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Using formal MS/OR modeling to support disaster recovery planning

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Abstract

All organizations are susceptible to a non-zero risk of experiencing out-of-course events, whether natural or man-made, that can lead to internal "disasters" with respect to business operations. Different types of events (e.g. flood, earthquake, fire, theft, computer failure) have implications for the operations of modern organizations. Hence, there is a critical need for planning and recovery strategies for the effects of disasters. Disaster recovery plans (DRPs) aim at ensuring that organizations can function effectively during and following the occurrence of a disaster. As such, they possess cost, performance, reliability, and complexity characteristics that make their development and selection non-trivial. To date, there has been little modeling of disaster recovery issues in the MS/OR literature. We believe that many of the issues involved can benefit from the application of quantitative decision-making techniques. Consequently, in this paper our contribution is prescriptive rather than descriptive in nature and we propose the use of mathematical modeling as a decision support tool for successful development of a DRP. In arriving at a final DRP, decision-makers must consider a number of options or subplans and select a subset of these subplans for inclusion in the final plan. We present a mathematical programming model which helps the decision maker to select among competing subplans, a subset of subplans which maximizes the "value" of the recovery capability of a recovery strategy. We use hypothetical situations to illustrate how this technique can be used to support the planning process.

Keywords: Disaster recovery strategy; Disaster recovery planning; Subplan selection; Heuristics

1. Introduction

A disaster recovery plan (DRP) or disaster recovery strategy (DRS) is a system for internal control and security that focuses on quick restoration of service for critical organizational processes when there are operational failures due to

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natural or man-made disasters. A DRP aims to minimize potential loss by identifying, prioritizing and safeguarding those organizational assets that are most valuable and that need the most protection. In recent years various factors including government regulations in certain industries (e.g. banking, credit unions), the occurrence of natural disasters (e.g. hurricane Andrew of 1993), and the occurrence of social disasters (e.g. L.A. riots of 1992) have led to increasing interest in the development, testing and maintenance of DRPs. This has resulted in intense customer and vendor interest in the development of tools for disaster recovery (e.g. Sclafane, 1996; Violino, 1996; Tevis, 1996; Carson, 1997). For example in just the NT (operating system) recovery area, it is estimated that customers spent $ 102 million in 1996, with the projected amount being $ 324 million for the year 2000 (Torode, 1997).

Although the field of DRP has attracted the interests of information technology practitioners and vendors for a number of years, very little formal management science type research (e.g. Sarker et al., 1996) has been done in this area. Thus, while there is a large volume of publications on DRP in numerous and various practitioner-oriented journals (e.g. Banking Technology, Network World, Communications News), the subject has received scant attention in the management science (including information systems) research journals. It appears that while much attention has been paid by vendors and organization to the development of hardware and software tools for addressing specific aspects of a disaster (e.g. Dryden, 1997; Bucholz, 1997; Merrill, 1997), little attention has been paid to formal modeling of the DRP process. In the instances where the problem has appeared in the academic journals the focus has been on examining the general features of a disaster recovery plan rather than on decision support. But as noted by Jackson (1997), "Creating a good plan is no easy task". For DRPs are inherently complex, given the various types of possible interactions that could occur between target resources, solution resources and the environment. Also as observed by Howard (1997), "the danger is not over once the fire has been put out", so that survival is not just a matter of putting out the fire, and there must be a clear plan for recovery that requires various resources including personnel, hardware and infrastructure.

The dearth of models in the MS/OR literature shows quite clearly that the benefit of MS/OR methodology has not yet been brought to bear on this emerging discipline. Although recently Jenkins (2000) has explored the use of integer programming techniques for selecting disaster scenarios, it would appear that the largest body of relevant quantitative analysis exists primarily in the area of risk assessment (Levitt, 1997; Tamura et al., 2000), or has been reactive in focus, being restricted only to the operational post-disaster phase such as the deployment of crews (Pidd et al., 1996; Sarker et al., 1996). Our research, we believe, will be a welcomed addition to the contribution of MS/OR to disaster recovery research. Recognizing that little modeling of disaster recovery issues has taken place to date in the MS/OR literature, our model represents a forward step in providing what is a fast growing discipline with rigorous models for supporting decision making. Consequently, our contribution is prescriptive rather than descriptive in nature. We introduce the application of MS/OR to DRP at the pre-disaster planning/development phase. MS/OR has potential for contributing to the strategic levels of decision-making in DRP to ensure that plans operate as expected/desired when put into operation. There are opportunities for applying MS/OR at all levels of DRP planning, development, implementation and operation, however we focus on the development phase where MS/OR has been most noticeably absent and can have its greatest impact. In this paper we presents a mixed-integer mathematical decision model for selecting subplans for a DRP. We use randomly generated hypothetical problems to demonstrate the feasibility of MS/OR for decision support in DRP development.

The rest of the paper is organized as follows: Section 2 provides an overview of DRP concepts; Section 3 provides a sample of outstanding DRP research problems; Section 4 provides an OR-based solution approach for addressing one of the research problems described in Section 3; and finally in Section 5, the paper terminates with a brief discussion of the contribution of the paper and possible directions for future research.

2. Overview of DRP concepts

2.1. Some general axiomatic statements about DRPs

We begin this subsection by listing some general axiomatic statements about DRPs:

- Several possible disasters can occur.
- Each disaster has a set of possible debilitating effects.
- Each effect has the ability to affect a number of business functions.
- To protect against each effect, a set of (solution) resources are necessary.
- Two strategies are possible: prevention (risk mitigation) and recovery.
- Some recovery resources may be substitutable.
- Substitutable resources do not necessarily possess the same level of efficiency (e.g., a back hoe and a set of hand-held shovels do not have the same efficiency level).
- Some resources can be used to handle more than one effect.
- Some resources will require the existence of other resources.
- A disaster recovery plan is made up of a set of subplans, resources, rules, and procedures and must aim at recovering from at least one effect.

A DRP is made up of procedures and rules that utilize solution resources (e.g. hot sites) that are aimed at protecting and/or reviving target organizational resources, functions, or processes (e.g. information systems). Because there are different types of disasters that could occur, each of which could have different effects on different organizational target resources, a DRP or DRS is made up of a set of component subplans, each of which is aimed at protecting/reviving a set of target resources from the debilitating effects of a specific disaster. It is not uncommon for alternate recovery subplans to exist for the same disaster effect (for example internal versus external hot sites, or hot sites versus cold sites for the recovery of a data processing function). Each subplan, however, will have its own resource requirements, its own activation and escalation procedures, its own recovery time objective (RTO), and its own reliability profile. In developing the DRP, an organization must select among competing alternatives. Typically budget limitations, resource limitations, and complexity issues are major driving forces behind the need to first generate alternative plans, and secondly to design the DRP by selecting from the set of alternatives. A mathematical modelling approach provides the capability to select these subplans in a rational manner and simultaneously address concerns about consistency, feasibility, completeness, and reliability.

2.2. Properties of good DRPs

A DRP should have the properties of *feasibility*, *completeness*, *consistency*, and *reliability*. The *feasibility* property relates to whether the DRP is feasible in terms of resources (e.g. skilled and unskilled manpower, hardware and software resources, time) availability. Now complete mock-up testing of a DRP is rarely feasible, and so testing is usually restricted to a narrow focus area of DRP which is covered by a subplan. However, even this partial testing of the DRP has major disadvantages including disrupting operations and manpower costs, while not guaranteeing the feasibility of the full DRP. The *completeness* property relates to whether the DRP covers all important target organizational resources and functions from the debilitating effects of disasters. Are there some resources that we believe are covered by our DRP that are not in fact covered by the DRP? The *consistency* property is concerned with whether the different components of the DRP are consistent. Because the focus is often on local feasibility, it is possible that though two subplans of the DRP are individually feasible, that taken together they are infeasible. This could be caused by the fact that both subplans require the use of the same set of solution resources at the same time. Finally, the *reliability* of a DRP is a measure of the likelihood of the plan achieving its pre-established continuity, recovery, and restoration objectives. Because, the implementation of a DRP is essentially the activation of a project, it is very likely that parts of the project network could fail. Hence the critical path to recovery can be severely affected by unforeseen events.

2.3. Developing DRPs

Development of a disaster recovery plan or strategy involves the following phases: (1) vulnerability assessment, (2) organizational impact assessment (or business impact analysis (BIA)), (3) definition of detailed requirements and continuity, recovery, and restoration objectives, (4) development of alternative subplans; (5) the evaluation and selection of the subplans which will constitute the DRP, (6) testing of the DRP, and (7) maintenance of the DRP. Testing is usually done at the local subplan level, and so while it addresses the property of feasibility, it does not address the other properties. Because we are focusing on business continuity, these considerations should be included in the design/development phase of the process. Although phases 5 and 6 are often performed separately and sequentially in practice, they are not independent. The objective of testing the DRP is to determine whether the plan will execute according to the specified performance levels if and when it becomes necessary. The testing of DRP is supposed to result in some degree of confidence that the plan will execute successfully. There is no mechanism at stage 5 to integrate some of the concerns at stage 6 in determining the outcomes of stage 5. The mathematical model provides a mechanism for effectively integrating concerns at stages 5 and 6 so that at the end of stage 6, the outcome will be at a higher degree of confidence.

3. A sample of outstanding DRP research problems

In this section we present an overview of three DRP problems that could be suitably addressed by mathematical modeling techniques. In the following section we present a mathematical model for addressing the subplan selection problem.

3.1. Subplan selection

Our aim here is to determine the resources that should be acquired in order to maximize the total expected value of the recovery capability. In this model it is assumed that for each disaster effect, there is a set of disaster recovery subplans (DRSP) that could be used to effectively (i.e. exceeds target effectiveness) protect against that effect. The full DRP thus consist of a set of DRSPs. Each such DRSP has an associated procedure that utilizes a subset of the solution resources in a specified way. The level of utilization of a given resource varies from subplan to subplan. Again some of these solution resources may require other solution resources for their effective use in the given subplan. We require that all these solution resources (both primary and secondary) be explicitly linked with the given subplan. We also assume that some subplans are mutually exclusive. The reasons for this could vary. One possibility is that both plans could require the full utilization of a particular resource.

3.2. DRP implementation and testing costs

For this problem we are required to develop a DRP that protects a set of business functions from a specific set of disasters. Now each of the component DRSP has associated cost of implementation, cost of testing, and time to test the DRSP. Given that testing of a DRSP tends to disrupt regular operations there is an interest in having the total test time to be as small as possible. As usual there would be an interest in minimizing the total cost (i.e. implementation cost plus test cost) of the DRP. This problem thus involves the attempt to ideally simultaneously minimize three objectives (i.e. total implementation cost, total test cost, total test time) in a manner that results in the DRP having the feasibility, consistency, completeness and reliability properties.

3.3. Risk of lock out

An off-site disaster recovery vendor has several primary customers. There will be a number of subsets of customer locations based on geographical proximity that will have simultaneous disaster declarations from a storm, tornado, hurricane, etc. For other locations, disasters would occur at the customers' sites independent of each other. Given that the demand for the resource is triggered by the occurrence of one of several causes (fire, flood, accidents, human error, plane crash, earthquake, etc.), there is the risk of two or more customers requiring the site at the same time. That risk is high if the disaster is a natural disaster (hurricane, tornado, etc.). The company needs to assess the risk of contracting with a given vendor.

4. A mathematical model of the subplan selection problem

In this section, we present a mixed-integer model for the subplan selection problem (i.e. selecting a group of subplans from a number of alternatives in order to establish the disaster recovery capability for the organization).

Notation

K	set of business functions
R_1	set of solution resources that occur in real quantities (e.g., time)
R_2	set of solution resources that occur in integer quantities (e.g., equipment)
R	set of solution resources: $R = R_1 \cup R_2$
J	set of disaster effects
I	set of disaster types
S	set of recovery subplans
S_j	set of subplans that can protect against disaster effect j
S_r	set of subplans that use resource r
M_q	the qth set of mutually exclusive plans
Q	a set of indices, $1, 2, \ldots, \lvert Q \rvert$
f_{ij}	the likelihood of disaster type i having disaster effect j
a_k	the relative importance (or criticality) of business function k
h_{jk}	the likelihood that effect j would affect business function k
p_j	given a disaster has occurred, the likelihood of experiencing effect j, $p_j = \sum_{i \in I} f_{ij}$
g_j	the relative importance of a disaster effect j based on its potential business impact where $g_j = \sum_{k \in K} a_k h_{jk}$
B	budget limit
u_{rs}	the quantity of solution resource r required by subplan s
c_r	the unit cost for solution resource r
e_s	the reliability measure of subplan s
e_{avg}	the minimum desired average of the reliability measures for the selected set of subplans
w_{sj}	a binary parameter (0,1) whether subplan s provides recovery capability for effect j
v_s	a value measure of the recovery potential of subplan s, $v_s = \sum_{j \in J} w_{sj} g_j p_j$
y_s	a binary variable that indicates whether subplan s is acquired is selected
z_r	a binary variable that indicates whether solution resource "r" is acquired

4.1. The mathematical formulation

$$\text{Max} \quad \sum_{s \in S} v_s y_s \tag{1}$$

subject to:

$$\sum_{r \in R} c_r z_r \leqslant B, \tag{2}$$

$$\sum_{s \in S_j} y_s \leqslant 1, \quad j \in J, \tag{3}$$

$$\sum_{s \in S_r} u_{rs} y_s - z_r \leqslant 0, \quad r \in R, \tag{4}$$

$$\sum_{s \in S} (e_s - e_{\mathrm{avg}}) y_s \geqslant 0, \tag{5}$$

$$y_s \in (0, 1), \quad s \in S, \tag{6}$$

$$Z_r > 0 \text{ and real}, \quad r \in R_1, \tag{7}$$

$$Z_r \geqslant 0 \text{ and integer}, \quad r \in R_2. \tag{8}$$

The objective of the model is to maximize the total value of the recovery capability of the set of subplans chosen. Constraint (2) is a budget constraint that stipulates that the cost of solution resource requirements for the selected subplans must not exceed a specified budget limit. Constraint (3) states that at most one subplan from the set of primary plans for a given effect can be selected. Constraint (4) is a logical constraint which allows the required solution resources for a selected subplan to be acquired. Constraint (5) ensures that the average of the reliability measure for a selected set of subplans exceed the minimum specified value e_{avg}.

4.2. Comments on the model

4.2.1. Properties of DRPs

The major desirable DRP properties of completeness, feasibility and reliability would be addressed both in the mathematical model itself and through pre-processing procedures such as described in Section 4.2.2. In this model the *feasibility property* is addressed in this model by constraints (2) and (4), the *consistency property* is addressed by constraint (4), and the *reliability property* is addressed by constraint (5). For this particular DRP problem the *completeness property* is addressed in the first four phases of the DRP development cycle that would precede the application of the mathematical model (i.e. vulnerability assessment, business impact analysis, definition of detailed requirements, and development of alternate subplans), and also in the mathematical model. A pre-processing procedure that would partly address the completeness property and also lead to the determination of relevant parameters is described in Section 4.2.

In ascertaining the *cost* associated with the subplans selected, we chose to compute total cost by costing out the individual resources. While it is possible to cost individual subplans and thereby reduce the number of variables in the model, it is highly likely that a number of resources are sharable and may be double-counted if subplans instead of resources were costed out. For example, two subplans calling for the use of a hard disk where it is unlikely that both subplans would be activated at the same time, would account for the purchase of two hard disks instead of one if cost is determined by subplans. The *utilization* of resources within subplans is measured in accordance with the fraction of the time between escalation and restoration that the resource will be in use. This resource would incur a lease or purchase cost depending on the nature of the subplan (e.g., external vs. internal hot site). Resources occur in the form of equipment, facilities, or manpower, and can be purchased or leased. The *reliability measure* indicates the likelihood of a given subplan achieving its RTO. This measure can be established by a careful analysis of the potential failure points of a subplan.

4.2.2. Description of a pre-processing procedure

Determination of the relevant sets and parameter values can be done using a set of interaction matrices (e.g. matrices A, B, C, D below). Below we describe a process for accomplishing this.

Step 1:

- Identify the relevant set of disaster types I.
- Identify the relevant possible disaster effects J. This is done by identifying the target infrastructural and system resources that support each business function (see Matrix *A1*). For each such supporting target resource (e.g. computers, electric power lines, roads, personnel), identify the effects that each disaster could have on the target resource. Each "*X*" in the matrix corresponds to a disaster effect, but multiple "*X*" entries could correspond to the same disaster effect.
- Cross reference the disaster types and the disaster effects in *Matrix B*, providing for each cell an estimate f_{ij} of the likelihood of disaster "*i*" having disaster effect "*j*".
- Cross reference the disaster effects and the Business Functions in *Matrix C*, providing for each cell an estimate h_{jk} of the likelihood of disaster effect "*j*" affecting business function "*k*".

Step 2:

- For each disaster effect "*j*", generate a set of disaster recovery subplans S_j that provide recovery capability for disaster effect "*j*".
- Cross reference the disaster effects and the disaster recovery subplans in *Matrix D*, providing for each cell a binary value w_{sj} that indicates whether disaster recovery subplan "*s*" provides recovery capability for disaster effect "*j*".
- For each disaster recovery subplan "*r*", identify the set of solution resources required to execute the subplan.
- Cross reference the disaster recovery subplans and the solution resources required to execute the subplan in *Matrix E*, providing for each cell

a value u_{rs} that indicates the amount of resource "r" required by disaster recovery subplan "s".

Matrix A1: Business function (BF)/target resource (TR) association

	TR_1	TR_2	...	TR_j
BF_1	X	X		
BF_2		X		
BF_k	X			

Matrix A2: Disaster type (DT)/target resource (TR) association

	TR_1	TR_2	...	TR_j
DT_1	X	X		X
DT_2		X		
DT_I	X			

Matrix B: Disaster type (DT)/disaster effect (DE) association

	DE_1	DE_2	...	DE_j	$DE_{\|J\|}$
DT_1	f_{11}	f_{12}		f_{1j}	
DT_2	f_{21}	f_{22}		f_{2j}	
DT_I	f_{j1}	f_{j2}		f_{ij}	
$DT_{\|I\|}$					

Matrix C: Disaster effect (DE)/business function (BF) interaction

	BF_1	BF_2	...	BF_k	$BF_{\|K\|}$
DE_1	h_{11}	h_{12}		h_{1k}	
DE_2	h_{21}	h_{22}		h_{2k}	
DE_j	h_{j1}	h_{j2}		h_{jk}	
$DE_{\|J\|}$					

Matrix D: Disaster recovery subplan (DRSP)/disaster effect (DE) interaction

	DE_1	DE_2	...	DE_k	$DE_{\|J\|}$
$DRSP_1$	w_{11}			w_{1k}	
$DRSP_2$	w_{21}			w_{2k}	
$DRSP_s$	w_{s1}			w_{sk}	
$DRSP_{\|S\|}$					

Matrix E: Solution resource (SR)/disaster recovery subplan (DRSP) interaction

	$DRSP_1$	$DRSP_2$	...	$DRSP_s$	$DRSP_{\|S\|}$
SR_1	u_{11}			u_{1s}	
SR_2	u_{21}			u_{2s}	
SR_r	u_{r1}			u_{rs}	
$SR_{\|R\|}$					

4.3. Solution of the subplan selection model (PSM)

A close examination of the PSM will show that the model as a whole possesses no unique underlying constraint structure. There are multiple choice constraints (3) and (4), and knapsack constraints (2) and (6), coupled by a logical constraint (5). However, to exploit either of these groups of constraints, a significant relaxation of the constraint set is required thereby causing a significant loss in model integrity. A further complicating matter is that the model contains binary variables and real and/or general integer variables. We, therefore, explored two heuristic approaches to the problem that make use of off-the-shelf solvers such as CPLEX.

Heuristic 1. The first approach is to solve the original model using a standard branch-and-bound approach and terminate the procedure after a fixed number of branches have been examined. The best feasible solution found is used as the solution to the problem. We will refer to this method as brute-force with termination (BFT).

Heuristic 2. The second approach to the problem involves a three-phase procedure. The idea is to attempt to reduce the size of the solution space over which the original problem is solved. Intuitively, this method would be useful if there are many alternative subplans for each effect, and when the number of variables is large.

Each of the three phases represents a relaxation of the original problem. Phase I determines a set of subplans that minimizes the total cost of the selected subplans while ensuring that all effects receive coverage, and the reliability criterion is met. We call this the minimum cost total coverage model. Phase II selects a set of subplans which maximizes the total value of their recovery capability. Cost is ignored in this phase. We call this a maximal value total coverage model. The optimal set of subplans from phases I and II are combined into a single set. Let Y^1 and Y^2 be the optimal set of subplans to Phase I and Phase II, respectively. Define $\Phi = Y^1 \cup Y^2$. The original problem is subsequently solved over the set Φ. The corresponding models are shown below.

Phase I: Minimum cost total coverage

$$\text{MC}: \quad \text{Min} \quad \sum_{r \in R} c_r z_r \tag{10}$$

subject to:

$$\sum_{s \in S_j} y_s = 1; \quad j \in J; \tag{11}$$

(4)–(9).

Phase II: Maximal value total coverage

$$\text{MV}: \quad \text{Max} \quad \sum_{s \in S} v_s y_s \tag{12}$$

subject to: (4), (6), (7), (11).

Phase III: The restricted problem

$$\text{RP}: \quad \text{Max} \quad \sum_{s \in \Phi} v_s y_s \tag{13}$$

subject to: (2), (8), (9),

$$\sum_{s \in S_j \cap \Phi} y_s \leqslant 1, \quad j \in J, \tag{14}$$

$$\sum_{s \in S_r \cap \Phi} u_{rs} y_s - z_r \leqslant 0, \quad r \in R, \tag{15}$$

$$\sum_{s \in \Phi} (e_s - e_{\text{avg}}) y_s \geqslant 0, \tag{16}$$

$$y_s \in (0, 1), \quad s \in \Phi. \tag{17}$$

4.4. Computational results

As mentioned earlier, there is a dearth of models addressing selection of disaster recovery subplans, and so there is no standard set of test problems for this model. To test our model, we generate 12 hypothetical problems using a variety of parameter settings (see Table 1). Most of the parameters are generated using uniform distributions. Disaster effects can be recovered by 1–5 alternative subplans. Resource unit costs vary between \$ 50 and \$ 250. Utilization levels for a given resource in a given subplan varies between .25 and 2.0. The value measures for recovery capability vary between 10 and 50. We consider scenarios, with 5, 10, and 15 effects. Resources for subplans are selected from a set of 25 types in one case, and from a set of 50 types in another. The number of resources per subplan are randomly sampled. Two cases are considered. In one case, subplans possess between 1 and 5 resources. In the second case, subplans possess between 1 and 10 resources. A budget limit for the model is obtained as follows. For each effect, determine the cheapest subplan that can cover the effect. Determine the total cost value of these subplans and set the budget to a percentage of the total cost. A value is randomly sampled between 55% and 75%.

Table 1
Problem parameters

Parameter	Distribution
Subplans per effect	Uniform (1, 5)
Resource unit costs (c_r)	Uniform (50, 250)
Resource utilization (u_{rs})	Uniform (0.25, 2)
Subplan values (v_s)	Uniform (10, 50)
Number of effects	5, 10, and 15
Number of resource types	25 or 50
Number of resources per subplan	Uniform (1, 5) and Uniform (1, 10)
Budget limit (B)	Uniform (0.55, 0.75)

In generating the problem set, three key parameters were varied: the number of effects (three levels), the number of resources types (two levels), and the number of resources per subplan (two levels). A single problem in each category was generated resulting in 12 test problems shown in Table 2.

Table 3 shows solutions for the LP relaxation of the model, the three-phase heuristic, the BFT heuristic, and the brute-force MIP solution of the model. CPLEX was used as the off-the-shelf solver, and no special tuning of the solver was done. The BFT heuristic terminates the solver after five feasible solutions have been produced or when a 20,000 iteration limit has been reached. From the results we see that the three-phase heuristic performed extremely well. In 11 cases the solution obtained by the three-phase approach is verifiably optimal. In problem 11, however, the methodology provided the better of the two feasible solutions with a duality gap of less than 2%.

4.5. Computational and implementation issues: Problem size and solution difficulty

The proposed mathematical formulation for the DRP requires data for various parameters in the following table and as indicated in the notation at the beginning of Section 4:

Set parameter	Where used
Set of business functions, K	Incorporated into technological coefficient
Set of solution resources, R	Part of constraint set
Set of disaster effects, J	Part of constraint set
Set of disaster types, I	Incorporated into technological coefficient
Set of recovery subplans, **S**	Part of constraint set

Most of these data will be estimated and are required to compute the technological coefficients for the decision variables and do not affect the size of the formulated problem. Therefore they do not pose any difficulty in terms of solution methodology. The key parameters in terms of problem size are as follows:

Set parameter	Probable range of cardinality	Size of entity
Set of disaster effects, J	$\|J\| = 5$–25	Small business to a large city
Set of solution resources, R	$\|R\| = 5$–1000	Small business to a large city
Set of recovery subplans, S	$\|S\| = 3$–100	Small business to a large city

The parameters that translate directly into constraint types are the sets J, R, and S. The ranges of probable cardinality values for these sets are dependent on the granularity of the definition of the disaster effects for these disaster types and the size of the organization or entity to be covered by the plan. This granularity will determine the solution resources and the scope of the subplans for risk mitigation and/or disaster recovery. If a subset of disaster effects calls for identical set of resources then those effects can be aggregated into a single effect. Also a large number of subplans, depending on the size of the organization, will likely include plans that are redundant since other plans will cover the same set of effects. The lower limits of these ranges indicate a subjective determination of the size of the problem for small

Table 2
Problem characteristics

Problem number	No. of effects	No. of resources	No. of resources per subplan
1	5	25	1–5
2	5	25	1–10
3	5	50	1–5
4	5	50	1–10
5	10	25	1–5
6	10	25	1–10
7	10	50	1–5
8	10	50	1–10
9	15	25	1–5
10	15	25	1–10
11	15	50	1–5
12	15	50	1–10

Table 3
Results of the three-phase heuristic

Problem no.	LP relaxation	Three-phase heuristic	BFT heuristic	MIP optimal
1	2047	1767	1767	1767
2	2047	1767	1767	1767
3	2047	1956	1956	1956
4	2047	2047	2047	2047
5	4437	4437	4437	4437
6	4437	4437	4437	4437
7	4437	4437	4437	4437
8	4437	4437	4437	4437
9	6043	6043	5763	6043
10	6043	6043	6043	6043
11	6043	5977	5697	n/a
12	6043	6043	6043	n/a

business organizations, which could be solved by inspection or without expensive computational tools. The largest realistic problem anticipated by our formulation will have about a thousand constraints, but the size of most problems will likely be in the range of a hundred. There are tools that can handle a million constraints, and a thousand constraints will not present a computational challenge for most tools, and the heuristic three-phase procedure proposed in this research, further disaggregates the problem and provides a realistic approach to deriving an optimal solution.

5. Conclusion

In this paper, we have shown how MS/OR modeling can be used to provide strategic decision support for DRP selection. We have presented a new model for selecting subplans in building a DRP/DRS that addresses the concerns of feasibility, consistency and completeness. The objective of the model is to maximize the total value of the coverage provided by the set of selected subplans subject to several constraints. The model, which contains, real, binary, and general integer variables can be solved using a variety of methods. In this paper we used the off-the-shelf solver called CPLEX to solve a number of hypothetical problems using both optimal and heuristic approaches. The results demonstrate that reasonable solutions can be found in reasonable time. Recognizing that little modeling of disaster recovery issues has taken place to date in MS/OR literature, our model represents a forward step in providing what is a fast growing discipline with rigorous models for supporting decision making. Consequently, our contribution is prescriptive rather than descriptive in nature. The model can also be expanded to include operational costs by allowing a temporal dimension. By using 3–5 year life cycles for subplans and considering various types of cost functions (linear, convex, concave, etc.) for subplans, economic issues can be given more realistic consideration in designing a cost-effective recovery strategy.

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