versus Group Performance in Resource-Allocation Behavior

The third purpose of the thesis is to determine how the resource-allocation performance of individuals compares to the resource-allocation performance of groups of varying sizes (i.e., the two-person, three-person, and four-person groups).

Individuals versus Groups in the Number of Solutions

The eighth question in this research was to see whether groups are superior (i.e., more effective) to individuals when solving a resource-allocation problem. When analyzing the data as Watson (1928), Shaw (1932) and others did, results demonstrate that groups (i.e., the two-person, three-person, and four-person groups) are superior to the individuals. Specifically, no individuals under any of the treatment conditions were able to find the optimal LP solution in all eight deployments, whereas two two-person groups, three three-person groups, and three four-person groups, all under Certainty were able to find the optimal LP solution in all eight deployments. This is consistent with the individual versus group problem-solving literature (for reviews, see Davis, 1969; Duncan, 1959; Lorge, Fox, Davitz, & Brenner, 1958).

When analyzing the data using the "nominal" group technique developed by Taylor (1954), groups were still superior to individuals. This is inconsistent with Marquart's (1955) finding where "nominal" groups were equal to "real" groups. The reason for the contradiction is that none of the individuals who made up the "nominal" groups of two-, three-, and four-person groups were able to find the optimal LP solution in all eight deployments.

Individual versus Groups in the Number of Person-Minutes

The ninth question in this research was to determine if individuals are superior (i.e., more efficient) in the amount of person-minutes used to solve the resource-allocation problem as opposed to groups. Under Certainty, the individuals took a significantly longer amount of time to solve the problem across all eight deployment cycles than all the groups (i.e., the two-person, three-person, and four-person groups).

Under Risk and Uncertainty, there was no significant difference between the individuals and groups (i.e., the two-person, three-person, and four-person groups) with respects to the amount of time taken to solve the problem across all eight deployment cycles.

Overall, groups did demonstrate a meaningful savings of person-minutes when solving the resource-allocation problem as compared to the individuals under the Certainty condition therefore making groups more efficient than individuals. However, under Risk and Uncertainty groups did not demonstrate a meaningful savings of person-minutes as compared to individuals therefore making individuals more efficient than groups.

Conclusion

Gingrich and Soli (1984), Busemeyer et al. (1986), Langholtz et al. (1993, 1994, 1995, 1997), and Ball et al. (1998) have demonstrated how individuals behave in resource-allocation tasks where the objective is to achieve a maximum payoff with a fixed amount of resources. The primary objective of the present study was to determine how groups of varying sizes (i.e., the two-person, three-person, and four-person groups) perform when asked to solve a maximization resource-allocation task. This study demonstrates not only that groups are capable of solving maximization problems, but that groups are superior to individuals acquiring more correct solutions and in addition, obtaining solutions at a higher percent of z* than what has been found in previous studies on maximization problems with individuals. In addition, in terms of the number of person-minutes, this study demonstrates that groups are more efficient than individuals under Certainty, but individuals are more efficient than groups under Risk and

Uncertainty. Also this study demonstrates that all the groups are capable of performing resource-allocation tasks best under Certainty and after some practice, Risk and Uncertainty.

This study adds to our understanding of resource-allocation behavior, but this is not the end. As was stated in the introduction, it would be of valuable interest to study group processes to ascertain how members of a group facilitate or inhibit the development of a group product (i.e., the resource-allocation solution). For example, Steiner's (1972) analysis of individuals versus groups stressed the importance of task demands and suggested that clearer insights into group processes result from comparing groups' actual productivity with their potential productivity. When looking at groups in this mindset, groups routinely fall short of their potential. For example, when the most capable members of a problem-solving group are not confident, have low status, or are not talkative, the group is likely to under-utilize its resources. The inability of everyone in an interacting group to talk and think at the same time can likewise impede optimal group performance.

As we gain more knowledge about such group processes, we may be better able to help groups achieve their full potential. Group resource-allocation decisions are ubiquitous in everyday life and additional studies are needed in order to reveal how groups perform various resource-allocation tasks.

Appendix A

<u>Introduction presented to the Certainty, Risk, and Uncertainty conditions</u>

You are a Commander in the United States Coast Guard and have been assigned to oversee a four-day law enforcement deployment staged from the Caribbean Islands. In this deployment, the Coast Guard will be using two different helicopters: the H-65 and the H-52. The H-65 and H-52 differ in their personnel and fuel requirements. The H-65 requires 6 personnel hours for each hour of flight and 50 gallons of fuel for each hour of flight, whereas the H-52 requires 4 personnel hours for each hour of flight and 75 gallons of fuel for each hour of flight. In addition, you are required to schedule at least a combined minimum of 1.5 total hours of flight per day.

For this four-day law enforcement deployment, you will have a total of 90 personnel hours and a total of 1125 gallons of fuel that you will have to allocate over the four-day deployment. Your job is to find the most efficient way to allocate all the resources (i.e., the 90 personnel hours and the 1125 gallons of fuel) between the two helicopters while maximizing the total number of flight hours over the area patrolled in the four-day law enforcement deployment.

You will be repeating this four-day deployment for eight consecutive times. At the end of each four-day deployment, the helicopters will return to their parent station and take any remaining personnel hours and gallons of fuel with them. Resources (i.e., personnel hours and gallons of fuel) cannot be carried over from one four-day deployment to another four-day deployment. A fresh H-65 and H-52 will arrive for the start of each four-day law enforcement deployment.

<u>Presented to the Risk Condition after the Introduction</u>

During previous law enforcement deployments, unforeseen events such as sickness and injury have caused a decrease in the number of personnel hours available. There is a 25% chance that such a problem can occur on any day during the four-day deployment. When these types of events have occurred, there has been a loss of 12 personnel hours. The loss in personnel hours can only occur once during each four-day law enforcement deployment because additional personnel will be brought in to prevent any loss beyond 12 personnel hours.

Presented to the Risk and Uncertainty Conditions when the Personnel Loss Occurs

The flu has affected several personnel at the Coast Guard station. Due to the sickness of personnel, the available amount of personnel hours has been reduced from X –12, where X is the amount of personnel hours that you have remaining at the time the personnel loss occurred. The remaining amount of fuel at the time of the personnel loss has not been affected. This loss of personnel hours will remain constant for the remainder of the four-day law enforcement deployment.

Appendix B

The structure of the four-day resource-allocation scenario can be represented as an LP problem with the following set of equations:

Under Certainty, the Objective Function:

$$\text{Maximize } T = \{H\text{-}65(1) + H\text{-}65(2) + H\text{-}65(3) + H\text{-}65(4)\} + \{H\text{-}52(1) + H\text{-}52(2) + H\text{-}52(3) + H\text{-}52(4)\} \qquad (1)$$

Where the variable T represents the total hours of flight over the course of the four-day law enforcement deployment. H-65(x) and H-52(x) represent the total number of flight hours obtained on Helicopter H-65 or from Helicopter H-52 respectively on day x.

Personnel constraint:

$$90 \geq \sum_{x=1}^{4} \{6H\text{-}65(x) + 4H\text{-}52(x)\} \qquad (2)$$

Where the values 6 and 4 are the number of personnel hours required for each hour of flight by helicopters H-65 and H-52, respectively. The total amount of personnel hours allocated for both helicopters over the course of the four-day deployment must be less than, or equal to, 90 hours.

Fuel constraint:

$$1125 \geq \sum_{x=1}^{4} \{50H\text{-}65(x) + 75H\text{-}52(x)\} \qquad (3)$$

Where the values 50 and 75 are the number of gallons of fuel consumed each hour by helicopters H-65 and H-52, respectively. The total amount of fuel allocated for both helicopters over the course of the four-day deployment must be less than, or equal to, 1125 gallons.

Minimum flying constraint:

$$1.5 \leq H\text{-}65(x) + H\text{-}52(x) \quad (4)$$

Equation (4) states that the total number of flight hours flown by the H-65 and H-52 on any day x, must be greater than, or equal to, 1.5 hours.

Non-negativity constraint:

$$0 \leq H\text{-}65(x),\ H\text{-}52(x) \quad (5)$$

Equation (5) requires the number of hours flown on day x by the H-65 and H-52, must be greater than, or equal to, 0.

Under Risk and Uncertainty:

The objective function, fuel constraint, minimum flying constraint, and non-negativity constraint are exactly the same for the Risk and Uncertainty conditions. The personnel constraint is the only constraint that changes.

Personnel constraint:

$$78 \geq \sum_{x=1}^{4} \{6H\text{-}65(x) + 4H\text{-}52(x)\} \quad (6)$$

Where the values 6 and 4 are the number of personnel hours required for each hour of flight by helicopters H-65 and H-52, respectively. The total amount of personnel hours allocated for both helicopters over the course of the four-day deployment must be less than, or equal to, 78 hours.

Table 1

The Number of "Units" in the 4 x 3 Level Design

	Certainty	Risk	Uncertainty
Individuals	6 units n = 6 participants	6 units n = 6 participants	6 units n = 6 participants
Two-Person Groups	6 units n = 12 participants	6 units n = 12 participants	6 units n = 12 participants
Three-Person Groups	6 units n = 18 participants	6 units n = 18 participants	6 units n = 18 participants
Four-Person Groups	6 units n = 24 participants	6 units n = 24 participants	6 units n = 24 participants

Note. N = 180 participants.

Table 2

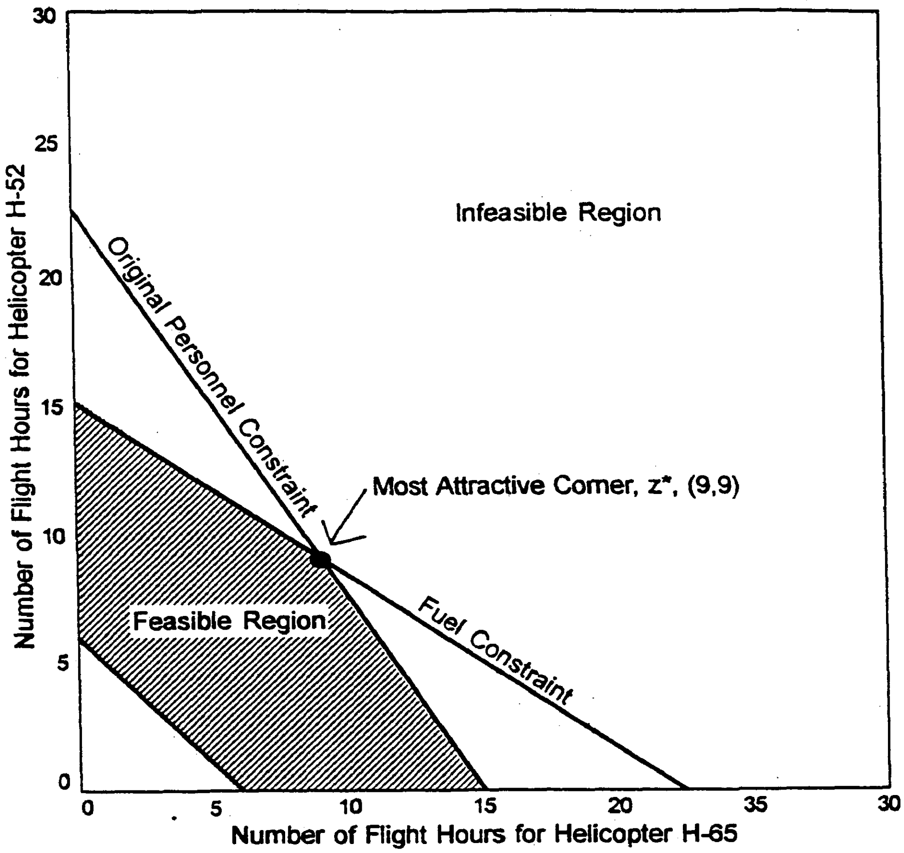
Timing of Personnel Loss Situation for Risk and Uncertainty Conditions

Deployment Cycle	Personnel Loss Situation
1	No personnel loss situation
2	Personnel loss situation at the start of Day 2
3	Personnel loss situation at the start of Day 3
4	Personnel loss situation at the start of Day 4
5	No Personnel loss situation
6	Personnel loss situation at the start of Day 4
7	Personnel loss situation at the start of Day 3
8	Personnel loss situation at the start of Day 2

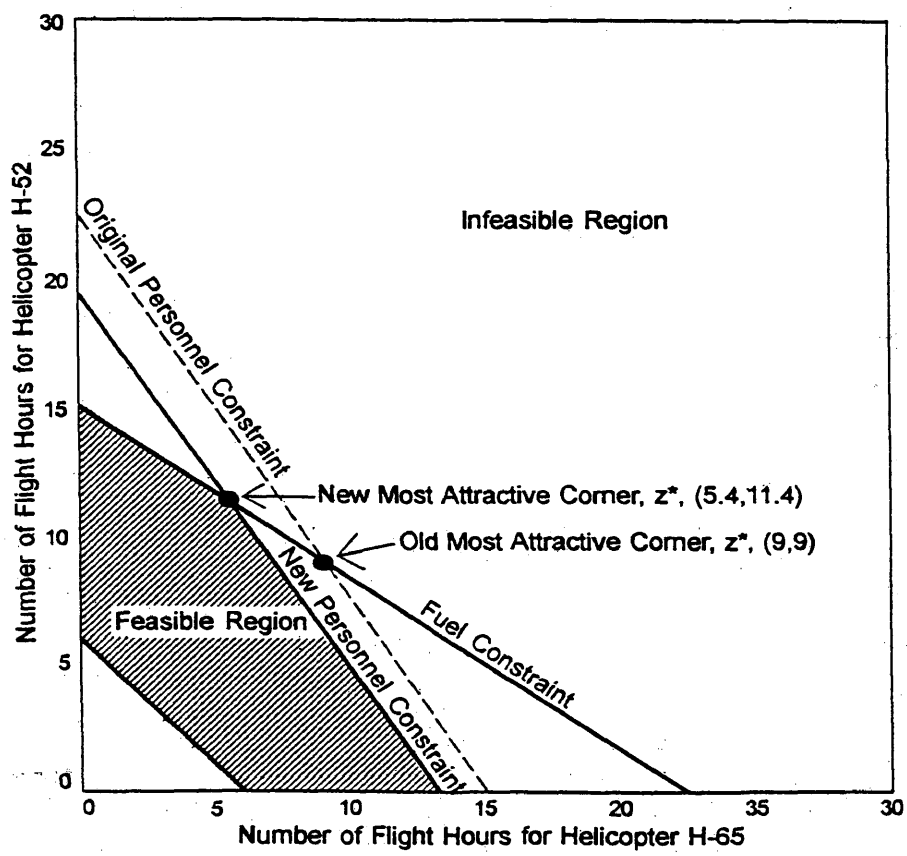
Note. Personnel loss situation is X –12 where X is the amount of personnel hours that the individuals and groups have remaining at the time this personnel loss occurred.

Figure Caption

Figure 1. Graphical representation of the feasible regions under Certainty, Risk, and Uncertainty for the four-day deployment. In Panel A, the feasible region with no personnel loss, indicated with shading, is bounded by the original personnel constraint, fuel constraint, and minimum time constraint. The optimal solution, z*, or the most attractive corner, is at the intersection of the original personnel constraint and fuel constraint. In Panel B, the feasible region with a 12-hour personnel loss, indicated with shading, is bounded by the same fuel and minimum time constraints, as in Panel A, and with the new personnel constraint. The optimal LP solution is at the intersection of the new personal constraint and the fuel constraint.



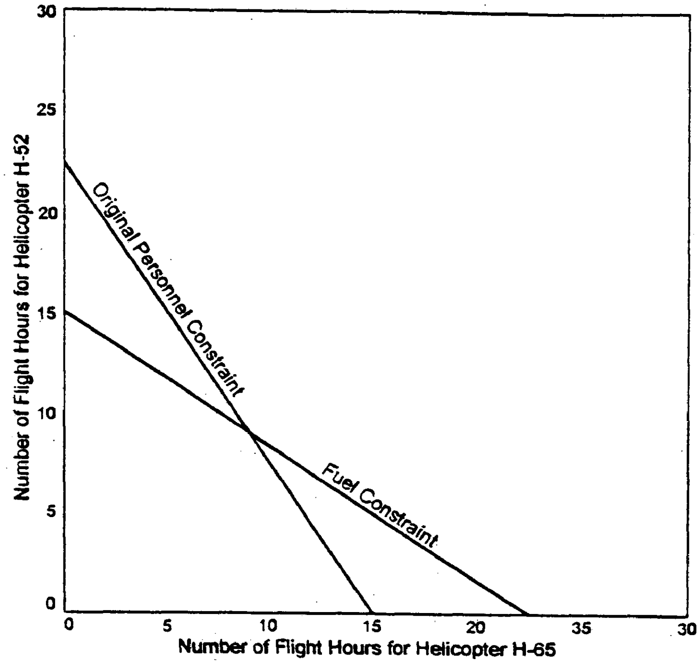
Panel A: Certainty and no personnel loss under Risk and Uncertainty



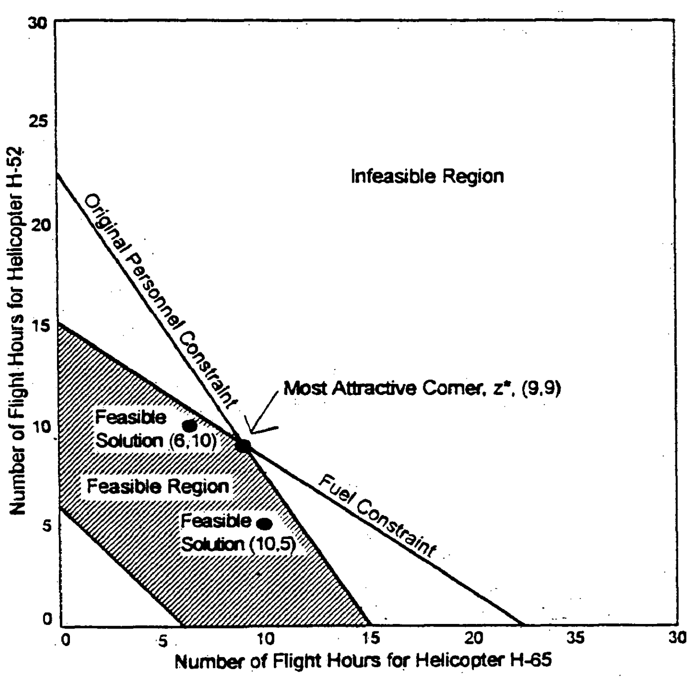
Panel B: Personnel loss under Risk and Uncertainty

Figure Caption

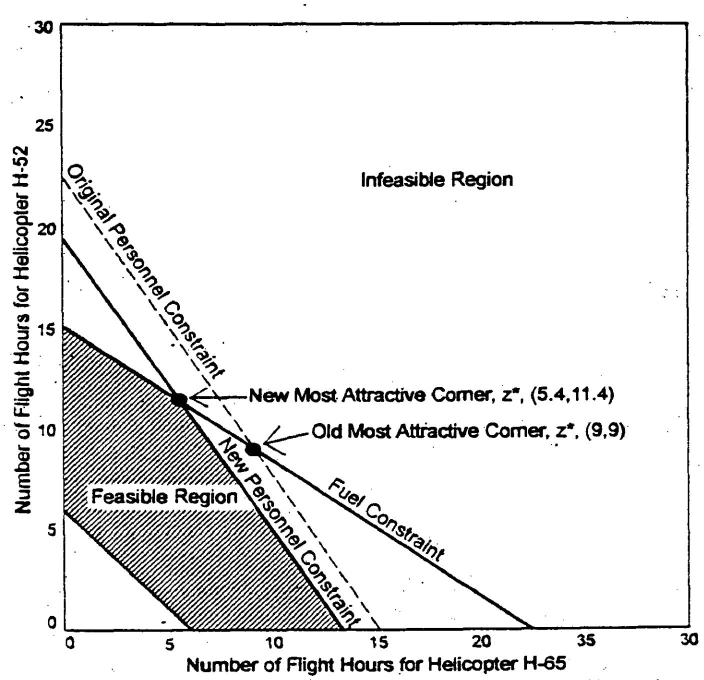
Figure 2. The three panels above show the basic components of an LP structure using the graphical solution method. Panel A represents the two dimensions of the maximization problem represented on the x axis and y axis and the personnel and fuel constraint lines determined by equations 2 and 3 as shown in Appendix B. In Panel B, several possible feasible solutions are depicted in the feasible region, but only one of the feasible solutions is the most attractive corner, z*, or the optimal LP solution. Panel C provides a comparison of the original personnel constraint line and old most attractive corner to the new personnel constraint line and new most attractive corner in order to depict the shift that is created as a result of a decrease in the amount of available personnel hours under Risk and Uncertainty.



Panel A: The two available allocation alternatives for the maximization resource-allocation problem (i.e., the H-65 on the x-axis and the H-52 on the y-axis) with the personnel and fuel constraint lines



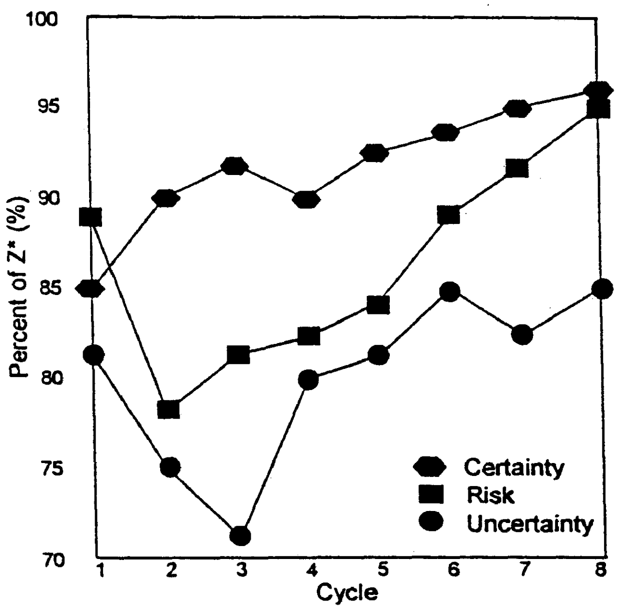
Panel B: The feasible solution region, feasible solutions, and the most attractive corner included as z*



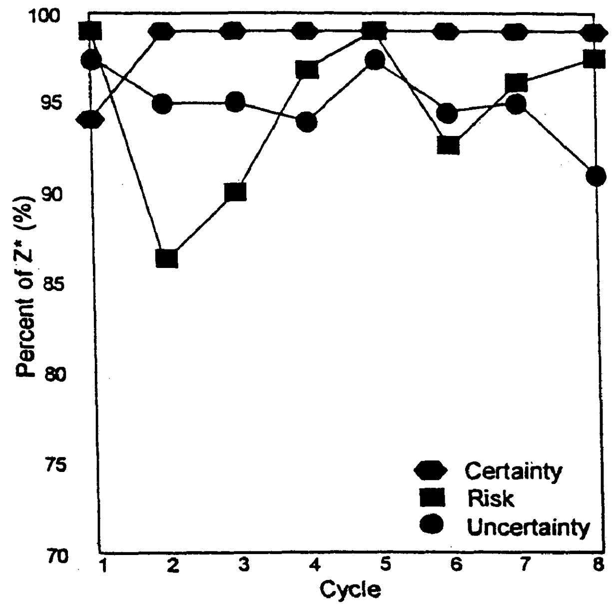
Panel C: The resource-allocation problem under Risk and Uncertainty

Figure Caption

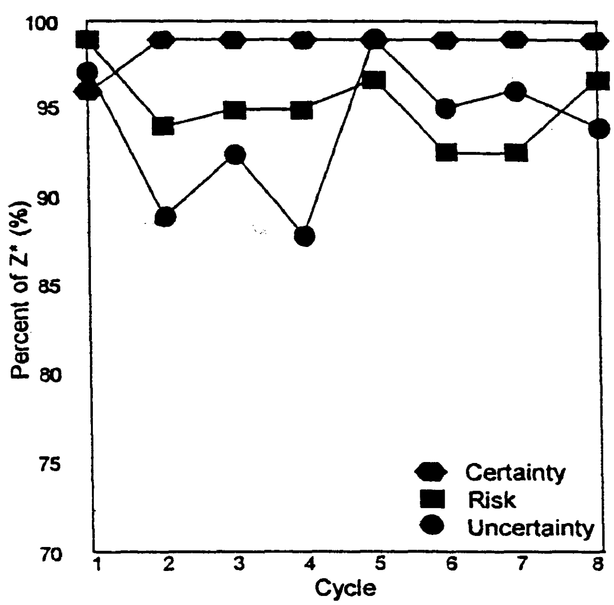
Figure 3. Percentage of the optimal LP solution for individuals, two-person, three-person, and four-person groups under Certainty, Risk, and Uncertainty. In Panel A, despite the 85% of z* acquired by the individuals in the Certainty condition on the first cycle, they quickly learned and immediately progressed up to 92% of z* by the third cycle and then up to 96% of z* on the eighth cycle. Individuals in the Risk condition did not learn as quickly, but progressed up towards 95% of z* by the eighth cycle, whereas individuals in the Uncertainty condition did not show any pattern of learning. In Panel B-D, two-person, three-person, and four-person groups under Certainty immediately progressed to 99% of z* by the second deployment cycle. Two-person, three-person, and four-person groups under Risk did not learn as quickly, but progressed up to 97%, 96%, and 96% of z*, respectively, by the eight cycle. In the Uncertainty condition, two-person, three-person, and four person groups did not show any pattern of learning.



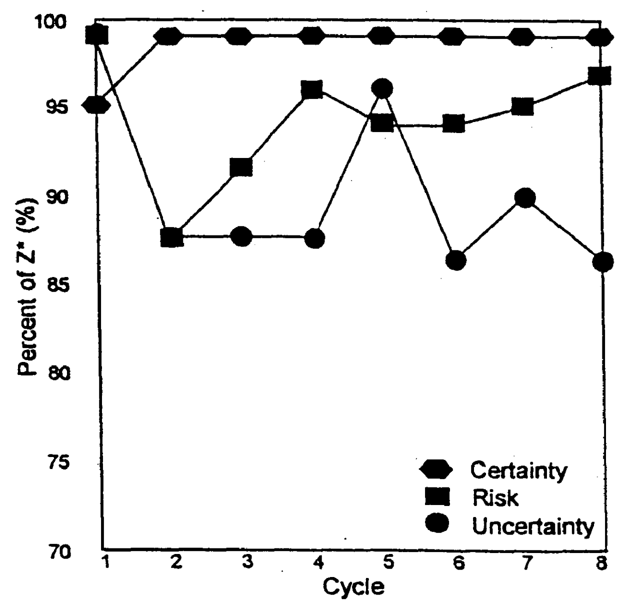
Panel A: Individuals



Panel B: Two-Person Groups



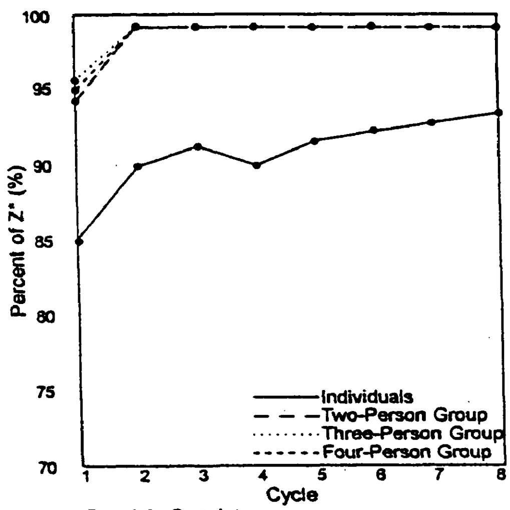
Panel C: Three-Person Groups



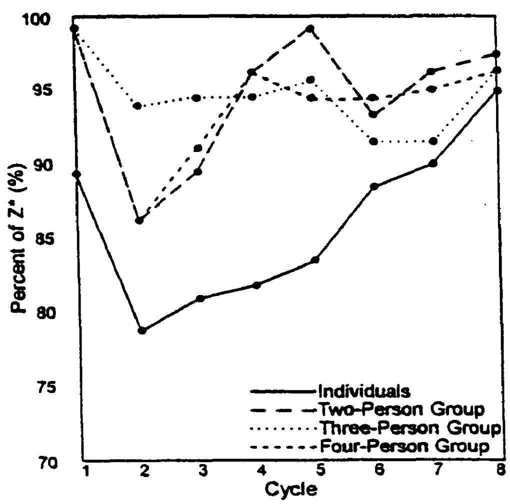
Panel D: Four-Person Groups

Figure Caption

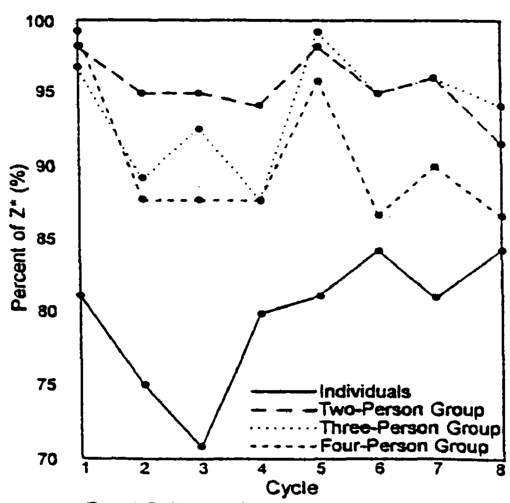
Figure 4. Comparison of the performances of individuals, two-person, three-person, and four-person groups under Certainty, Risk, and Uncertainty. In Panel A under Certainty, individuals began at 85% of z* and slowly progressed towards z* where by the eighth cycle they achieved 96% of z*. However, the two-person, three-person, and four-person groups immediately progressed to 99% of z* by the second cycle and stayed at 99% of z* for the remaining deployment cycles. In Panel B under Risk, individuals did not begin to progress towards z* until after the third cycle once the individuals were able to adjust appropriately to the personnel loss. By the eighth cycle, they achieved 95% of z*. Two-person, three-person, and four-person groups wavered across the deployment cycles but none of the groups achieved lower than 88% of z*. In Panel C under Uncertainty, the individuals did not progress at all towards z* and did not acquire any solutions higher than 85% of z* on any of the deployment cycles. Two-person, three-person, and four-person groups on the other hand, wavered across the deployment cycles but at a higher percent of z* with none of the groups performing lower than 88% of z*.



Panel A: Certainty



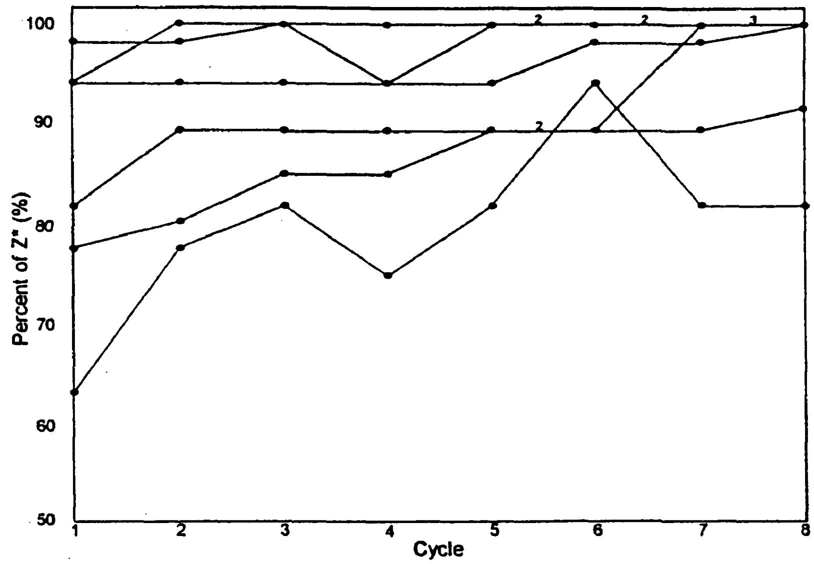
Panel B: Risk



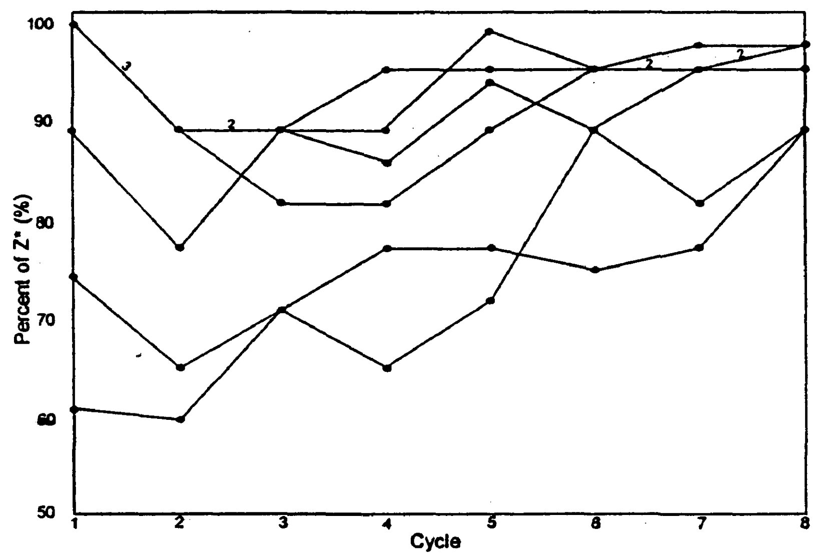
Panel C: Uncertainty

Figure Caption

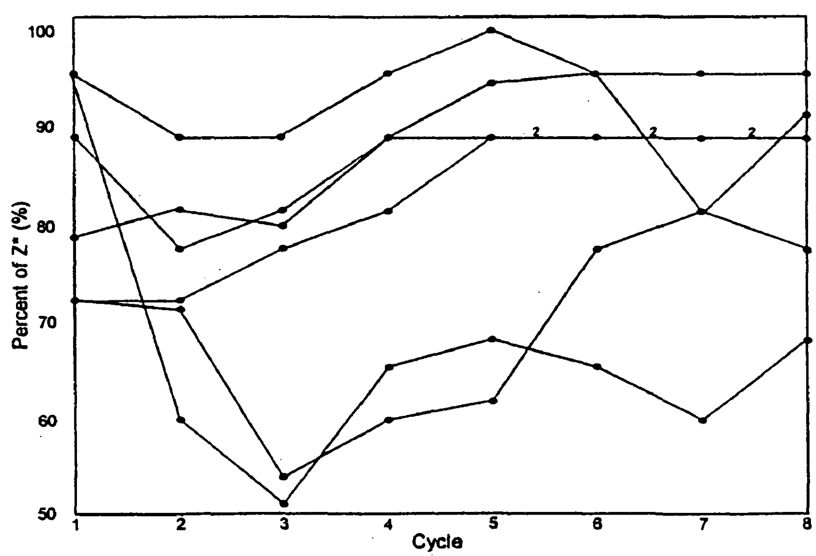
Figure 5. The individual trends over the eight deployment cycles under Certainty, Risk, and Uncertainty for individuals. In Panel A under Certainty, it was until the sixth cycle that all but two individuals were above 90% of z*. By the eighth cycle, all but two individuals had reached z*. In Panel B under Risk, individuals had difficulty obtaining z* across the eight deployment cycles. It was until the eighth cycle that only two individuals were below 90% of z*. In Panel C under Uncertainty, individuals had the most trouble achieving the optimal LP solution throughout all eight deployment cycles.



Panel A: Individuals under Certainty



Panel B: Individuals under Risk

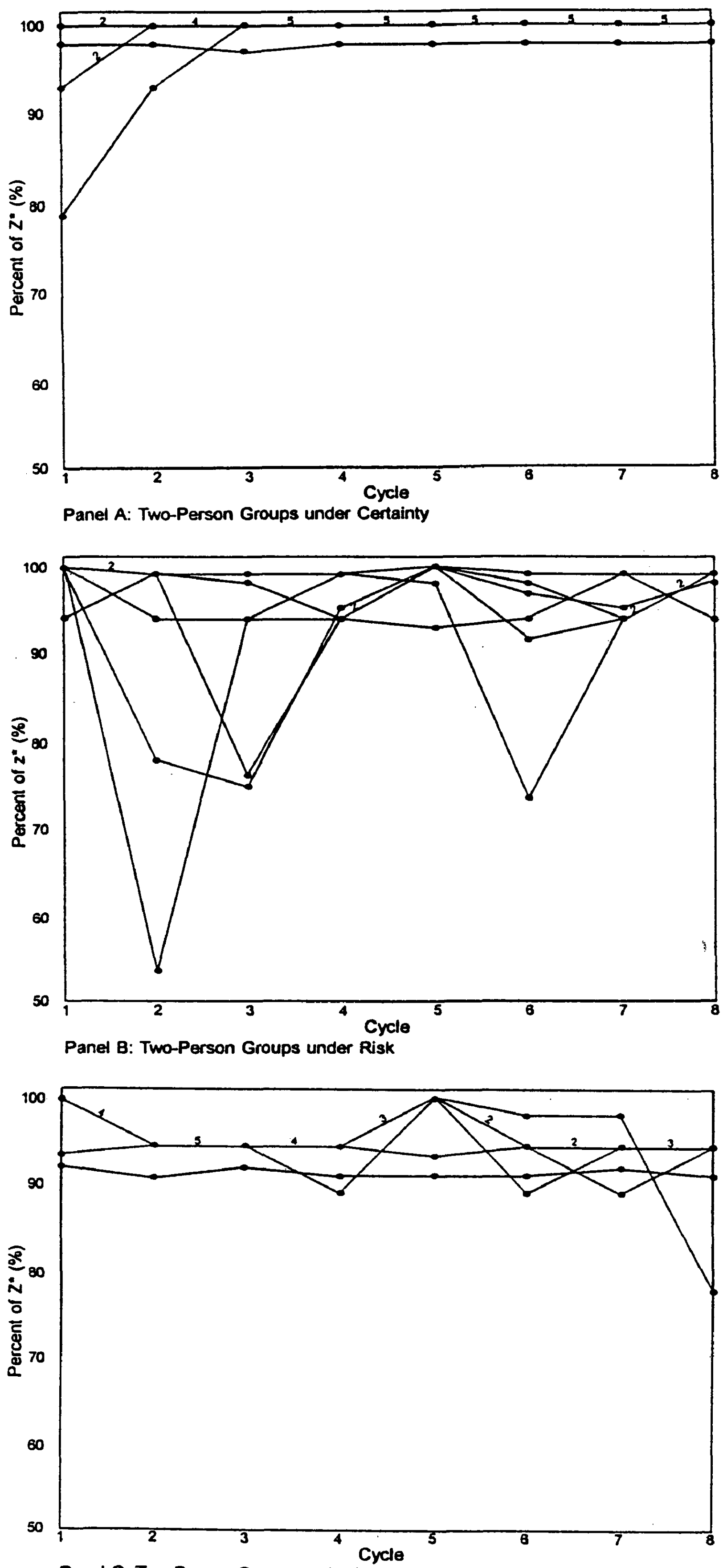


Panel C: Individuals under Uncertainty

Note. The numbers on top of the individual performance lines represent the exact number of participants that performed the same allocation strategy from cycle to cycle.

Figure Caption

Figure 6. The individual trends over the eight deployment cycles under Certainty, Risk, and Uncertainty for two-person groups. In Panel A under Certainty, after the third cycle, all but one two-person group had reached z*. In Panel B under Risk, two-person groups had difficulty obtaining z* on the deployment cycles when the loss of personnel occurred. By the eighth cycle, all of the two-person groups were above 94% of z*. In Panel C under Uncertainty, two-person groups displayed consistent but suboptimal performance across the eight deployment cycles with the two-person groups hovering around 93% of z*.

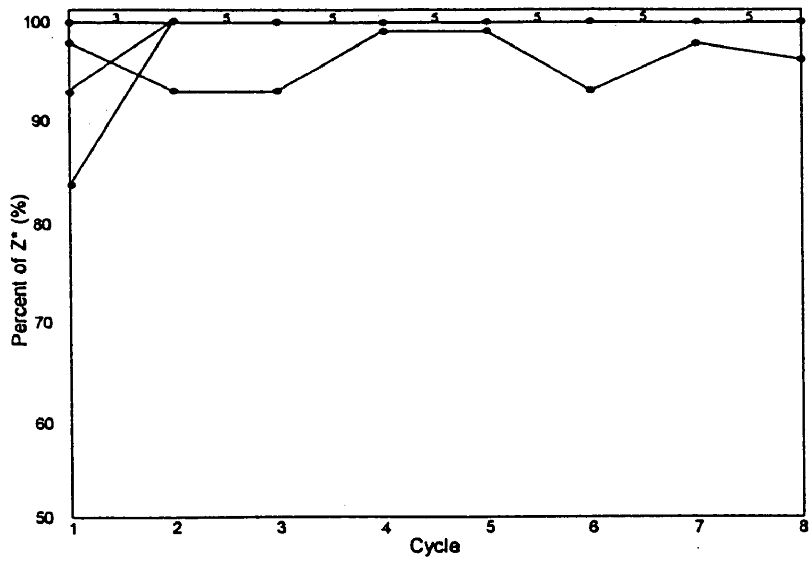


Panel C: Two-Person Groups under Uncertainty

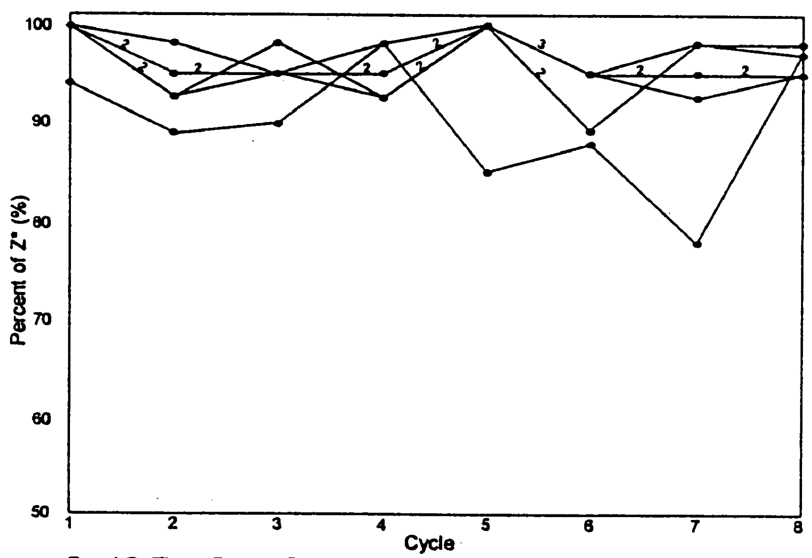
Note. The numbers on top of the individual performance lines represent the exact number of participants that performed the same allocation strategy from cycle to cycle.

Figure Caption

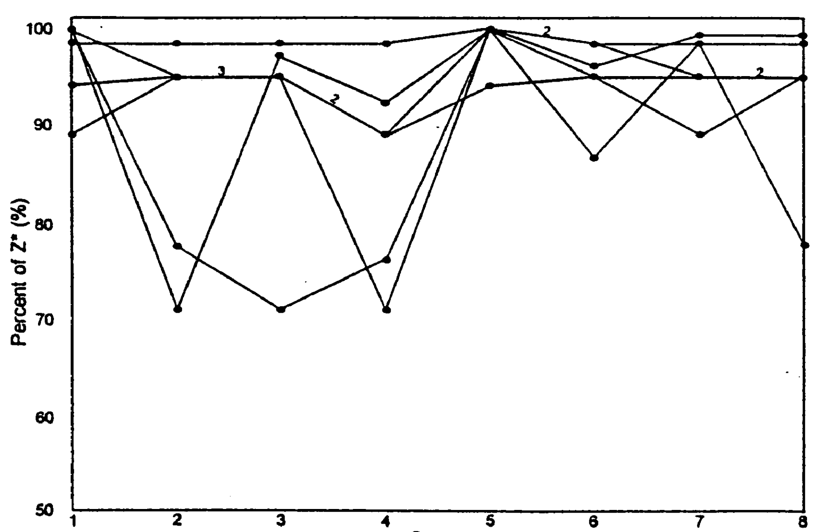
Figure 7. The individual trends over the eight deployment cycles under Certainty, Risk, and Uncertainty for three-person groups. In Panel A under Certainty, after the second cycle, all but one three-person group had reached z*. In Panel B under Risk, three-person groups had difficulty obtaining z* on the deployment cycles when the loss of personnel occurred. By the eighth cycle, all of the three-person groups were above 94% of z*. In Panel C under Uncertainty, three-person groups displayed inconsistent behavior across the eight deployment cycles except on the fifth cycle, when no personnel loss occurred. On the fifth cycle, only one three-person group did not obtain the optimal LP solution.



Panel A: Three-Person Groups under Certainty



Panel B: Three-Person Groups under Risk

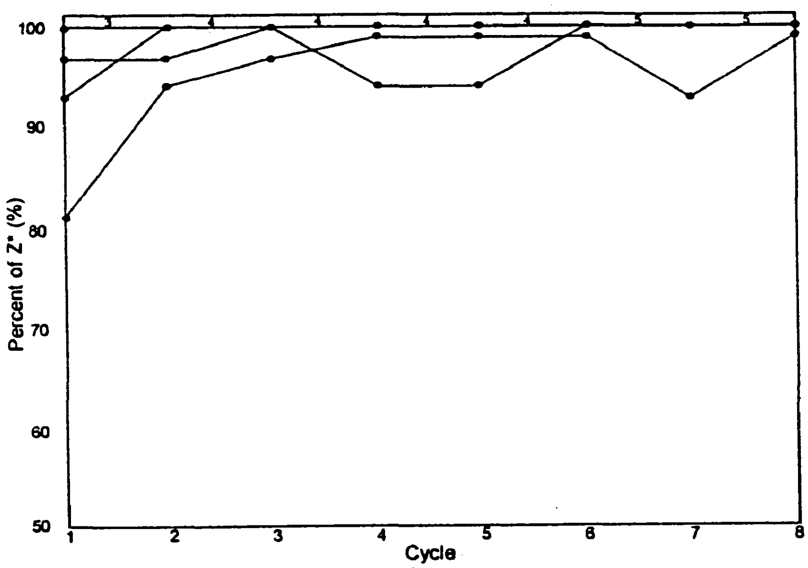


Panel C: Three-Person Groups under Uncertainty

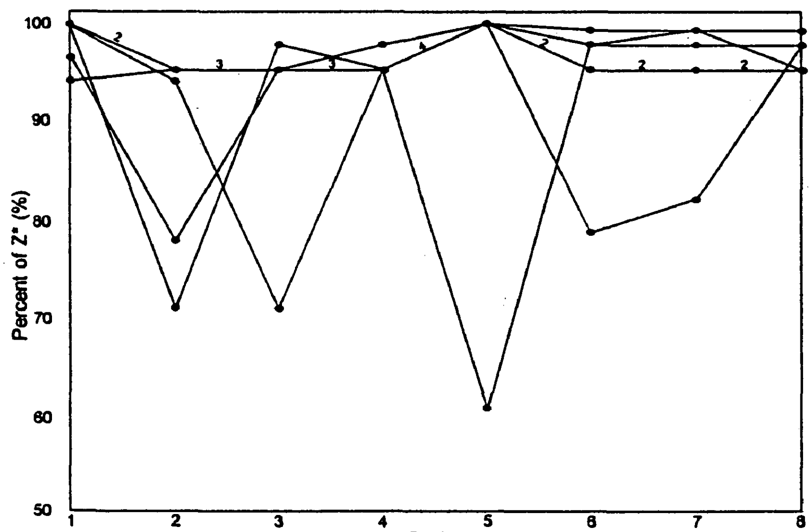
Note. The numbers on top of the individual performance lines represent the exact number of participants that performed the same allocation strategy from cycle to cycle.

Figure Caption

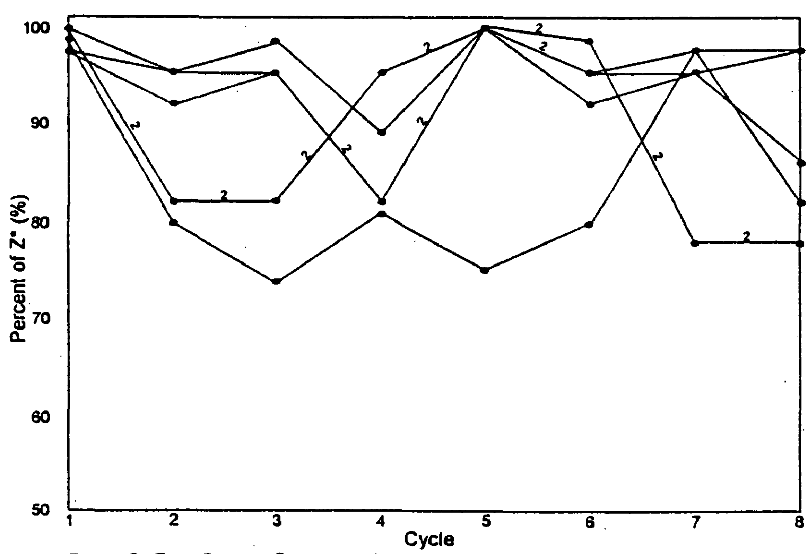
Figure 8. The individual trends over the eight deployment cycles under Certainty, Risk, and Uncertainty for four-person groups. In Panel A under Certainty, after the second cycle, all but two four-person groups had reached z*. By the sixth cycle, all but one four-person group had achieved z*. In Panel B under Risk, four-person groups had difficulty obtaining z* on the deployment cycles when the loss of personnel occurred. By the eighth cycle, all of the four-person groups were above 94% of z*. In Panel C under Uncertainty, four-person groups displayed inconsistent behavior across the eight deployment cycles except on the fifth cycle, when no personnel loss occurred. On the fifth cycle, only one four-person group did not obtain the optimal LP solution.



Panel A: Four-Person Groups under Certainty



Panel B: Four-Person Groups under Risk

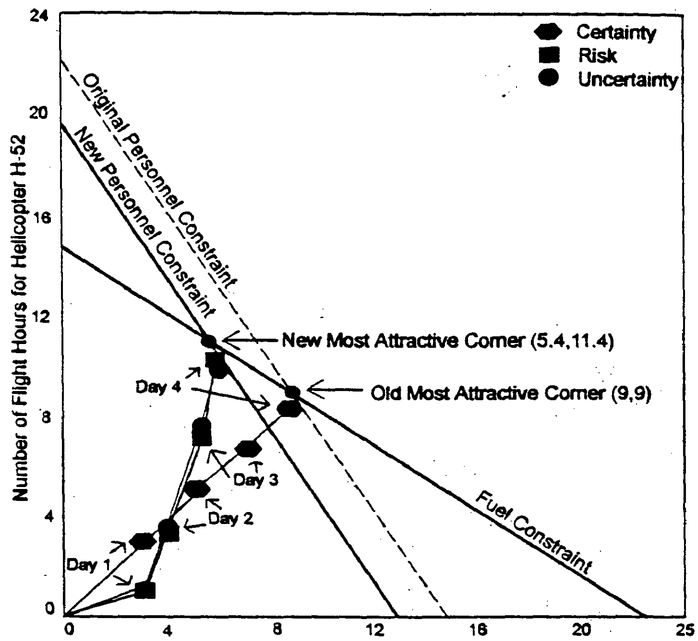


Panel C: Four-Person Groups under Uncertainty

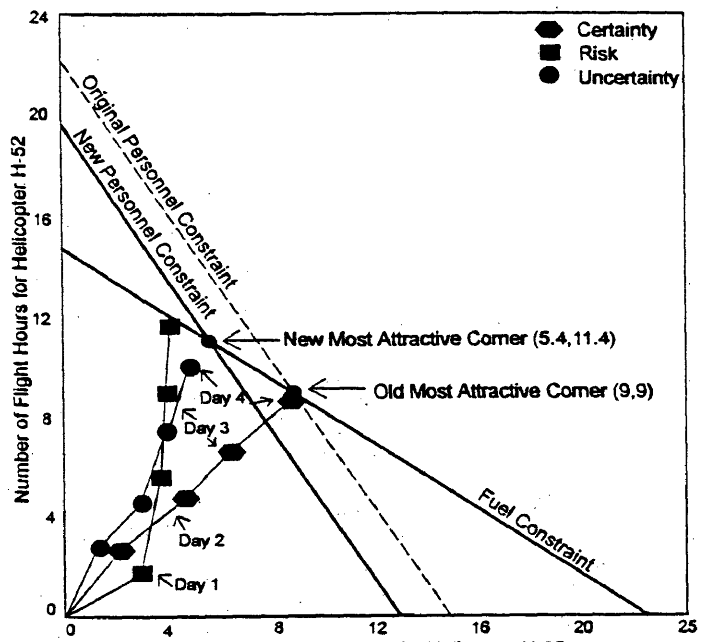
Note. The numbers on top of the individual performance lines represent the exact number of participants that performed the same allocation strategy from cycle to cycle.

Figure Caption

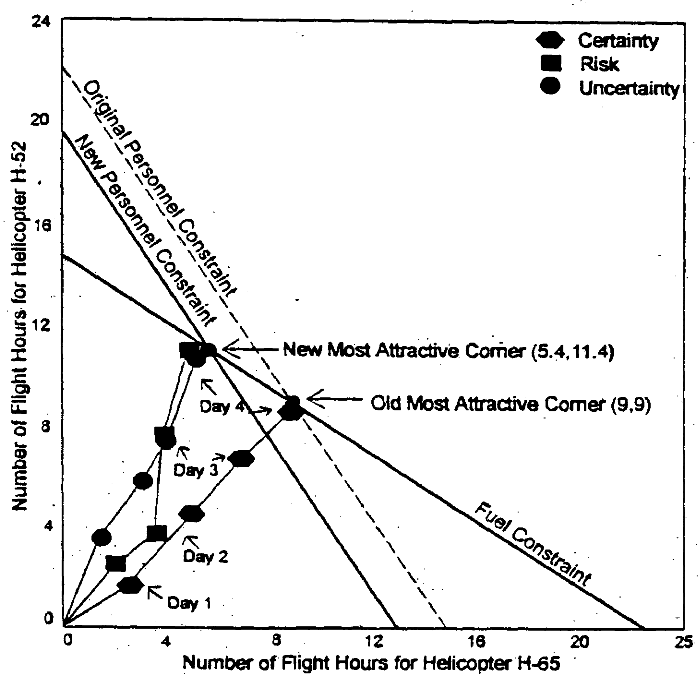
Figure 9. Mean daily solutions. In Panels A-D, the mean daily solutions under Certainty, Risk, and Uncertainty for individuals, two-person, three-person, and four-person groups during days 1 through 4 in cycle eight (i.e., the personnel loss begins at the start of the 2nd day) respectively.



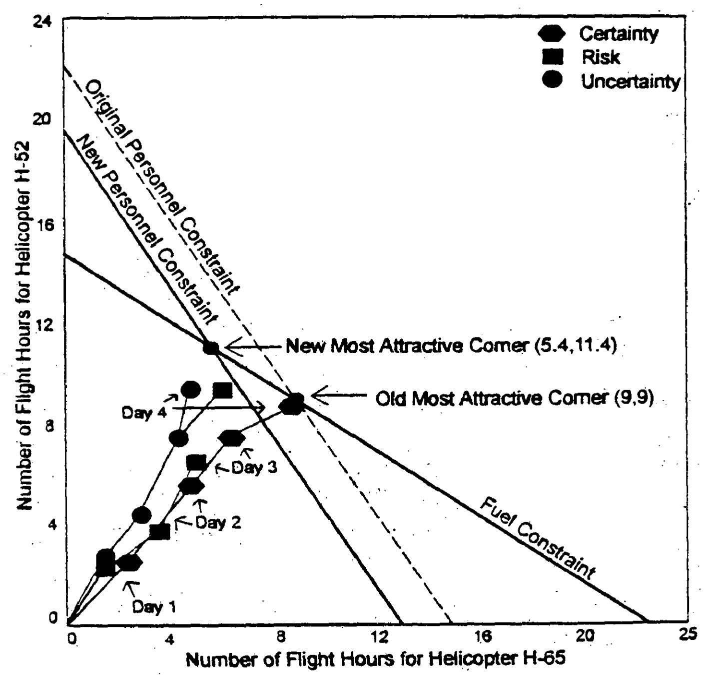
Panel A: Individuals



Panel B: Two-Person Groups



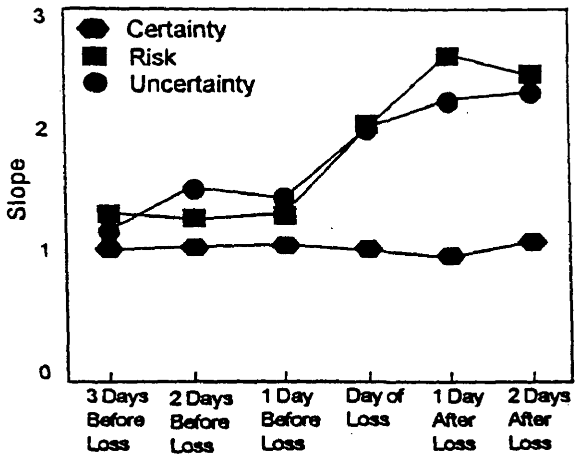
Panel C: Three-Person Groups



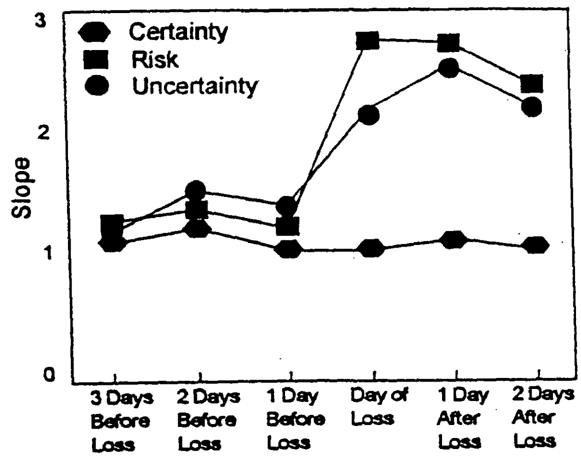
Panel D: Four-Person Groups

Figure Caption

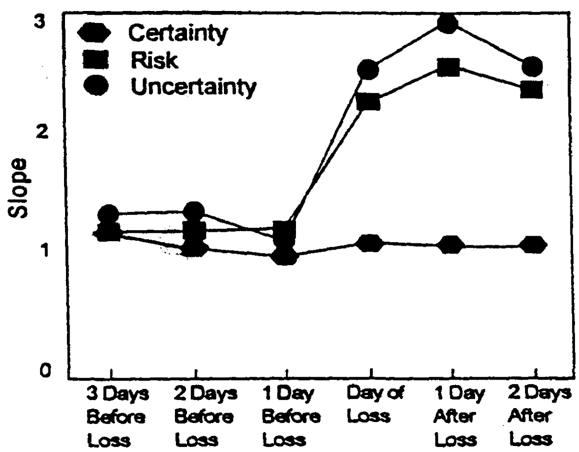
Figure 10. The slope of allocation line (i.e., the ratio of the H-65 hours to the H-52 hours) for days before, during, and after a personnel loss. In Panels A-D, individuals, two-person, three-person, and four-person groups under Certainty are shown as a control – there was no personnel loss under Certainty. In Panels A-D, individuals, two-person, three-person, and four-person groups in the Risk and Uncertainty conditions can be seen changing their allocation strategy on the day of the personnel loss and maintaining the mid-course adjustment during the personnel loss days, hence producing a distinctively greater slope and a turn toward the new most attractive corner.



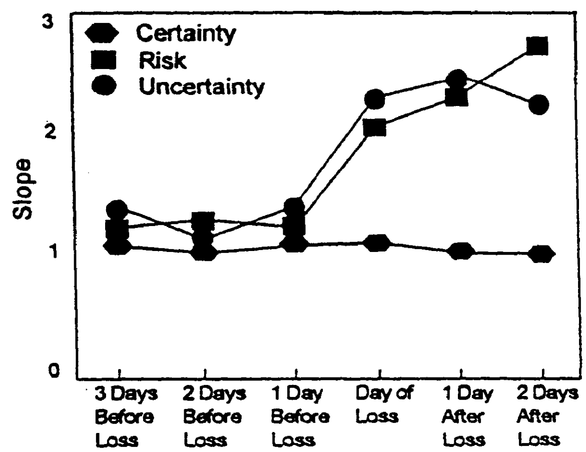
Panel A: Individuals



Panel B: Two-Person Groups



Panel C: Three-Person Groups



Panel D: Four-Person Groups

Figure Caption

Figure 11. Percentage of flight hours flown on Days 1 through 4 under Certainty, Risk, and Uncertainty. There is a clear tendency on the part of all treatment conditions across the four conditions (i.e., individuals, two-person, three-person, and four-person groups) to allocate more resources on Day 1 and less on each subsequent day. In Panel A, the number of hours that the individuals flew on Day 1 under Certainty, Risk, and Uncertainty was 32, 33, and 34%, respectively. These values dropped by 8% from day 1 to day 2 and approximately 3% on the remaining days for all treatment conditions. In Panel B, the number of hours that the two-person groups flew on Day 1 under Certainty, Risk, and Uncertainty was 29, 28, and 29%, respectively. These values dropped by 3% per day for all treatment conditions. In Panel C, the number of hours that the three-person groups flew on Day 1 under Certainty, Risk, and Uncertainty was 28, 27, and 26%, respectively. These values dropped by approximately 3% per day for all treatment conditions. In Panel D, the number of hours that the four-person groups flew on Day 1 under Certainty, Risk, and Uncertainty flew was 30, 28, and 29%, respectively. These values dropped by approximately 3% per day for all treatment conditions. This shows a tendency for individuals and all groups of varying sizes studied to consume early and have proportionally less resources remaining on subsequent days.

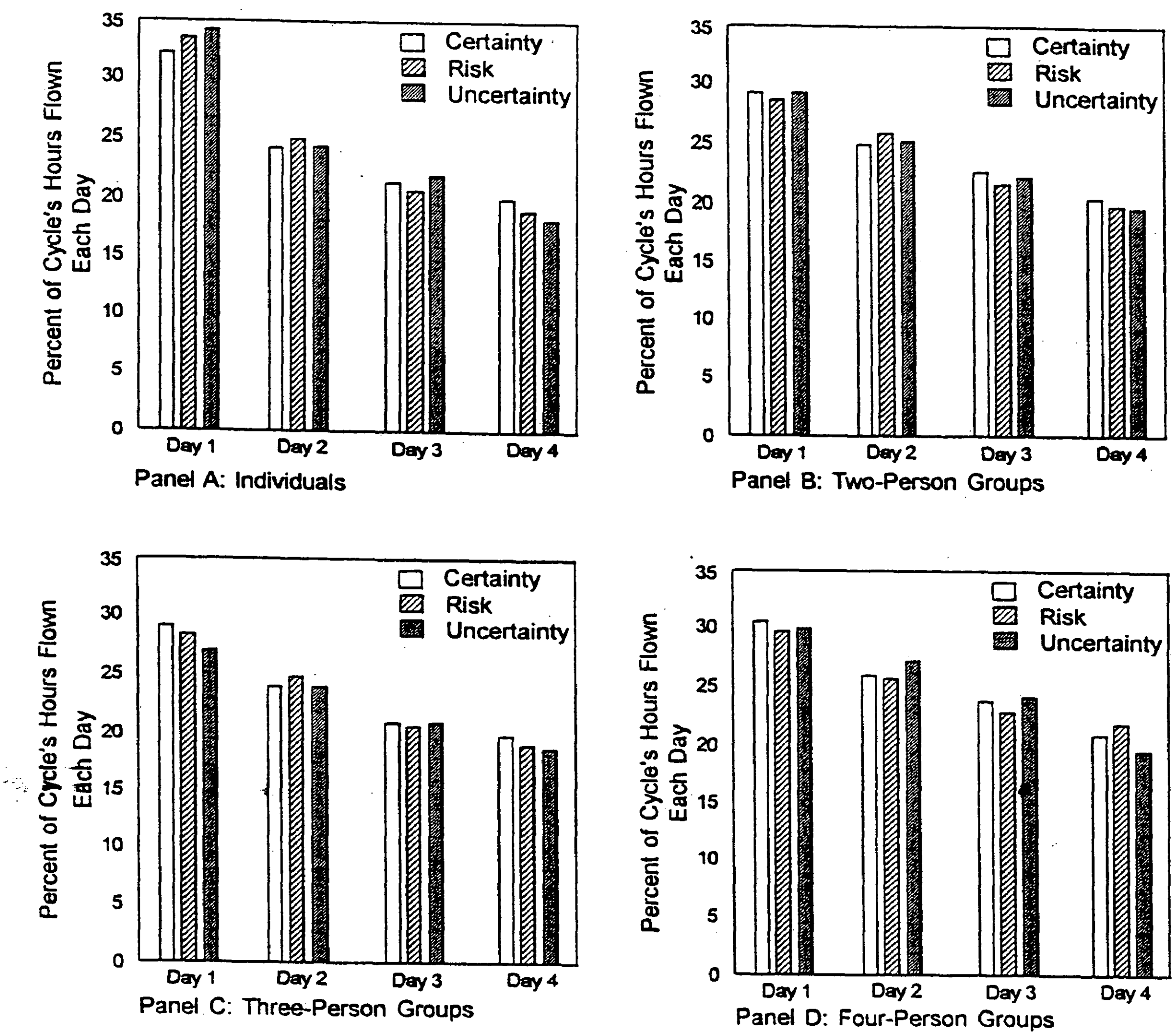
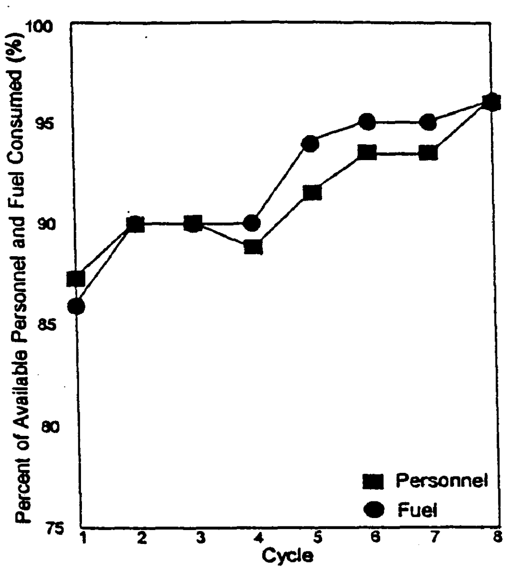
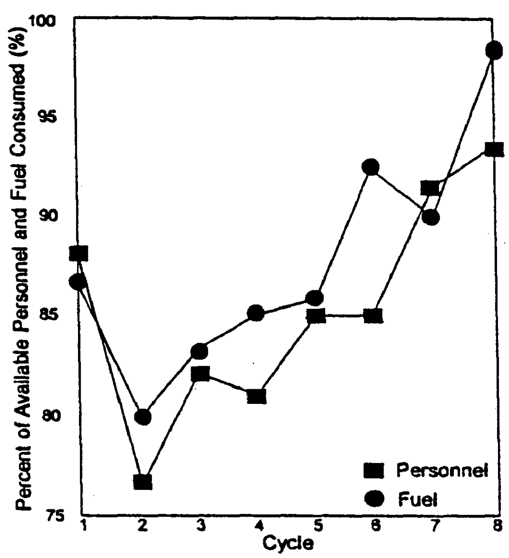

Certainty
Risk
Uncertainty
Percent of Cycle's Hours Flown Each Day
35
30
25
20
15
10
5
0
Day 1
Day 2
Day 3
Day 4
Panel A: Individuals
Panel B: Two-Person Groups
Panel C: Three-Person Groups
Panel D: Four-Person Groups

Figure Caption

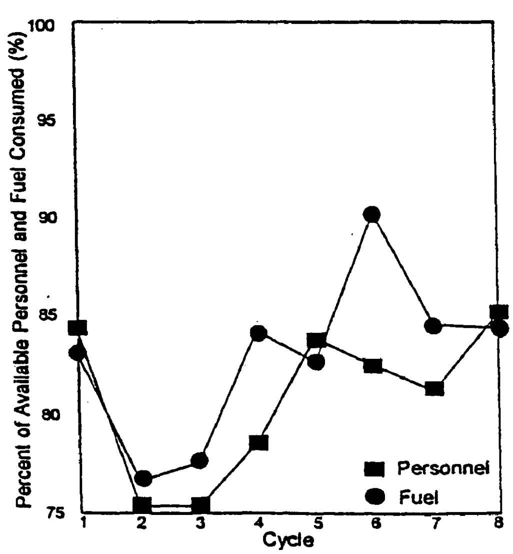
Figure 12. Percent of available personnel and fuel consumed each cycle by individuals. In Panel A under Certainty, the individuals learned quickly to allocate efficiently and on the fifth cycle they were utilizing 94% of personnel and 92% of fuel. Panel B shows the individuals did not learn efficient resource-allocation as quickly under Risk as under Certainty. By the eighth cycle, individuals were able to allocate a mean of 94% of personnel and 98% of fuel. In Panel C, individuals under Uncertainty did not show any learning and generally left 15-25% of resources unallocated.



Panel A: Individuals under Certainty



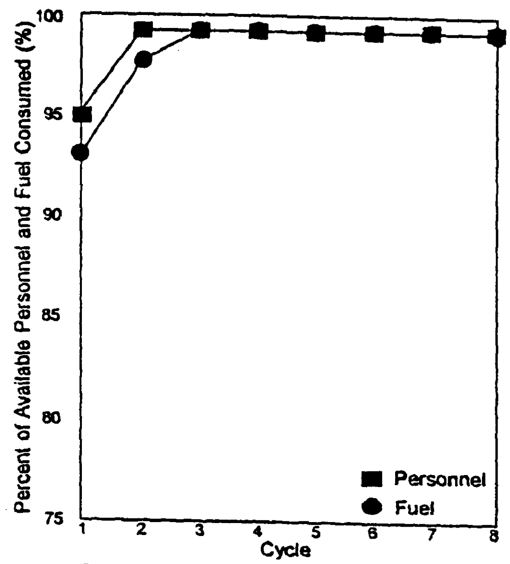
Panel B: Individuals under Risk



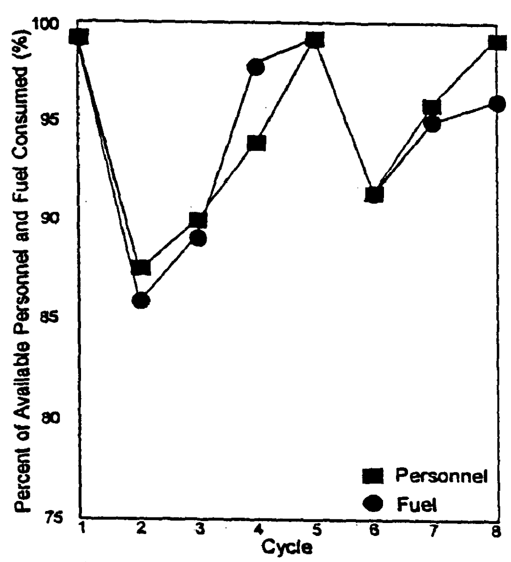
Panel C: Individuals under Uncertainty

Figure Caption

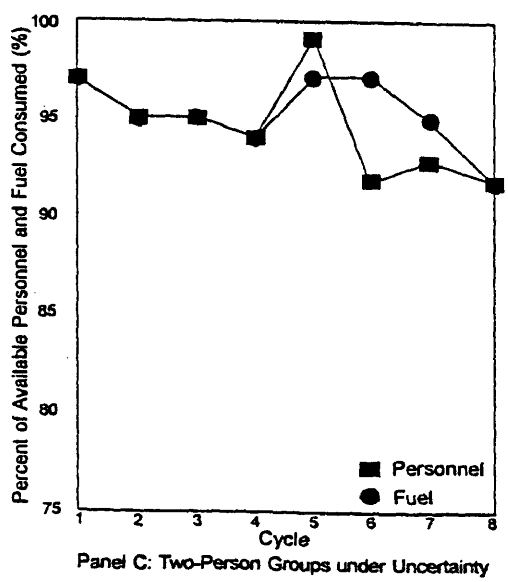
Figure 13. Percent of available personnel and fuel consumed each cycle by two-person groups. In Panel A under Certainty, the two-person groups learned quickly to allocate efficiently and by the third cycle they were utilizing 99% of personnel and fuel. Panel B shows the two-person groups did not use efficient resource-allocation on deployment cycles when a personnel loss occurred, but by the eighth cycle, the two-person groups were able to allocate between 99% of personnel and 96% of fuel. In Panel C, two-person groups under Uncertainty showed a consistent but suboptimal allocation of resources with the two-person groups generally leaving about 5-8% of resources unallocated.



Panel A: Two-Person Groups under Certainty



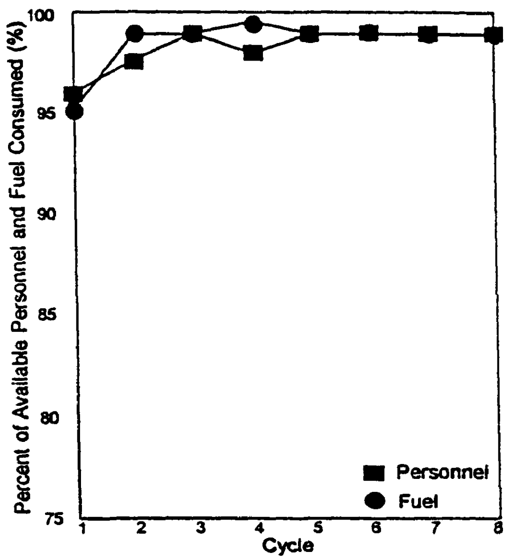
Panel B: Two-Person Groups under Risk



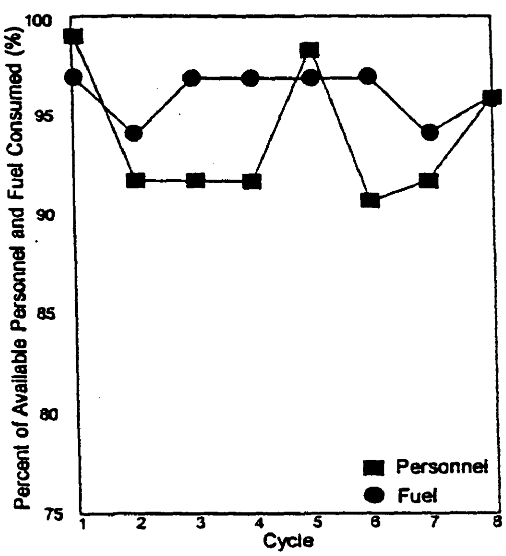
Panel C: Two-Person Groups under Uncertainty

Figure Caption

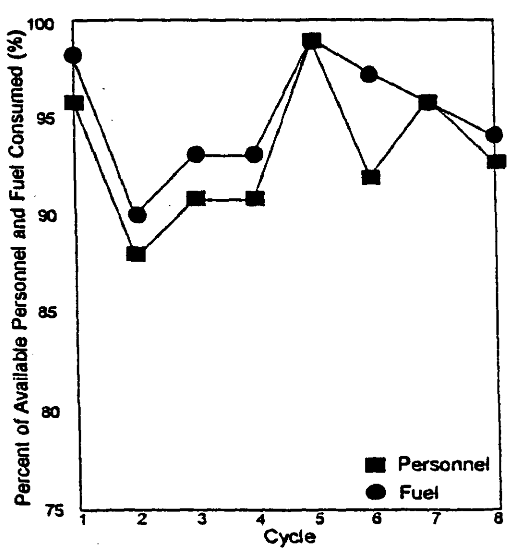
Figure 14. Percent of available personnel and fuel consumed each cycle by three-person groups. In Panel A under Certainty, the three-person groups learned quickly to allocate efficiently and by the fifth cycle they were utilizing 99% of personnel and fuel. Panel B shows the three-person groups did not use efficient resource-allocation on deployment cycles when a personnel loss occurred. Three-person groups typically showed consistent but suboptimal performance and typically left about 3-8% of resources unallocated. In Panel C, three-person groups under Uncertainty showed efficient allocation of resources on the deployment cycles where no personnel loss occurred, but struggled during deployment cycles where a personnel loss occurred.



Panel A: Three-Person Groups under Certainty



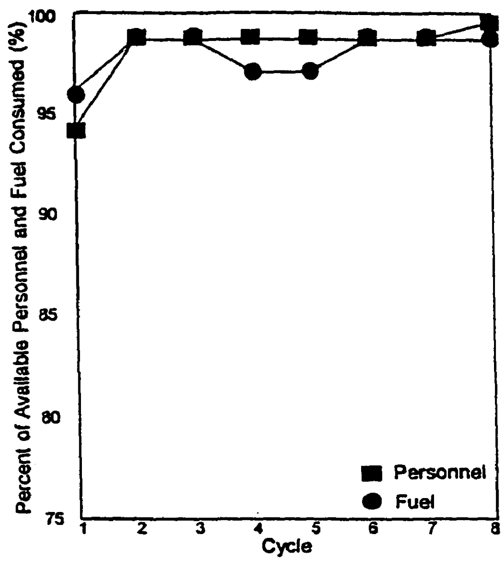
Panel B: Three-Person Groups under Risk



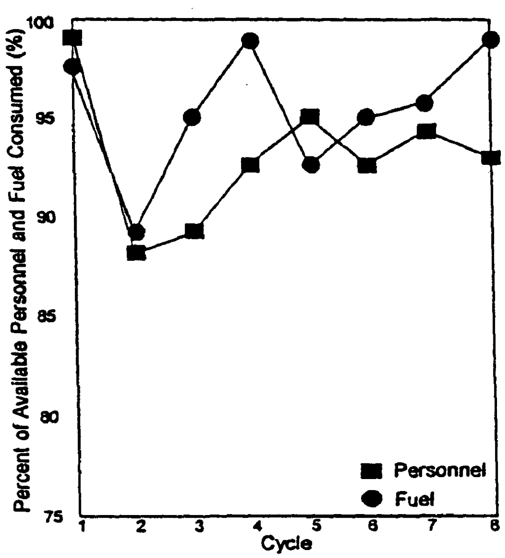
Panel C: Three-Person Groups under Uncertainty

Figure Caption

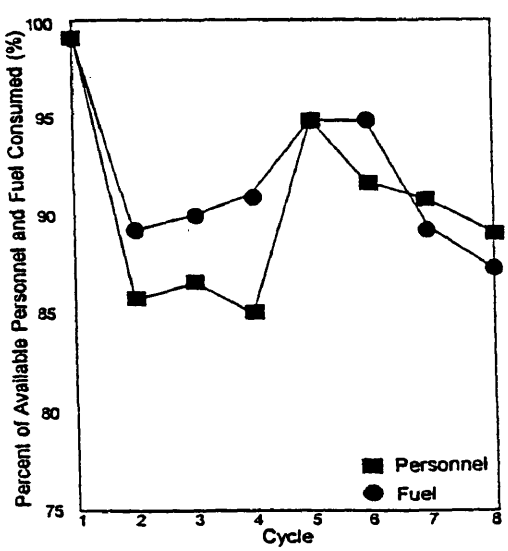
Figure 15. Percent of available personnel and fuel consumed each cycle by four-person groups. In Panel A under Certainty, the four-person groups learned quickly to allocate efficiently and by the second cycle they were utilizing approximately 98% of personnel and fuel. Panel B shows the four-person groups did not use efficient resource-allocation from the second through eighth deployment cycle. By the eighth cycle, four-person groups allocated 94% of personnel and 99% of fuel. In Panel C, four-person groups under Uncertainty did not show any learning and progressively got worse as the deployment cycles progressed.



Panel A: Four-Person Groups under Certainty



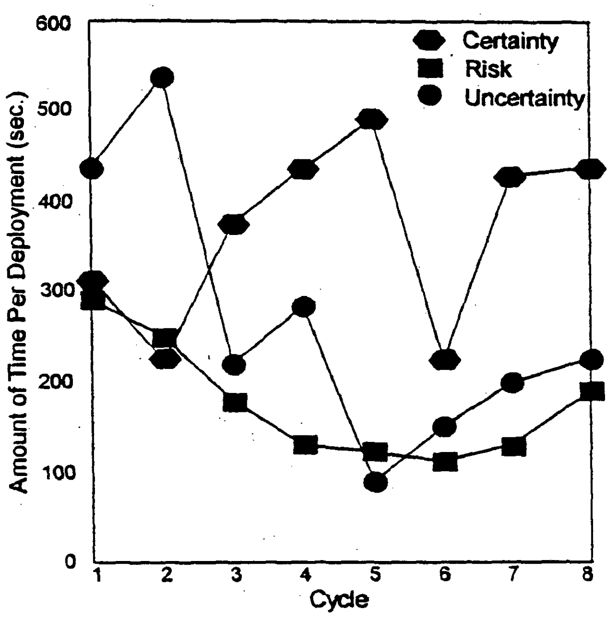
Panel B: Four-Person Groups under Risk



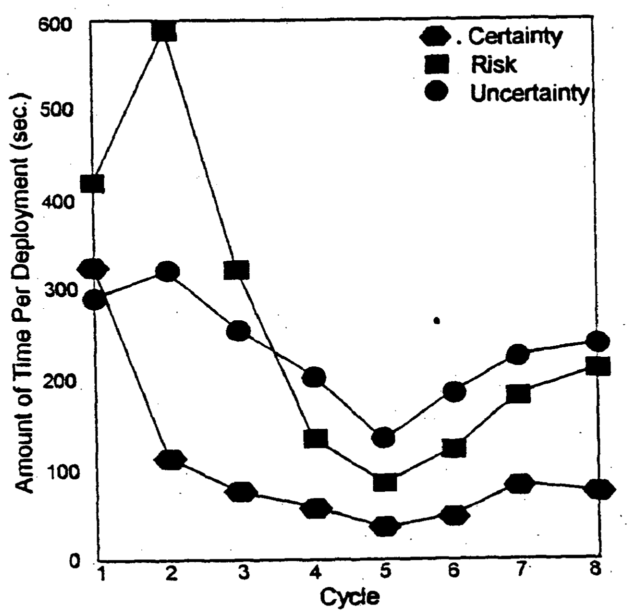
Panel C: Four-Person Groups under Uncertainty

Figure Caption

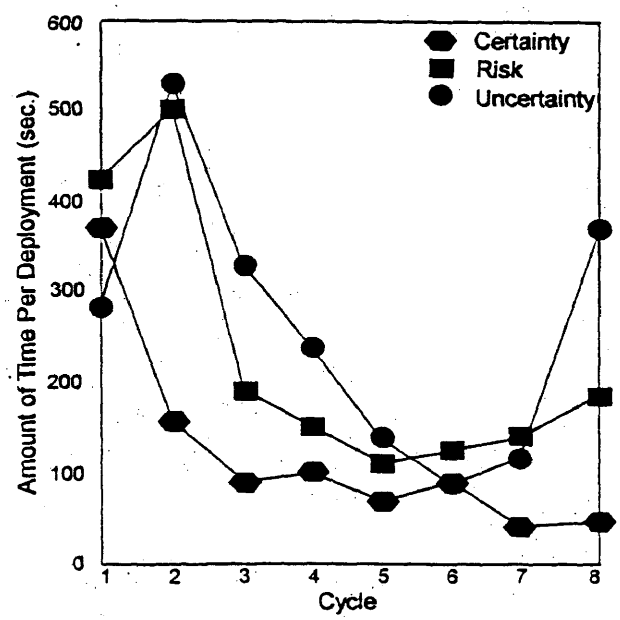
Figure 16. Amount of time taken to solve the four-day problem for individuals, two-person, three-person, and four-person groups under Certainty, Risk, and Uncertainty. In Panel A, after the second cycle, individuals in the Certainty condition displayed longer periods of time solving the four-day problem unlike the two-person, three-person, and four-person groups under Certainty (Panels B-D) who immediately used less time to solve the four-day problem after the second cycle. In Panels A-D, after the first four deployment cycles, individuals, two-person, three-person, and four-person groups under Risk and Uncertainty consistently used less time to solve the four-day problem on the remaining deployment cycles.



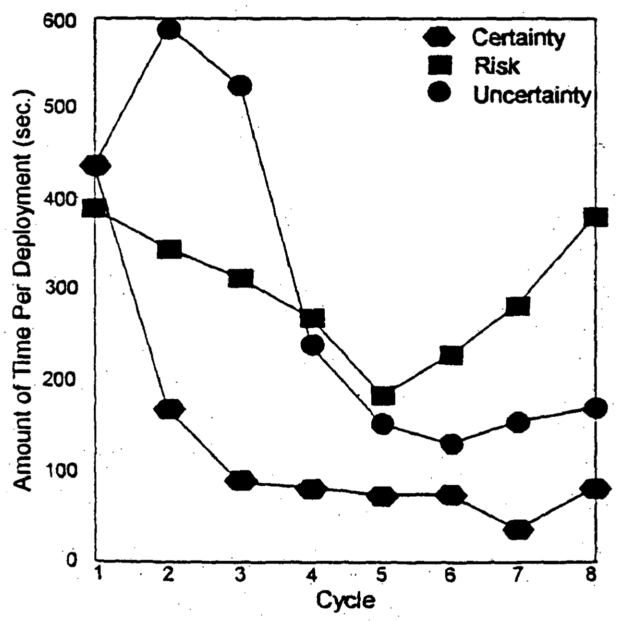
Panel A: Individuals



Panel B: Two-Person Groups



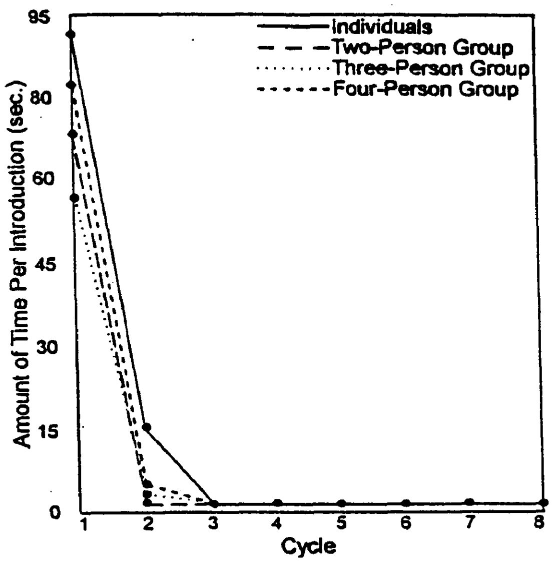
Panel C: Three-Person Groups



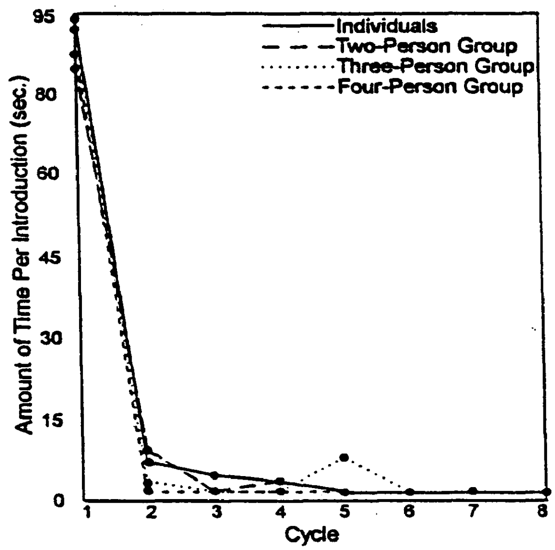
Panel D: Four-Person Groups

Figure Caption

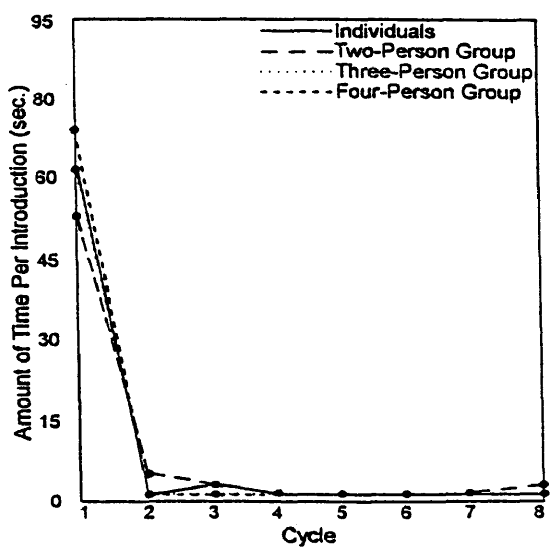
Figure 17. Comparison of the amount of time taken to read the introduction of the four-day problem for individuals, two-person, three-person, and four-person groups under Certainty, Risk, and Uncertainty. In Panels A-C, individuals, two-person, three-person, and four-person groups under Certainty, Risk, and Uncertainty took longer to read the introduction for the first time as opposed to the remaining seven deployment cycles.



Panel A: Certainty



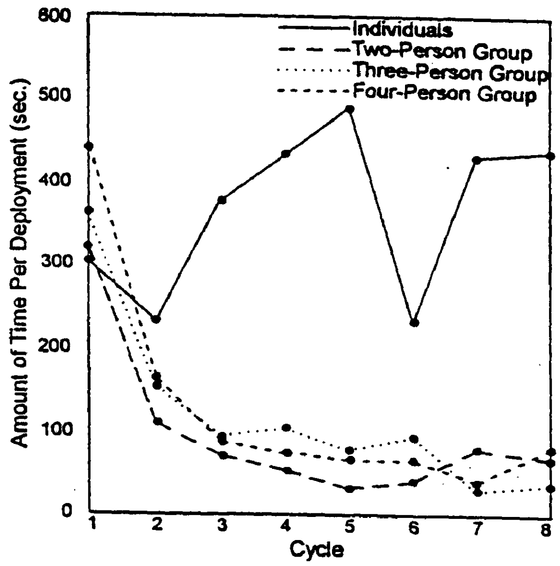
Panel B: Risk



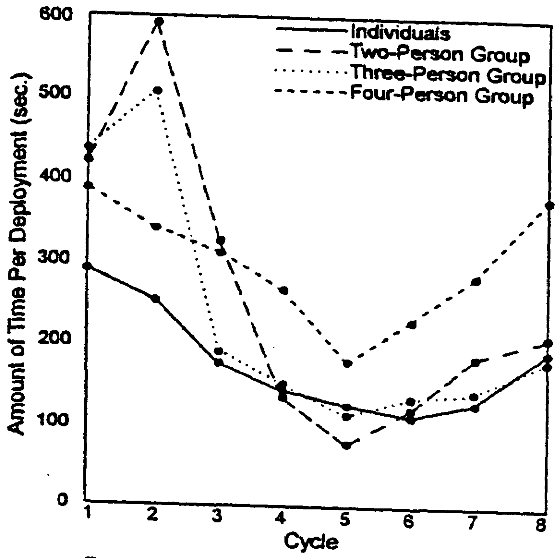
Panel C: Uncertainty

Figure Caption

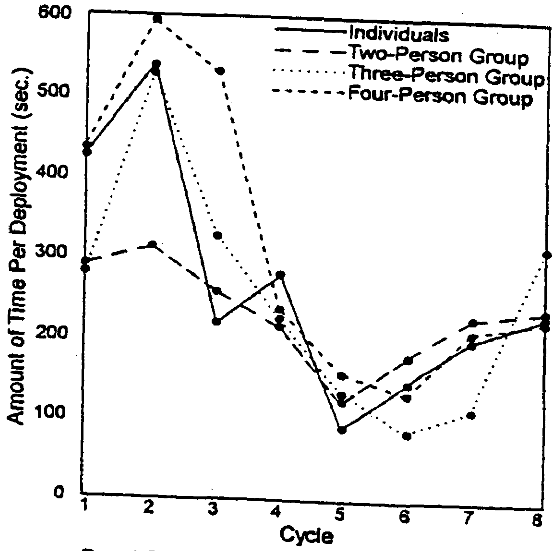
Figure 18. Comparison of the amount of time taken to solve the four-day problem for individuals, two-person, three-person, and four-person groups under Certainty, Risk, and Uncertainty. In Panel A, after the second cycle, the individuals under Certainty took a longer amount of time to solve the four-day problem as the deployment cycles progressed as opposed to the two-person, three-person, and four-person groups who progressively took less time. In Panel B under Risk, individuals progressively took less time to solve the problem despite the occurrence of a personnel loss. Two-person and three-person groups took approximately eight minutes to solve the problem during the second cycle while the four-person group only took approximately five minutes. After the fourth cycle, only the four-person group took a longer amount of time than the two-person and three-person groups. In Panel C under Uncertainty, the individuals, three-person, and four-person groups took approximately eight minutes to solve the problem, while the two-person group took only five minutes. It was until the fifth cycle, when no personnel loss occurred, that the individuals and groups took approximately two minutes. After the fifth cycle, the individuals and groups progressively took more time to solve the problem.



Panel A: Certainty



Panel B: Risk



Panel C: Uncertainty

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