Optimizing emergency management: the role of Operational Research

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Definition

Operational Research
is a scientific discipline that studies
the solution of (complex) decision problems
through mathematical models
and computer algorithms.

Disaster, Data and Decisions

Disaster (natural, attack...)

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Data from different sources

(GISs, EOS, data-bases, sensor networks...)

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Decision-maker(s):

- coordinating rescue operations
- emergency logistics
- etc...

Decisions in emergency

- Decision problems are complex, they may have combinatorial nature and may be large enough to preclude any possibility to find good solutions manually.
- Decisions must be effective, because their effects may be dramatic.
- Decisions must be efficient, because available resources are limited.
- Decisions must be timely, because time is often the most critical resource.
- Decisions must be robust, because data can be missing, incomplete or even wrong and the emergency scenario may change as time passes.
- Decisions must be coordinated, because different stakeholders are involved at different levels in the response to an emergency.
- Decisions must be understandable and defendable, because they imply enormous responsibilities.

From data to decisions

- ICT infrastructure provides support for timely, accurate, detailed, complete, consistent DATA.
- Operational Research (also called “Decision Science”) provides support for effective, efficient, timely, robust, coordinated, rational DECISIONS.

- From a chronological viewpoint ICT should have the precedence, because decision algorithms are useless without data but not vice versa.
- From a conceptual viewpoint the opposite is true: the intelligence of the whole system resides in decision support models and algorithms.

Examples

- Example 1: Civil protection teams workshifts
- Example 2: Scheduling deteriorating jobs
- Example 3: Critical infrastructure protection
- Example 4: Interoperability optimization

Civil protection teams workshifts

- Assignment between given teams, sites and periods.
- All sites must be assigned to a team in each period.
- All teams must be active for the same number of times.
- The number of active teams in each period must be balanced.
- Minimize the maximum response time.

Civil protection teams workshifts

- The problem can be formulated as an Integer Linear Programming (ILP) problem with binary decision variables.
- Solved via mathematical programming techniques such as Lagrangean relaxation, subgradient optimization and branch-and-bound with constructive and local search heuristics.
- Instances with up to 210 sites, 10 teams and 3 periods were solved to proven optimality in 45 minutes; instances with up to 1000 sites, 10 teams and 4 periods have been approximated within a few percentage points from optimality.
- The improvement on manually computed solutions was about 30%.

Scheduling deteriorating jobs

- A set of tasks must be accomplished by a single agent, without preemption, possibly with release dates.
- Either the processing time of each job increases with time (fire fighting, epidemic containment) or the value associated with each job decreases with time (probability of finding people alive).
- Minimize the maximum time needed to complete all jobs or maximize the overall value of the solution.

Scheduling deteriorating jobs

- There are as many solutions as the number of permutations of the jobs (*N!*).
- Solved via branch-and-bound and dynamic programming.
- Optimal solutions have been obtained for problems with up to 20 deteriorating jobs in 6 seconds and with up to 50 deteriorating jobs in a few minutes.
- The same approach also allows to develop fast heuristics to tackle larger problem instances.

Critical infrastructure protection

- A set of p critical infrastructures are under threat: the attacker can select q of them; the defender can fortify r of them.
- An attack against a fortified facility has no effect.
- The cost of each "attack pattern" is known.
- Select which facilities to fortify to minimize the damage in the worst case.

Critical infrastructure protection

- This is a combinatorial bi-level programming problem (see for instance: R.L.Church and M.P.Scaparra, *Protecting critical assets: the r-interdiction median problem with fortification*, Working paper n.79, Kent Business School, 2005)
- Enumeration of interdiction patterns
- Set covering problem with special structure and additional constraints
- The largest problem instance solved so far has 20 facilities, q=10 and r=4.

Interoperability optimization

- A set of entities (data-bases, institutions) can use a set of possible protocols for communication.
- Each entity must choose one of them and pays an associated cost.
- Each communication between a pair of entities also has a cost depending on the two corresponding protocols.
- Select the protocol for each entity in order to minimize the overall costs.

Interoperability optimization

- This is a combinatorial optimization problem with binary variables and a non-linear objective function (known as the *“edge-weighted max clique problem with multiple choice constraints”*).
- It can be linearized by introducing auxiliary binary variables.
- Solved by branch-and-bound and Lagrangean relaxation.
- Optimal soutions for instances with up to 75 protocols and 5 entities in less than 2 hours.
- Solvable by semidefinite programming.

Final remarks

- Data are valuable only if we can make good decisions out of them.
- The development of the ICT infrastructure must be accompanied by the development of the suitable decision support tools.
- The O.R. scientific community must be heavily involved in research programs on emergency planning, management and recovery.