Robust Management of Heterogeneous Systems under Uncertainties

Yuri Ermoliev, Marek Makowski, and Kurt Marti

Abstract The chapter summarizes the key issues related to robust management of heterogeneous systems under uncertainties. It focuses on challenges types of decision problems under uncertainties for which standard approaches are inadequate, and builds on the related background and key concepts discussed during all workshops on *Coping with Uncertainties*. The selected key issues are summarized in a condensed manner, and illustrated by simple examples.

1 Context

Global change processes, in particular climate change, involve inherently unpredictable complex interactions between natural and human-created systems therefore proper modeling of these processes must rely on adequate treatment of uncertainties, socio-economic and environmental heterogeneities, and their interdependencies with human's decisions. Traditional natural science models are based on relations whose validity is estimated from repetitive experiments and observations. If experiments do not affect the underlying relations, and the processes are stationary, then repetitive observations allow to develop the corresponding models by using the statistical decision theory. In reality, however, human-created processes do not follow fixed relations. Such processes have typically structure, relations, and parameters that not only change over time but also depend on the decisions that affect the processes; for example, introduction of new technologies may

M. Makowski (✉) · Y. Ermoliev
International Institute for Applied Systems Analysis, Laxenburg, Austria
e-mail: ermoliev@iiasa.ac.at; marek@iiasa.ac.at

K. Marti
Federal Armed Forces University Munich, Aerospace Engineering and Technology, Neubiberg/Munich, Germany
e-mail: kurt.marti@unibw-muenchen.de

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increase or reduce uncertainties, modify threats, interdependencies, create systemic risks, critical thresholds, and potential discontinuities. Such new type of decision problems under inherent uncertainty requires qualitatively new approaches than methods supported by the traditional statistical decision theory.

Traditional models based on statistical decision theory deal with situations in which a model of uncertainty, and the corresponding optimal solutions are defined by a sampling model characterized by a probability measure P with an unknown vector x of "true parameters" x^*. Vector $x = x^*$ defines a desirable optimal solution, the performance of which can be observed from the sampling model providing a sequence $\{\omega^1, \omega^2, \dots\}$ of random observations of x^*. Therefore, the problem is to recover x^* from these data. Potential estimates of x^* define feasible solutions x of the corresponding statistical decision problem. It is essential that x does not affect the sampling model P so that the performances of solutions x can be evaluated by a distance from x^* by using observable performance $\{\omega_1, \omega_2, \dots\}$.

Support for the new type of decision-making under uncertainty requires fundamentally new approaches. The model of uncertainty, feasible solutions, and performance of the optimal solution are not given; all of these elements have to be modeled based on analysis of the decision making situation, i.e., considering heterogeneous dimensions, such as socioeconomic, technological, environmental, and safety. Moreover, there is no information on the actual optimal performance; therefore the performance of desirable solutions cannot be characterized by a distance from an observable, actual optimal performance. Thus, the general decision problems typically have rather diversified facets (dimensions) of robust performance.

Actually, good evaluations of global change processes are unrealistic because such processes are non-stationary, have delayed responses, and experiments are dangerous or even impossible. Moreover, some human or natural actions qualitatively change the underlying processes, e.g., causing discontinuities or irreversibilities. Under inherent uncertainty of such heterogeneous processes, the role of integrated modeling rests on its ability to guide comparative analysis of rational decisions. Although exact evaluations are impossible, the preference structure among decisions can provide a stable basis for a relative ranking of alternatives, and thus enable designing robust policies, which are, in a sense, optimal against all relevant uncertainties. To illustrate this approach let us recall a commonly known observation: finding out (without exact measurements) which of two given parcels is heavier is much easier than evaluating weight of each of them.

The term *robust* was first introduced into statistics in 1953 by Box (1953); it was widely recognized after publication of a path-breaking paper by Huber (1981), who admitted that researchers had long been concerned with the sensitivity of standard estimation procedures for "bad" observations (outliers). Appeal for robustness (Hampel et al. 1986) probably dates back to prehistory of statistics. A distant outlier in observations ruins the least square analysis, therefore rejection of outliers is considered a robust statistical procedure. The mean is not robust to outliers, whereas the median is robust; therefore, switching from the mean to the median for long-tailed data increases robustness. According to Huber, . . . *any statistical procedure. . . should be robust in the sense that small deviations*