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Multi-criteria evaluation model: an application of MRP parameterization

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ABSTRACT

This paper presents a multi-criteria evaluation model applied to the parameterization of the MRP method. Existing optimization approaches that address this problem tend to adopt a means of simulation. A simulated solution is characterized by a pair (parameters, performance indicators). In the context of the evaluation of solutions, the work of Barth, Damand et al. (2003) propose a heuristic approach to extracting knowledge from a solution set. The approach is based on the definition of a multi-criteria solution comparison function. The objective of this paper is to present the detailed modeling of this comparison function. Ultimately, this result contributes to the formalization of a multicriteria optimization problem. A problem solving strategy is proposed.

1. Introduction

Parameterization of the MRP method consists of dynamically specifying all the values of the method's input parameters (*AP*), taking into account the performance objectives, the parameter constraints and any new aspects of the situation under consideration. In some cases, it is possible to respond to the evolutions rapidly through programmed decisions. In the case of this paper, the decision-maker, hereinafter called "the planner ", does not have the prerequisites for the action, but is in a problem-solving situation. Conducting research implies having a means of simulation that can answer 'what if' type scenarios. The output values of the method enable the system's performance to be measured, generally expressed in performance indicators (*PI*). A solution is thus described as a relationship between an *AP* configuration and a *PI* configuration (hereinafter called an *AP-PI* relation). The evaluation of the set of solutions allows the properties characterizing the *APs*, the PIs and the *AP-PI* relations in the situation under consideration to be identified. The properties are inferred from an interaction between the planner's assessment questions and his representation of the overall structure of a set of solutions. In the performance space achieved, example generic evaluation questions include [2,6,8,15]:

- What is the effect of *APs* on *PIs*?
- Which performance areas are attainable?
- Are there any equivalent solutions?
- How does an *AP-PI* relationship stand with regard to other relations?
- How does an *AP-PI* relationship stand in the absolute (rejection, waiting, acceptance)?

The type of questions presented above deal with issues concerning the multi-criteria decision-making support (sorting (β), ranking (γ) describing (δ) selecting (α)) introduced by [18]. In this case, the methods must, first, include the decider's preferences and second, propose an intelligible global representation depending on the issues under consideration. In the context of the parameterization of the MRP method, in [2], the authors put forward a model called the plan of preferences, which combines both the sorting and the ranking issues. As a research perspective, the authors motivate a performance exploration problem in the plan of preferences. The problem described is a combinatorial optimization problem. Two optimization problems are formulated as follows: (A) What are the best least good solutions with respect to the models of

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preference (ranking and sorting)? (B) Are there any solutions in this or that area of performance of the plan of preferences? The multi-criteria comparison function of the solutions is defined. However, the authors did not formalize the method required to construct the proposed model. The aim of this paper is therefore to formalize this method.

The paper is divided into 5 sections. Section 2 describes the theoretical background. Section 3 presents the plan of preferences concept. Section 4 describes the formalization of the plan of preferences construction method. Finally, section 5 concludes with the research perspectives generated by this work.

2. Theoretical background

Relations between *APs* and *PIs* have been widely covered in the academic literature. In the last 30 years, there have been 10 states of the art: [7,9,10,11,12,13,14,17,19,22]. These papers address three classes of AP-PI relations, namely, relations linked to: stock |7,22,12], the planning method [17,19] and a simultaneous stock and planning method [13, 14, 11,9,10].

One recent state of the art [10], based on an analysis of 87 papers from 1976 to 2017, listed studies involving 31 *AP*s, 29 *PIs* and 247 *AP-PI* relations. Not all the relations have been studied, however. The most widely studied *APs* are: demand variations, lot-sizing rule, planned lead time, freezing proportion, planning horizon, product structure, schedule rule, and replanning periodicity. The most frequently studied *PIs* are: (setup + carrying + ordering) costs, schedule instability, service level, (carrying + setup) costs, stockout (number of units, etc.), and capacity utilization. For an *AP-PI* relation, the 'what if' question is addressed as follows: what is the sense of the *PI* variation if the value of the *AP* increases or decreases? To illustrate this, we can mention the *AP-PI* relations identified in the following 3 studies:

1. Total increase in cost if the freezing proportion increases [20],
2. Increase in schedule instability if the freezing proportion [21],
3. Decrease in schedule instability if the freezing proportion increases [1].

Studies are mainly distinguished by the operating conditions and the number of *AP-PI* relations studied. Operating conditions are characterized in four ways: number of manufacturing levels (single-level or multi-level), type of demand (deterministic or stochastic), capacity (uncapacitated systems or capacitated systems), and item numbers (multiple or single). In [10], the authors highlight the contextual nature of the findings above. In effect, results may vary depending on changes to the operating conditions. For example, the relations 2 and 3 above are contradictory. The experiments by [21] and [1] respectively differ according to the operating conditions linked to the 'capacity' modality.

It is unlikely that the results of these studies could be used as a decision-making support for the parameterization of the MRP method in general cases. However, it would be feasible to use the 'simulation- experimental design' methodology linked to a set of *AP-PI* relations and interpreted by the planner of specific systems.

In such a case, one difficulty would lie in the multicriteria evaluation of the *AP-PI* relations. A parameterization study may include several hundred multicriteria relations; the study by [16] for instance is described as follows: 6 *PI*, 4 *AP*, 448 simulated *AP-PI* relations.

3. The plan of preferences concept

To facilitate multicriteria evaluation and comparison of *AP-PI* relationships in a specific environment, the paper titled "*How Can We Ascertain, Understand and Interpret the Performance Level of A Production System? A Visual Method: The Plan of Preferences*" [2] propose a way of considering support for the evaluation from a set of *AP-PI* relations thanks to the description of the properties related to ranking (rank of a *AP-PI* relationship) and sorting (class of a *AP-PI* relationship). The issues pertaining to ranking and sorting are complementary. The drawback in the case of ranking is that the evaluation of the *AP-PI* relationship is made with respect to the other relations. Thus, a situation can very well emerge as the best of a set of relations, even though it is bad in the absolute. Sorting, on the other hand, involves steering the investigation towards highlighting an assignment of relationships to predefined classes. These predefined classes specify the absolute value of relations. "Relative and absolute" evaluations correspond to two value judgements identified in cognitive psychology [3].

The *AP-PI* relations are represented on a plan (Figure 1). The *X* and *Y* axes respectively support the two relations of preference (sorting and ranking). The coordinates of a solution s_1 (a specific *AP-PI* relation) are: *X* assigned class C_1, *Y* rank R_1.

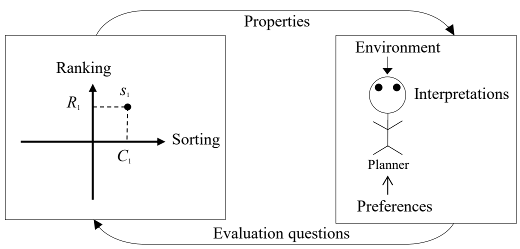


Figure 1. Plan of preferences in the *AP-PI* relations evaluation process

The purpose of the plan is to visualize an elaborate representation of all the performance achieved enriched by the planner's preferences.

This involves dialogue with the representation to extract properties. In [2], the authors suggest beginning the dialogue between the decision-planner and the plan of preferences with the following intuitive question: "*How does the initial solution fit in with the new situation*?" Subsequent questions are formed and linked together according to the interpretations of the properties extracted from the plan of preferences. This method draws on gradually acquired information. The decision planner intervenes throughout the multicriteria analysis to give information on his or her true preferences. Using the preference plan, the multicriteria method helps decision-makers construct their overall preferences (called pre-order of the decision-maker [18]).

This outcome is not only based on the logic of the preference plan, but also on the logic of the decision planner as it is revealed from information obtained at different stages of the evaluation process. These revelations, however, remain within the logical framework set by the model. This takes us on to the following section.

4. Formalisation of the plan of preferences construction method

This section presents respectively the formalization of *AP-PI* relations, scales of preferences supported by the *XY*-axes and the evaluation rules of the plan of preferences.

4.1. AP-PI table

Notation

$AP_j(s_i)$: level of AP_j ($\{AP_j \mid j = 1, \ldots, t\}$) of the solution s_i ($\{s_j \mid i = 1, \ldots, n\}$);

$PI_j(s_i)$: value of the PI_j ($\{PI_j \mid j = 1, \ldots, m\}$) of the solution s_i.

The set of AP-PI relations derived from simulation are summarized in a table called the *AP-PI* table (Table 1).

Table 1. *AP-PI* table

s_i	AP_j			PI_j		
	AP_1	…	AP_t	PI_1	…	PI_m
s_1	$AP_1(s_1)$	…	$AP_t(s_1)$	$PI_1(s_1)$	…	$PI_m(s_1)$
…	…	…	…	…	…	…
s_n	$AP_1(s_n)$	…	$AP_t(s_n)$	$PI_1(s_n)$	…	$PI_m(s_n)$

One line of the table corresponds to an *AP-PI* relation. An *AP-PI* relation, also called solution s_i (**Hata! Başvuru kaynağı bulunamadı.**) in what follows, is represented by the values of *AP* ($AP_1(s_i)$, $AP_2(s_i)$, …, $AP_j(s_i)$, …, $AP_t(s_i)$) and the values of *PI* ($PI_1(s_i)$, $PI_2(s_i)$, …, $PI_j(s_i)$, …, $PI_m(s_i)$). The number of lines in the table depend on several factors. Let's assume that the system is controlled by t AP_i parameters. Each parameter is associated with several levels. If the parameter is qualitative, the number of levels will correspond to the number of possible parameter conditions. If the parameter is represented by a quantitative variable, only a finite number of possible values for the parameter will be retained. If we note N_i as the number of levels respectively associated with the AP_i parameters, the potential number of lines on the table will be: $\prod_i Ni$.

The analysis space is the space whose dimensions are represented by performance indicators. In a multicriteria approach, solutions are estimated by analyzing the values they take for each PI_j. Moreover, the PI_j are real variables. The PI_j space is thus always mathematically represented. To analyze the structure of the performances achieved, we need to prepare the information contained in the *AP-PI* table for this purpose.

4.2. Y-axis, solutions ranking scale

4.2.1. Construction of the ranking relationship

Ranking consists of differentiating the solutions according to their relative interest in a decreasing order of preference. In the study context, *PIs* are highly heterogeneous and difficult to compare. Thus, an outranking method has been adopted. This approach is based on an elementary mechanism, namely, the pairwise comparison of solutions, *PI* by *PI*. It involves a set of conditions leading to the acceptance or rejection of an outranking at global level.

The family of outranking methods is dominated by the ELECTRE method [18] and the PROMETHEE method [4]. The outranking method applied is the PROMETHEE II method [4,5]. This is based on concepts with a physical interpretation that are easy for the decision-planner to understand. In addition, the nature of the outranking hypothesis introduced in the PROMETHEE method allows for the graduation of outranking credibility.

This is the "... better than ..." relationship richer within the framework of the study of this paper than the "… at least as good as…" relationship of the ELECTRE method. When a s_i solution outranks a s_k solution, it is indeed important to know the degree of credibility that can be attached to the statement "s_i outranks s_k".

The principles of building and exploiting the ranking relations adapted to the problem are developed below.

For each PI_j, we consider,

$s_i >_j s_k$, means strict preference of s_i over s_k (1)

iff $PI_j(s_i) > PI_j(s_k) + p_j$ (p_j: the preference threshold)

$s_i \approx_j s_k$, (means indifference between s_i and s_k) (2)

iff $-q_j \leq PI_j(s_i) - PI_j(s_k) \leq q_j$ (q_j: indifference threshold)

$s_i >^{wp_j} s_k$, (means weak preference (wp) of s_i over s_k) (3)

iff $PI_j(sk) + q_j < PIj(si) < PI_j(sk) + p_j$

For each pair of solutions (si, sk), we consider a preference index $C(si, sk)$,

$$C(s_i, s_k) = C(d(s_i, s_k)) \quad (4)$$

with,

$$C(d(s_i, s_k)) = \begin{cases} 0 \\ (d(s_i, s_k) - q_j)/(p_j - q_j) \\ 1 \end{cases}$$

$d(s_i,s_k) = PI_j(s_i) - PI_j(s_k)$

$$\begin{cases} 0 & \text{if } d(s_i, s_k) \leq q_j \\ (d(s_i, s_k) - q_j)/(p_j - q_j) & \text{if } q_j < d(s_i, s_k) \leq p_j \\ 1 & \text{if } d(s_i, s_k) > p_j \end{cases}$$

if $d(s_i, s_k) \leq q_j$	Indifference
if $q_j < d(s_i, s_k) \leq p_j$	Weak preference
if $d(s_i, s_k) > p_j$	Strict preference

Assuming a given weight of w_j (w_j>0) reflecting the importance of PI_j, normalised ($\sum_j w_j$=1), the preference index $C(s_i, s_k)$ is calculated as follows:

$$C(s_i, s_k) = \sum_j w_j \, C_j(d(s_i, s_k)) \quad (5)$$

4.2.2. Exploitation of the ranking relationship

The PROMETHEE method translates the outranking relationship through the information pertaining to the flow.

For a solution s_i, we consider:

$\phi^-(s_i) = \sum_x C(x, s_i)$, the entering flow or weakness of s_i; x is every solution other than s_i (6)

$\phi^+(si) = \sum_x C(s_i, x)$, the leaving flow or power of s_i (7)

$\phi(s_i) = \phi^+(s_i) - \phi^-(s_i)$, the net flow or qualification of s_i (8)

Finally, the complete PROMETHEE II pre-order (P_{II}, I_{II}) is defined by

$$\begin{cases} s_i \, P_{II} \, s_k, (s_i \text{ globally } outranks \; s_k) \text{ iff } \phi(s_i) \geq \phi(s_k) & (9) \\ s_i \, I_{II} \, s_k, (s_i \; is \; indifferent \; to \; s_k) \text{ iff } \phi(s_i) = \phi(s_k) & (10) \end{cases}$$

The s_i solutions are positioned on a scale of preference whose states represent the solutions qualification $\phi(s_i)$. To visualise the ranking, the scale of preference is supported by a vertical and restricted axe, called Y-axis (

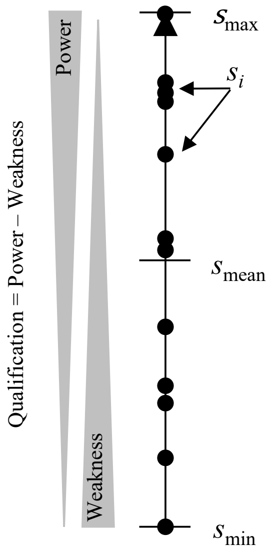
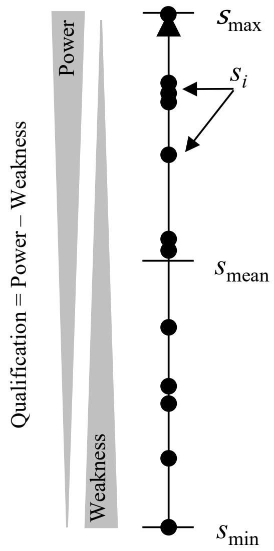


Figure **1**).



Properties

N, all solutions

s_{max}, ideal solution such that $\phi(s_{max})$= Card(N)-1

s_{mean} mean solution, such that: $\phi(s_{mean})$= 0

s_{min} anti-ideal solution, such that: $\phi(s_{max})$= -Card(N)-1

Figure 1. Y-axis

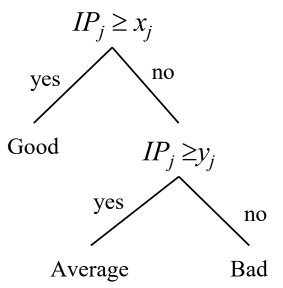
4.3. X-axis, solutions sorting scale

4.3.1. Construction of the sorting relationship

The sorting relationship is developed within the framework of the study of this paper.

Sorting consists of examining the values of each solution's PI_j in order to put forward a recommendation from a set of possible recommendations, specified in advance. By linking a class to each recommendation, the problem boils down to the allocation of solutions to predefined classes. These classes are ordered and correspond respectively to the following judgements: "accepted or good", "pending or average" and "rejected or bad". The "good, average and bad" judgements are generally accepted by the decision-makers. The concepts relative to the definition of classes are defined below.

To express the users' preferences, each PI_j is segmented into three leaves, respectively judged as good, average and bad. For each PI_j, one or several threshold values are defined. These threshold values make it possible to express a judgment on each value of an PI_j (**Hata! Başvuru kaynağı bulunamadı.**).



xj, *yj* : threshold values for *IPj*

Figure 2. Example of a PI_j segmentation

The segmentation of each PI_j indicator makes it possible to characterize each s_i solution by a triplet ($a(s_i)$, $b(s_i)$, $c(s_i)$), where $a(s_i)$, $b(s_i)$ and $c(s_i)$ are respectively the number of indicators whose value is judged as good for the s_i solution, the number of indicators whose value is judged as average for the s_i solution and the number of indicators whose value is judged as bad for the s_i solution.

The solutions characterized by the same triplet belong to the same class leaf. The potential number of classes is $1+m+\frac{m(m+1)}{2}$ (with m: number of *PI*). These classes form a partition of all the performances. An *si* solution belongs to just one class and one only. For any given system, some classes may be empty.

A total order is defined for all class leaves. Let there be two *X* and *Y* classes defined respectively by the triplets (*ax*, *bx*, *cx*) and (*ay, by, cy*). The relation of preference (>) between the classes is defined as follows:

$$X < Y \iff \begin{cases} cx > cy \\ \text{or} \\ cx = cy \text{ and } ax < ay \end{cases} \qquad (11)$$

The conditions of preference define a total pre-order of solutions as several solutions may be assigned to a same class leaf. In this case, the solutions are equivalent. The relation of preference (≥) between the solutions is defined as follows:

$$s_i \leq s_j \iff \begin{cases} a(s_i) = a(s_j) \text{ and } b(s_i) = b(s_j) \text{ and } c(s_i) = c(s_j) \\ \text{or} \\ c(s_i) > c(s_j) \\ \text{or} \\ c(s_i) = c(s_j) \text{ and } a(s_i) < a(s_j) \end{cases} \qquad (12)$$

Lastly, the class leaves are partitioned into three aggregate classes:

1 class defined by $b = 0$ and $c = 0$ (called "Good");

m classes defined by $c = 0$ and $b \neq 0$ (called "Average");

$\frac{m(m+1)}{2}$ classes defined by $c \neq 0$ (called "Bad").

4.3.2. Exploitation of the sorting relationship

The successive definitions allow us to organize these in a hierarchy of partitions (**Hata! Başvuru kaynağı bulunamadı.**).

The class leaves are positioned on a scale of preference whose states represent the $1+m+\frac{m(m+1)}{2}$ class leaves. The scale of preference is supported by the *X*-axis (Properties: C_{max}: $b = 0$ et $c = 0$; C_{mean}: $a = 0$ et $c = 0$; C_{min}: $a = 0$ et $b = 0$ **Figure 3**).

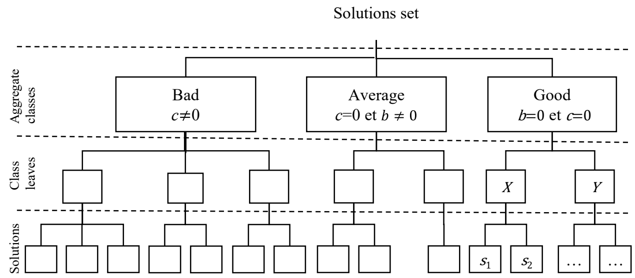
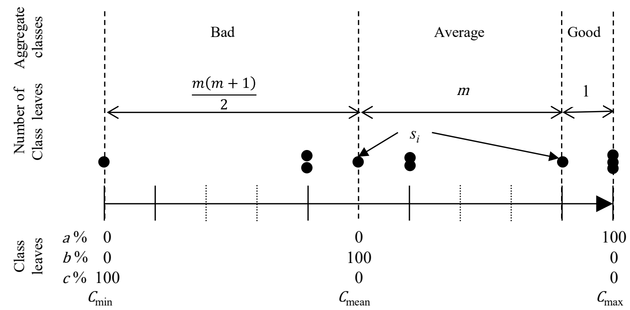


Figure 4. Hierarchy of partitions

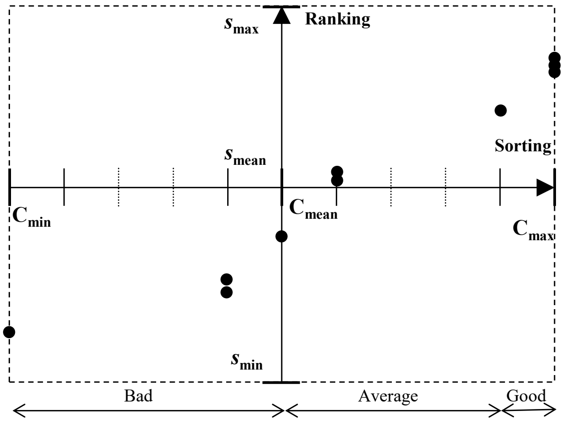


Properties: C_{max}: $b = 0$ et $c = 0$; C_{mean}: $a = 0$ et $c = 0$; C_{min}: $a = 0$ et $b = 0$

Figure 3. *X*-axis

4.4. XY-plane, the rules of evaluation of the plan of preferences

The plan of preferences (Figure 4) is obtained by crossing the *Y*-axis and the *X*-axis. The point of intersection of the coordinate axes is (C_{mean}, s_{mean}). Each s_i solution is represented by a coordinate point (Class leaf (s_i), ϕ (s_i)).



Class leaves	$\frac{m(m+1)}{2}+m+1$	….	m	….	1
a %	0		0		100
b %	0		100		0
c %	100		0		0

Figure 4. XY-Plane

Properties: Ideal point (C_{max}, s_{max}); Anti-ideal point (C_{min}, s_{min})

The rules of evaluating preferences are illustrated and expressed as follows:

Case 1 Rule 1 $$\text{if}\begin{cases} s_1 =_{X-axis} s_2 \\ s_1 =_{Y-axis} s_2 \end{cases} \text{then } s_1 = s_2 \qquad (13)$$

Case 2 Rule 2 $$\text{if}\begin{cases} s_1 >_{X-axis} s_2 \\ s_1 =_{Y-axis} s_2 \end{cases} \text{then } s_1 > s_2 \qquad (14)$$

Case 3 Rule 3 $$\text{if}\begin{cases} s_1 =_{X-axis} s_2 \\ s_1 >_{Y-axis} s_2 \end{cases} \text{then } s_1 > s_2 \qquad (15)$$

Case 4 Rule 4 $$\text{if}\begin{cases} s_1 >_{X-axis} s_2 \\ s_1 >_{Y-axis} s_2 \end{cases} \text{then } s_1 > s_2 \qquad (16)$$

Case 5 Rule 5 $$\text{if}\begin{cases} s_1 >_{X-axis} s_2 \\ s_1 <_{Y-axis} s_2 \end{cases} \text{then } s_1 \text{ and } s_2 \text{ are incomparable} \qquad (17)$$

With, "=": "is equivalent to"; ">": "is preferred to"; "<": "is not preferred to"

The two axes discussed (via case 1, 2, 3, 4, 5 below) in the *XY* plane are complementary. The comparison between solutions according to the two axes of preference allows us to separate strong or robust preferences (case 1, 2, 3, 4) from the other non-robust preferences (case 5). A non-robust preference corresponds to a contradictory ranking in accordance with the sorting and ranking axes. The contradictory rankings enable several preferred and incomparable solutions ($\{s_1, s_2\}$, case 5) to be identified in accordance with the two axes of preference.

5. Conclusion and perspectives

The actions described in this paper may be summed up as follows:

- Motivate the theoretical background: there are no general *AP-PI* relation,
- describe the concept of the plan of preferences,
- formalize the two preference comparison relations (ranking and sorting) and the rules for reading a solution s_i (Class leaf (s_i), ϕ(s_i)). The ranking method applied is the PROMETHEE II method. The sorting method was constructed in the study of this paper.

In view of the work undertaken, the results of this paper, especially the detailed modelling of the two relations of preference (ranking and sorting), contribute to the formalization of the issues of combinatorial optimization identified in [2]. The resolution of problems (A) and (B) (see Introduction and reformulated below), is now both conceivable, via optimization methods.

(A) *What are the best least good solutions with respect to the models of preference (ranking and sorting)?*

(B) *Are there any solutions in this or that area of performance of the plan of preferences?*

To conclude, it is proposed to continue the work already conducted in the framework of this paper, as a strategy of problem-solving for general cases using the solutions to problems A and B:

(1) Finding a solution to problem A with optimization methods and an initial definition of the performance zones accessible and non-accessible by the systems.

(2) Drawing up experimental designs which are as broad-sweeping as possible in view of the calculation potential.

(3) Applying the approach put forward in this paper to the dots calculated and deducing hypotheses on the structure of the performance levels.

(4) Fine-tuning the investigation and validating or invalidating the hypotheses by the detailed solving of multiple problems of type problem B.

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