

Dynamic Project Portfolio Management Using Multi-Criteria Decision-Making Methods – A Model for Periodic Revision Under Uncertainty

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Abstract. Managing a project portfolio in a volatile environment requires mechanisms for revising resource allocations after changes in project progress or resource availability have been observed. The aim of this article is to develop an interactive multi-criteria procedure for revising the unimplemented part of a given project portfolio plan while preserving terminal project requirements. Criterion weights are determined once, before the first planning stage, using a hybrid procedure combining an importance adjustment inspired by WINGS, DEMATEL analysis of direct and indirect relations, and DEMATEL-based ANP (DANP). Initial project evaluations and the resulting fixed criterion weights are then used once by VIKOR to establish the project hierarchy. This hierarchy remains unchanged throughout the planning horizon. A resource-feasible baseline plan is provided as an input to the procedure. After each implemented allocation decision, the observed portfolio state is compared with the planned state, and the feasibility of the unimplemented part of the baseline or most recently accepted plan is verified. When necessary, the remaining plan is revised without recalculating the VIKOR indices or changing the project hierarchy. The revision minimizes changes relative to the previously accepted plan, subject to resource, activity, competency, terminal, and decision-maker requirements. The procedure additionally reports the resource-buffer vector and project target-attainment times, which describe the operational flexibility and timing consequences of each proposed continuation. Its applicability is illustrated using a deterministic example in which an observed deviation from planned project progress triggers a revision of the remaining allocation plan. The proposed framework separates one-time preference modelling and project prioritization from periodic state observation and interactive plan revision.

Keywords: project portfolio management · multi-criteria decision-making · MCDM · interactive approach · prioritization · uncertainty · practical constraints.

1 Introduction

Project portfolio management (PPM) concerns the selection, prioritization, balancing, funding, and control of projects that compete for shared organizational resources. Its purpose is not merely to improve individual project execution, but to translate strategy into a coordinated and revisable set of investments [22, 10]. Organizations typically have more candidate or ongoing projects than they can execute simultaneously; portfolio decisions therefore combine strategic value with financial, human-resource, technological, and risk constraints [1, 4].

Three coupled questions arise in operational portfolio management: which projects should be active, how intensively each active project should be implemented, and how personnel should be allocated over successive periods. Treating these questions as a static selection problem suppresses their temporal structure. Current allocations change project progress, affect future costs and flexibility, and determine which terminal obligations remain attainable. Meanwhile, resource availability, project assessments, requirements, market windows, and risk exposures may change between portfolio reviews [21, 16].

The problem is also intrinsically multi-criteria. Strategic alignment, innovation potential, dynamic financial return, abandonment cost, resource bottlenecks, supply-chain stability, operational risk, requirement volatility, and decision flexibility cannot be expressed in a common natural unit. Moreover, these criteria are interdependent. For example, component availability affects technological alignment and operational risk; resource bottlenecks affect time to market; and funding commitments affect both abandonment cost and decision flexibility. Independent weights can hide these pathways.

Existing PPM studies provide static scoring and optimization models, multi-criteria ranking procedures, and accounts of dynamic organizational practices. However, insufficient attention has been paid to the reproducible integration of dependent evaluation criteria, a fixed project-priority structure, stage-specific resource allocations, observed project progress, and binding terminal requirements within a single plan-revision procedure. A project ranking alone is not sufficient because it does not determine a feasible allocation plan. Moreover, after an allocation decision has been implemented, the unimplemented part of the plan may cease to be feasible because the observed portfolio state or available resources differ from their planned values. The methodological problem addressed in this study is therefore not the repeated ranking of projects, but the periodic revision of the remaining allocation plan under a hierarchy established before the beginning of the planning horizon.

Accordingly, the aim of this study is to develop an interactive multi-criteria procedure for the periodic revision of the unimplemented part of a given project portfolio plan. The procedure integrates a fixed hierarchy of projects, stage-specific resource allocation, observed project progress, current resource availability, and terminal requirements. Project priorities are determined once before the first decision stage, whereas subsequent decisions concern only the verification and, when necessary, revision of the remaining part of the previously accepted allocation plan.

The study addresses the following research question:

RQ1. *How can a fixed project hierarchy derived from interdependent evaluation criteria be incorporated into periodic revisions of the unimplemented part of a resource-feasible project portfolio plan while preserving terminal project requirements?*

The contribution is threefold. First, the paper defines a state-transition representation linking project progress, implementation intensity, employee allocation, and terminal feasibility. Second, a hybrid WINGS-inspired DEMATEL–DANP procedure provides one vector of weights for dependent criteria, while VIKOR uses the initial project evaluations and these fixed weights to establish one project hierarchy before the first decision stage. Third, the paper introduces an interactive mechanism in which a given resource-feasible baseline plan is verified after each state update and, when necessary, its unimplemented part is revised. The revised plan is selected to minimize changes relative to the previously accepted plan and is accompanied by information on resource buffers and project target-attainment times, allowing experts to assess its operational flexibility and exposure to delays.

2 Literature Background

2.1 Project portfolio management and resource allocation

Classical PPM research emphasizes maximization of portfolio value, balance, strategic alignment, and a feasible number of projects relative to organizational capacity [2–4]. Archer and Ghasemzadeh [1] proposed an integrated framework separating preliminary screening, individual project analysis, comparative evaluation, portfolio optimization, and adjustment. This distinction remains important: a high-value project does not necessarily belong to the best feasible portfolio when projects compete for the same resources or interact through logical and technological dependencies.

Research later broadened the focus from formal selection to organizational practice. Strategic orientation influences portfolio structure and performance [17], while managerial involvement and portfolio governance shape decision quality [11]. Kester et al. [14] identify distinct mechanisms of portfolio decision making. Martinsuo [16] shows that PPM is contextual, negotiated, and affected by organizational interests rather than being a purely rational optimization routine. Consequently, quantitative models should structure deliberation without concealing the judgment that remains outside the formal representation.

Resource allocation connects strategic selection with operational feasibility. Portfolios compete for budgets, specialist employees, management attention, infrastructure, and components. Even a strategically balanced portfolio can be infeasible when several projects require the same scarce competence. Multi-project environments therefore face overload, resource conflicts, and weak coordination

[6]. The present study treats employee assignment and project intensity as explicit stage decisions rather than consequences determined after portfolio selection.

2.2 Dynamic portfolios, uncertainty, and terminal obligations

A project portfolio is repeatedly revised as project progress, costs, market conditions, strategic priorities, risks, and resource availability change. Petit and Hobbs [20] identify sources of uncertainty and sensing mechanisms in dynamic environments; Petit [21] further links uncertainty with portfolio organization. Killen et al. [15] interpret PPM as a dynamic capability involving sensing and reconfiguration. Risk management at the portfolio level can improve portfolio success [23], but project-level analyses often neglect how one allocation changes exposure elsewhere in the portfolio.

Terminal obligations make successive portfolio decisions interdependent. A funded project may be required to reach a milestone, produce a prototype, complete testing, or close by the end of the planning horizon. A decision that is attractive in the current period may still be unacceptable if it consumes resources required to achieve later obligations. The initial plan and every subsequent revision must therefore preserve at least one feasible continuation to the required terminal state. Periodic ranking alone is insufficient because it does not ensure that the resulting allocation decisions can be combined into a feasible plan for the remaining horizon.

2.3 Multi-criteria decision support in PPM

PPM applications use scoring, multi-attribute value theory, AHP/ANP, TOPSIS, outranking, data envelopment analysis, mathematical programming, and hybrid procedures. Golabi et al. [8] provide an early example of combining multi-attribute preferences with portfolio selection. Henriksen and Traynor [9] present a practical scoring tool for R&D selection. Reviews show both wide adoption and substantial methodological fragmentation [5].

Multi-criteria models face four recurring limitations. First, rankings can be sensitive to elicitation and normalization, while decision makers may interpret weights as generic importance statements rather than trade-offs. Second, additive models commonly assume criterion independence. Third, project-level ranking does not determine a feasible resource-allocation plan. Fourth, static planning models do not represent the need to revise the unimplemented part of an existing plan after changes in project progress or resource availability have been observed. The proposed procedure addresses the latter three issues by deriving criterion weights from an influence network, establishing a fixed project hierarchy, and incorporating this hierarchy into the periodic revision of a resource-feasible portfolio plan.

2.4 Dependent criteria and compromise ranking

DEMATEL derives a total-influence matrix from expert judgments about direct relations, thereby including indirect paths and feedback [7]. Its row and column summaries distinguish elements that predominantly exert influence from those that predominantly receive it. DANP uses DEMATEL relations to construct and weight an ANP supermatrix; its limiting values provide global criterion weights that reflect the network structure [24]. In the current model, intrinsic importance assessments are additionally retained through an adjustment inspired by WINGS [18]. The exact adjustment must be reported because mixing importance with influence changes the interpretation of the resulting weights.

VIKOR ranks alternatives by balancing aggregate group utility and the largest criterion-specific regret. This compromise logic is appropriate when no project dominates under all criteria and a committee requires an intelligible prioritization of competing undertakings. In the proposed procedure, VIKOR is applied once, before the first decision stage, using the initial project evaluations and the fixed criterion weights. The resulting hierarchy provides a stable priority structure for the entire planning horizon. VIKOR remains a ranking method: it does not determine employee allocations or guarantee terminal feasibility. The fixed hierarchy is therefore combined with resource, activity, competency, and terminal constraints when the feasibility of the given baseline plan is verified and when its unimplemented part is subsequently revised.

2.5 Positioning of the proposed approach

The proposed approach separates four analytical roles. First, the WINGS-inspired DEMATEL procedure represents intrinsic importance and direct and indirect influences among criterion groups and individual criteria. Second, DANP transforms this influence structure into one global vector of criterion weights. Third, VIKOR uses the fixed weights and the initial project evaluations to establish one hierarchy of projects before the first decision stage. Fourth, the planning procedure uses this fixed hierarchy together with resource, activity, competency, and terminal constraints to verify and, when necessary, revise the unimplemented part of a given feasible allocation plan.

The baseline plan is provided before the first decision stage and constitutes an input to the revision procedure. After the allocation planned for a given period has been implemented, the actual portfolio state and current resource availability are observed. The feasibility of the unimplemented part of the most recently accepted plan is then verified. If this continuation remains feasible and is accepted by the decision maker, it is retained. Otherwise, the remaining allocation plan is revised. The criterion weights, VIKOR indices, and project hierarchy are not recalculated. This separation distinguishes one-time preference modelling and project prioritization from periodic state observation and resource-feasible plan revision.

3 The analyzed case

A case study of a high-tech enterprise was conducted. The analysis revealed not only a dynamic environment in which decisions regarding project management must be made more than once a month, but also a complex structure of criteria used to evaluate projects.

The dynamics of a company stem not only from the need to timely complete subsequent stages of ongoing projects, but also from the need to respond to events related to completed projects. Sometimes, the products delivered by these projects require urgent adaptation to changing requirements or environmental conditions. This situation requires maintaining a certain buffer of available resources to adequately respond to such events.

On the other hand, the complex structure of dependent factors, called criteria, necessitates the use of multi-criteria approaches. Decision-making takes into account four groups of factors: strategic, financial, operational, and uncertainty or risk. This first group, related to the company's strategy, will be called SMC (Strategic & Market Criteria). The next group of factors, related to financial aspects, will be FEC (Financial & Efficiency Criteria). The third group, related to operational factors, will be ORC (Operational & Resource Constraints or Criteria). Finally, the last group, taking into account uncertainty or risks in operations, will be called RUC (Risk & Uncertainty Criteria).

The first step is to determine the importance of individual aspects in the company's operations. Is adherence to the company's strategy the most important, or is risk mitigation the most important? This assessment may change over time, but for this study, a fixed structure was initially established. Furthermore, certain relationships exist between these aspects. It was determined that strategy influences the remaining aspects, namely finance, operations, and the level of risk acceptance. No other relationships were identified. The strength of these influences was determined on a scale of 0 to 4 (where 0 indicates no influence, 1 indicates a low influence, 2 indicates a medium influence, 3 indicates a high influence, and 4 indicates an extreme influence of one aspect on another). The importance (strength) of individual aspects was assessed on a similar scale (the value of 0 was omitted here, because if any aspect received such a rating, it would indicate insignificance and should be removed from further consideration). The adopted structure of relationships, along with the ratings (in parentheses), is presented in Table 1.

Strategic aspects were rated as exceptionally strong (score 4). Financial and operational aspects were rated as very strong (score 3), while risk-related aspects were rated as weak (score 1). In terms of impact, SMC rated its impact on FEC as medium (score 2), on ORC as extreme (score 4), and on RUC as low (score 1).

For these aspects, criteria were defined for project evaluation. They are presented in the Table 2.

Table 1. Intrinsic strengths and directed relations among criterion groups.

Influencing group (strength)	Criterion group (intrinsic strength)	Influenced group (strength)
–	SMC (4)	FEC (2), ORC (4), RUC (1)
SMC (2)	FEC (3)	–
SMC (4)	ORC (3)	–
SMC (1)	RUC (1)	–

Table 2. Fixed evaluation structure.

Group	Code	Criterion
SMC	SMC_SA	Strategic Alignment Index
	SMC_IP	Innovation Potential and Competitive Advantage
	SMC_TMS	Time-to-Market Sensitivity
	SMC_TA	Technological Alignment
FEC	FEC_NPV	Dynamic Return on Investment
	FEC_AC	Abandonment or Suspension Cost
ORC	ORC_RBF	Resource Bottleneck Factor
	ORC_SCS	Supply-Chain Stability and Component Availability
RUC	RUC_ORE	Operational Risk Exposure
	RUC_RV	Requirement Volatility
	RUC_ROV	Real Options Value

4 Methods

4.1 Research framework

The procedure consists of the following steps: (1) define the portfolio, employees, planning stages, state variables, initial conditions, terminal requirements, and the given baseline plan; (2) establish the fixed structure of evaluation criteria; (3) before stage $h = 0$, elicit the intrinsic importance and direct influences among criterion groups and individual criteria; (4) calculate the total-influence matrices and derive one global criterion-weight vector using DANP; (5) use the initial project evaluations and the fixed weight vector to establish one project hierarchy using VIKOR; (6) verify that the given baseline plan satisfies the resource, activity, competency, and terminal constraints; and (7) after each implemented allocation decision, observe the actual portfolio state, verify the feasibility of the unimplemented part of the most recently accepted plan, and revise it when necessary. Every proposed continuation is accompanied by its resource-buffer vector and project target-attainment times. The criterion weights, VIKOR indices, and project hierarchy remain unchanged throughout the planning horizon.

4.2 Sets, indices, and case assumptions

The portfolio consists of N projects P_i , indexed by $i = 1, \dots, N$. Let $\Pi = \{P_i : i = 1, \dots, N\} = \{P_1, \dots, P_N\}$ denote the project portfolio. We have also

Table 3. Core notation.

Symbol	Meaning
s_h	portfolio state at the beginning of decision stage h , before action a_h is selected.
a_h	employee-to-project allocation selected at stage h
y_{ijh}	1 if employee j is assigned to project i at stage h
x_{ih}	number of employees assigned to project i at stage h
p_{ih}	progress or achieved work state of project i
ω_k	fixed weight of criterion k , calculated once before stage 0
$\mathcal{A}_h^F(s_h)$	set of feasible actions to terminal set
$\mathcal{F}_h(\tilde{s}_h)$	the set of feasible continuations starting from $\tilde{s}_h$.

J_h employees. Generally number of employees may vary in time, but in this paper we considet constant number of employee, $j = 1, \dots, J$. Let H denote the number of planning periods. The set of decision stages is $\mathcal{H} = \{0, \dots, H-1\}$ whereas portfolio states are indexed by $\mathcal{H}^S = \{0, \dots, H\}$. The criterion set is $\mathcal{C} = \{C_1, \dots, C_K\}$. The planning horizon contains H months. In each month h , a decision is made concerning the allocation of employees to the projects. Core notation is preseted in Table 3.

4.3 State representation and decisions

The state must contain all information required to determine feasible future decisions and terminal attainability. In month h , the allocation decision is $x_h = (x_{1h}, \dots, x_{Nh})$, where x_{ih} denotes the number of employees assigned to project P_i . A general state representation is

$$s_h = (p_{1h}, \dots, p_{Nh}, \rho_h), \quad h = 0 \dots, H. \quad (1)$$

where p_{ih} is project progress, and ρ_h describes available personnel and relevant competencies. If employees are treated as heterogeneous, the decision variable is

$$y_{ijh} = \begin{cases} 1, & \text{if employee } j \text{ is assigned to } P_i, \\ 0, & \text{otherwise,} \end{cases} \quad x_{ih} = \sum_{j=1}^J y_{ijh}. \quad (2)$$

Thus x_h is the monthly decision concerning the intensity of all N projects. Using only x_{ih} is justified when employees are interchangeable with respect to all projects. If competencies differ, $y_h = [y_{ijh}]$ identifies individual assignments and determines x_h through Eq. (2).

The principal feasibility constraints are

$$\sum_{i=1}^N \mathbf{1}(x_{ih} > 0) \leq P_{max} \quad h \in \mathcal{H}, \quad (3)$$

$$\sum_{i=1}^N x_{ih} \leq J \quad h \in \mathcal{H}, \quad (4)$$

$$\sum_{i=1}^N y_{ijh} \leq 1 \quad j = 1, \dots, J, \quad h \in \mathcal{H}, \quad (5)$$

$$y_{ijh} \leq q_{ij} \quad i = 1, \dots, N, \quad j = 1, \dots, J, \quad h \in \mathcal{H}. \quad (6)$$

where $q_{ij} = 1$ indicates that employee j is eligible for project i , and P_{max} is the maximum number of projects implemented simultaneously. Additional constraints can represent minimum project staffing, mandatory continuation, precedence, funding obligations, or activation and suspension rules.

At stage h , the procedure considers a continuation of the plan:

$$\chi_h = (\tilde{s}_h, a_h, s_{h+1}, a_{h+1}, \dots, a_{H-1}, s_H), \quad (7)$$

where $\tilde{s}_h$ is the currently observed portfolio state.

Let $\mathcal{F}_h(\tilde{s}_h)$ denote the set of feasible continuations starting from $\tilde{s}_h$. Every element of this set must satisfy the resource, activity, competency, continuity, precedence, and funding constraints, as well as the terminal requirement

$$s_H \in S^H. \quad (8)$$

4.4 State transitions and uncertainty

The selected action and information observed during the stage determine the next state:

$$s_{h+1} = g_h(s_h, a_h, \xi_h) \quad h = 0, \dots, H-1. \quad (9)$$

where ξ_h can include realized progress, employee availability, requirement changes, component end-of-life announcements, regulatory events, or risk occurrences. Project progress can be represented by

$$p_{i,h+1} = p_{ih} + \Delta p_{ih}(s_h(i), a_h(i), \xi_h(i)) \quad h = 0, \dots, H-1. \quad (10)$$

The computational example uses a deterministic transition function to generate the expected successor states. Uncertainty is represented through differences between an expected state and the state actually observed after an allocation decision has been implemented. When such a difference occurs, the observed state replaces the expected state as the initial condition for the remaining planning horizon, and the feasibility of the unimplemented part of the plan is verified again. The example does not assign probability distributions to future states and does not determine a state-contingent policy.

4.5 Terminal requirements and viability

Let S^H denote the admissible terminal-state set. If project required to reach a milestone satisfies

$$p_{i,H} \geq \bar{p}_i, \quad (11)$$

where $\bar{p}_i$ is the expected progress of the project and at the end of the planning period, then S^H is defined as:

$$S^H = \{s_H : p_{i,H} \geq \bar{p}_i, i = 1, \dots, N\}. \quad (12)$$

The action set considered during baseline planning and subsequent plan revisions is restricted to decisions that preserve at least one feasible continuation to the terminal set:

$$\mathcal{A}_h^F(s_h) = \{a_h \in \mathcal{A}_h(s_h) : \exists a_{h+1}, \dots, a_{H-1} \text{ such that } s_H \in S^H\}. \quad (13)$$

This viability condition prevents a currently attractive allocation from making the terminal requirements unattainable. It applies both to the initial plan and to every revision of its unimplemented part.

4.6 Evaluation criteria

Given the initial state s_0 , the terminal requirements represented by the admissible terminal set S^H , and the planning horizon H , we can achieve feasible portfolio trajectories as long as the end requirements can be achieved. A feasible trajectory has the form

$$\chi = (s_0, a_0, s_1, a_1, \dots, a_{H-1}, s_H), \quad (14)$$

where

$$s_{h+1} = g_h(s_h, a_h), \quad h = 0, \dots, H-1, \quad (15)$$

and

$$s_H \in S^H. \quad (16)$$

Each action

$$a_h = x_h = (x_{1h}, \dots, x_{Nh}) \quad (17)$$

specifies the number of employees assigned to the individual projects during period h . The trajectory must satisfy the resource, activity, competency, and terminal-feasibility constraints defined in Sections 4.3–4.5.

For every period, the number of employees not assigned to portfolio projects is represented by the resource buffer

$$b_h = J - \sum_{i=1}^N x_{ih}, \quad h = 0, \dots, H-1. \quad (18)$$

Consequently, the workforce balance is

$$\sum_{i=1}^N x_{ih} + b_h = J, \quad b_h \geq 0. \quad (19)$$

The vector

$$b(\chi) = (b_0, \dots, b_{H-1}) \quad (20)$$

describes the availability of uncommitted employees along trajectory χ . These employees may be used for urgent interventions, unexpected modifications to completed products, employee absence, or other events not represented in the planned project allocations. The buffer therefore provides an operational measure of portfolio flexibility. A larger buffer generally indicates a greater capacity to respond to unforeseen events, although it may also imply a slower realization of planned project objectives. The buffer should consequently be interpreted jointly with the progress and timing characteristics of the trajectory.

For every project P_i , the model also determines the first period in which the required project-specific target is attained. Let $\bar{p}_i$ denote the required progress level of project P_i . The target-attainment time is defined as

$$\tau_i(\chi) = \min \{h \in \{0, \dots, H\} : p_{ih} \geq \bar{p}_i\}. \quad (21)$$

For a feasible trajectory, $\tau_i(\chi)$ exists for every project subject to a terminal requirement. If a project has already attained its target in the initial state, then $\tau_i = 0$. The vector

$$\tau(\chi) = (\tau_1, \dots, \tau_N) \quad (22)$$

describes the temporal distribution of target attainment across the portfolio. A project for which $\tau_i = H$ reaches its target only at the end of the planning horizon and therefore has no temporal slack. Earlier attainment creates a time reserve equal to

$$\sigma_i(\chi) = H - \tau_i(\chi). \quad (23)$$

The vectors $b(\chi)$ and $\tau(\chi)$ are objective, trajectory-specific characteristics of a proposed allocation plan. They are presented to the decision maker together with the project allocations and portfolio states. The resource-buffer vector indicates the ability of the portfolio to absorb unexpected resource requirements, whereas the target-attainment vector indicates the timing of project obligations and their concentration near the end of the planning horizon.

These trajectory-specific characteristics are not inputs to the DANP–VIKOR project-prioritization procedure. DANP and VIKOR are applied before stage $h = 0$ to establish the fixed project hierarchy. During subsequent plan revisions, $b(\chi)$ and $\tau(\chi)$ support the evaluation of alternative feasible continuations but do not change the project evaluations, VIKOR indices, or project hierarchy.

4.7 Project prioritization

To determine the importance of projects, a project prioritization procedure is implemented by establishing criteria weights and evaluating the projects using these criteria. The criteria weighting procedure is performed once at the beginning. The assessment of the criteria structure may change at any stage, which may result in changes to their weights. However, in this study, we assume that this assessment will remain unchanged and as originally determined. Experts

first assess the intrinsic importance of each group and criterion on a four-point scale: 1 (low), 2 (medium), 3 (high), and 4 (extreme). They then identify direct influence relationships and rate their strength on a scale of 0 – 4, where 0 indicates no influence. Individual matrices are aggregated using the experts' pre-declared weights.

Two relation matrices are constructed: A for the four groups and B for the eleven criteria. In the hybrid input convention used here, diagonal entries record intrinsic group strength, whereas off-diagonal entries record directed influence from the row group to the column group. DEMATEL method (presented in Appendix A1) transforms the relation information into total-influence matrices T_D and T_C . The importance assessments are retained through a WINGS-inspired adjustment before or during matrix normalization.

DANP normalizes the blocks of T_C , forms the unweighted supermatrix, weights its blocks using normalized group influences from T_D , and obtains the limit supermatrix. The resulting criterion vector is

$$\omega = (\omega_1, \dots, \omega_K)^T, \quad \omega_k \geq 0, \quad \sum_{k=1}^K \omega_k = 1. \quad (24)$$

The criterion-weight vector is fixed for the entire planning horizon: $\omega_h \equiv \omega$ for $h = 0, \dots, H - 1$. The initial project evaluations are used together with this vector to calculate the VIKOR indices before stage $h = 0$. Neither the criterion weights nor the project evaluations used for prioritization are updated during the planning horizon. Consequently, the VIKOR indices and the resulting hierarchy also remain unchanged. Subsequent differences between portfolio plans result exclusively from changes in the observed portfolio state, resource availability, feasibility conditions, or requirements formulated by the decision maker. DANP algorithm is provided in Appendices A2.

Using the VIKOR method and the obtained ω weights, a ranking of projects is established. For each project i , its subjective assessment in criterion k is determined, marked as $d_{ik} \in [0, 10]$. After accounting for benefit and cost directions, let f_k^* and f_k^- denote the best and worst attainable values. The normalized loss $\bar{d}_{ik}$ yields group loss, maximum regret, and the compromise index using the same fixed ω :

$$S_i = \sum_{k=1}^K \omega_k \bar{d}_{ik}, \quad (25)$$

$$R_i = \max_k \{\omega_k \bar{d}_{ik}\}, \quad (26)$$

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1 - v) \frac{R_i - R^*}{R^- - R^*}. \quad (27)$$

with S (group utility loss), R (maximum regret), and Q (compromise index), as described VIKOR method in Appendixes A3. Lower values are preferred. The baseline uses $v = 0.5$.

Before stage $h = 0$, the VIKOR method is applied once to the initial project evaluations and the fixed criterion-weight vector ω . It produces the project indices

$$Q_i, \quad i = 1, \dots, N. \quad (28)$$

Their increasing order determines the project hierarchy

$$\pi = (\pi(1), \dots, \pi(N)), \quad (29)$$

such that

$$Q_{\pi(1)} \leq Q_{\pi(2)} \leq \dots \leq Q_{\pi(N)}. \quad (30)$$

Project $P_{\pi(1)}$ has the highest priority. If two projects have identical Q values, the project with the lower S value is ranked first. If both Q and S are identical, the lower R value is used. If Q , S , and R are all identical, the projects are ordered by their indices. The resulting deterministic order is fixed for the entire planning horizon and is not recalculated during plan revisions:

$$\pi_h \equiv \pi, \quad h = 0, \dots, H - 1. \quad (31)$$

4.8 Interactive plan-revision procedure

The initial proposal The initial proposal at stage h is selected from $\mathcal{F}_h(\tilde{s}_h)$. If

$$\mathcal{F}_h(\tilde{s}_h) = \emptyset, \quad (32)$$

the decision maker is informed that no feasible continuation exists for the current state, available resources, and terminal requirements. The resource limits, planning horizon, operational constraints, or terminal requirements must then be reconsidered. The decision maker is asked to relax the goals in the projects.

Presentation of a proposal In dialogue iteration r , the decision maker is presented with proposal $\chi_h^{(r)}$. The information includes the allocation matrix

$$X(\chi_h^{(r)}) = \left[a_t(\chi_h^{(r)}) \right]_{t=h, \dots, H-1}, \quad (33)$$

the target-attainment vector

$$\tau(\chi_h^{(r)}) = \left(\tau_1(\chi_h^{(r)}), \dots, \tau_N(\chi_h^{(r)}) \right), \quad (34)$$

and the resource-buffer vector

$$b(\chi_h^{(r)}) = \left(b_h(\chi_h^{(r)}), \dots, b_{H-1}(\chi_h^{(r)}) \right). \quad (35)$$

The fixed project hierarchy π is also presented, allowing the decision maker to assess whether the proposed resource allocation is consistent with the portfolio priorities determined at the beginning of the planning horizon.

Evaluation by the decision maker After examining proposal $\chi_h^{(r)}$, the decision maker may:

1. accept the proposal and terminate the dialogue at stage h ;
2. reject the proposal and specify the required modifications.

The decision maker may formulate the following requests.

A. Increasing the buffer at the cost of delaying a project The decision maker may require the resource buffer in stage t to reach at least $\hat{b}_t$:

$$b_t(\chi_h) \geq \hat{b}_t > b_t(\chi_h^{(r)}), \quad (36)$$

while allowing for a delay in achieving the project P_i goal if necessary. If only the direction of change is specified, the smallest meaningful change is assumed:

$$\hat{b}_t = b_t(\chi_h^{(r)}) + 1. \quad (37)$$

B. Accelerating one project at the cost of delaying another The decision maker may require project P_i to attain its target no later than stage $\hat{\tau}_i$:

$$\tau_i(\chi_h) \leq \hat{\tau}_i < \tau_i(\chi_h^{(r)}), \quad (38)$$

while permitting a delay in project P_j . If only the direction of change is specified, then

$$\hat{\tau}_i = \tau_i(\chi_h^{(r)}) - 1. \quad (39)$$

C. Accelerating a project at the cost of reducing the buffer The decision maker may require

$$\tau_i(\chi_h) \leq \hat{\tau}_i < \tau_i(\chi_h^{(r)}), \quad (40)$$

while allowing the buffer in stage t to decrease:

$$b_t(\chi_h) \leq \hat{b}_t < b_t(\chi_h^{(r)}). \quad (41)$$

If only the directions of the changes are specified, then

$$\hat{\tau}_i = \tau_i(\chi_h^{(r)}) - 1, \quad \hat{b}_t = b_t(\chi_h^{(r)}) - 1. \quad (42)$$

Several requests may be combined. In this case, all requirements are treated jointly.

Generation of a modified proposal Let the set of feasible continuations satisfying requirements is

$$\mathcal{F}_h^{(r+1)} = \{\chi_h \in \mathcal{F}_h(\tilde{s}_h) : \chi_h \text{ satisfies requirements}\}. \quad (43)$$

If $\mathcal{F}_h^{(r+1)} = \emptyset$, the decision maker is informed that no feasible continuation satisfies all stated requirements. The requirements are not relaxed automatically. The decision maker may withdraw a requirement, reduce the requested improvement, or permit the deterioration of an additional characteristic.

If $\mathcal{F}_h^{(r+1)} \neq \emptyset$, a new proposal is selected. To limit unnecessary changes to the current plan, the distance between two continuations is defined as

$$D(\chi_h, \chi_h^{(r)}) = \sum_{t=h}^{H-1} \sum_{i=1}^N |x_{it}(\chi_h) - x_{it}(\chi_h^{(r)})|. \quad (44)$$

The modified proposal is obtained from

$$\chi_h^{(r+1)} \in \arg \min_{\chi_h \in \mathcal{F}_h^{(r+1)}} D(\chi_h, \chi_h^{(r)}). \quad (45)$$

If several continuations attain the same minimum distance, the lexicographic rule used to generate the initial proposal is applied as a secondary selection criterion. The modified proposal, together with its allocation matrix, target-attainment vector, and resource-buffer vector, is then presented to the decision maker. The procedure returns to the proposal-evaluation step.

Acceptance and implementation The dialogue terminates when the decision maker accepts a proposal:

$$\hat{\chi}_h = \chi_h^{(r*)}. \quad (46)$$

Only the first allocation decision of the accepted continuation, $\hat{a}_h$, is implemented. After its implementation, the actual successor state $\tilde{s}_{h+1}$ is observed.

If $h+1 < H$, the unimplemented part of the accepted plan becomes the reference proposal for the next stage. Its feasibility is checked against the observed state $\tilde{s}_{h+1}$. If it remains feasible and is accepted by the decision maker, it may be continued without modification. Otherwise, the interactive procedure is repeated for the remaining planning horizon. Every revised proposal is generated using the same criterion-weight vector ω and the same project hierarchy π determined before stage $h=0$; neither VIKOR indices nor the hierarchy are recalculated.

The procedure continues until the end of stage $H-1$. It does not determine an optimal state-contingent policy and does not employ dynamic programming. Its result is a sequence of accepted and feasible revisions of the portfolio plan, adjusted to the observed portfolio states and the decision maker's preferences.

5 Computational example

The example illustrates three distinct operations: the one-time determination of the project hierarchy, the verification and interactive modification of a given feasible baseline plan, and the revision of the unimplemented part of the most recently accepted plan after a difference between the expected and observed portfolio states has been detected. The project hierarchy is not recalculated during the example.

The computational example concerns a modern-technology enterprise. The portfolio is $\Pi = \{P_1, P_2, P_3, P_4\}$, so $N = 4$. The organization has $J = 5$ employees, and the planning horizon is one quarter comprising $H = 3$ monthly stages. In each month $h \in \{0, 1, 2\}$, the decision vector $\mathbf{x}_h = (x_{1h}, \dots, x_{4h})$ specifies the allocation of the five employees up to four projects. No more than three projects may be active in a month, and $x_{ih} \in \{0, 1, \dots, 5\}$.

First, a panel of experts assesses the weighting of aspects, followed by the importance of individual criteria and their interdependencies. The resulting weighting vector is used to rank projects using the VIKOR method.

The structure of the aspects taken into account in project evaluation was discussed in Section 3. Matrix A is the input influence-intensity matrix used in the WINGS-inspired DEMATEL calculation. Its diagonal elements represent the intrinsic importance of the criterion groups, whereas its off-diagonal elements represent the assessed direct influences between the groups. Normalization and the subsequent DEMATEL calculations transform A into the direct-influence matrix and the total-influence matrix T_D . The resulting matrix A is as follows:

$$A = \begin{bmatrix} 4 & 2 & 4 & 1 \\ 0 & 3 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (47)$$

with row/column order SMC, FEC, ORC, RUC.

Using the same method, the structure of relationships between the criteria presented in Table 2 was determined. The results of the analysis are presented in Table 4.

After applying the DANP method (intermediate results, namely the matrices B , T_D , T_C , subsequent forms of the supermatrix, are not include here due to their size), we obtain criterion weights that take into account not only the strength of individual criteria but also the structure of the relationships between them. In the case analyzed, the links between the criteria are sparse, which means that the resulting supermatrix is not a primitive matrix. This is a necessary condition for the exponentiation process to converge to the limit matrix. However, the method of fictitious alternatives [12] was used here, which allowed us to obtain a limit matrix with a tolerance of 0.001 after $z = 32$ iterations. Following this procedure, a single fictitious alternative was added to all blocks of supermatrix. To avoid changing the relationship between the actual criteria, identical values were entered for all elements, satisfying the condition of matrix stochasticity.

Table 4. Intrinsic strengths and directed relations among criteria.

Influencing (strength)	criteria	Criteria (intrinsic strength)	Influenced (strength)	criteria
ORC_SCS(3)		SMC_SA(4)		
		SMC_IP(3)		
		SMC_TMS(3)		
		SMC_TA(4)		
		FEC_NPV(3)		
		FEC_AC(3)		
		ORC_RBF(3)		
		ORC_SCS(2)	SMC_TA(3)	
		RUC_ORE(2)		
		RUC_RV(1)		
		RUC_ROV(1)		

Once the limit supermatrix was obtained, the weight of the alternative was removed, and the weights of the remaining actual criteria were normalized. The resulting criterion weights are presented in the Table 5.

Table 5. Obtained weights ω_k .

Criterion	ω_k
SMC_SA	0.104
SMC_IP	0.092
SMC_TMS	0.092
SMC_TA	0.141
FEC_NPV	0.087
FEC_AC	0.087
ORC_RBF	0.087
ORC_SCS	0.080
RUC_ORE	0.078
RUC_RV	0.076
RUC_ROV	0.076

Let $Z = [z_{ik}]$ denote the matrix of initial evaluations of project P_i with respect to criterion C_k . For illustrative purposes, it was assumed that the first project received a maximum score of 10 across all criteria. The second project received a score of 6 across all criteria. The third project received a score of 3, and the fourth project received a minimal score of 0 across all categories. After considering the criterion weights presented in Table 5, the following index values were obtained, presented in Table 6.

The VIKOR calculations, produce the fixed project hierarchy

$$\pi = (P_1, P_2, P_3, P_4), \quad (48)$$

Table 6. Project prioritization by VIKOR

Project	S_i	R_i	Q_i	Position
P_1	0.000	0.000	0.000	1
P_2	0.400	0.056	0.400	2
P_3	0.700	0.099	0.700	3
P_4	1.000	0.141	1.000	4

The obtained index values meet the acceptance conditions. This hierarchy is established before stage $h = 0$ and remains unchanged during all subsequent revisions of the portfolio plan.

5.1 Input data specification

Progress will be measured as the actual percentage of project completion. It is typically expressed as a percentage, but in this paper it will be expressed as an absolute number.

For the project portfolio Π under consideration, the initial state will be denoted as:

$$s_0 = (0.8, 0.3, 0.1, 0). \quad (49)$$

The above notation means that project P_1 is 80% completed, project P_2 is 30% completed, and project P_3 is 10%. The portfolio also includes projects that have not been started (P_4).

In a real project, well-defined milestones allow us to determine the progress increment $\Delta p_{ih}(s_h(i), a_h(i), \xi_h(i))$. At a given point in the i th project schedule, which identifies the portfolio status $s_h(i)$, knowing the project work intensity resulting from the employee allocation $a_h(i)$, we can determine the expected progress increment Δp_{ih} . Of course, this is only an expected value, which can be distorted by underestimated productivity, random events, or employee unavailability. We can model these phenomena by randomly distorting the value of the expected progress increment Δp_{ih} . In this article, however, we will assume a deterministic progress value. Furthermore, for simplicity, we will assume that it is constant and depends solely on the work intensity, which is calculated based on the number of employees engaged in a given month on a given project. We will assume this increase of 10% if the planned number of employees is working on the project. Again, for simplicity, we will assume that each project is planned to have two people participating. If this number of people are assigned to the project, the actual project completion rate will increase by 10% per month. If only one person is involved, the project will increase by 5%. However, if three people are assigned, the project will increase by 15% after one month. This is, of course, a gross simplification, but it makes it easier to understand the other key elements of the proposed procedure. The adopted assumptions allow us to determine the following transition function for the progress of the i -th project:

$$p_{i,h+1} = \min\{1, p_{ih} + 0.05x_{ih}\} \quad h = 0, \dots, H-1, \quad (50)$$

as each employee contributes 5% to the project progress each month, and the maximum that can be achieved is 100% project completion.

By assigning employees to projects, we want to achieve the terminal requirements vector:

$$\bar{p} = (1, 0.5, 0.2, 0.1). \quad (51)$$

This means that we want to complete the first project. In the second, we want to achieve a milestone representing an actual project completion rate of 50%. In the third project, we want to complete 20%. Finally, in the fourth project, we want to achieve a milestone representing 10% project completion. It gives as terminal states set:

$$\mathcal{S}^H = \{s_3 : p_{1,3} \geq 1, p_{2,3} \geq 0.5, p_{3,3} \geq 0.2, p_{4,3} \geq 0.1\}. \quad (52)$$

In the following considerations, we will also ignore employee skills, which means that $q_{ij} = 1 \forall i, j$. This assumption will simplify further considerations. Employee allocation will be reduced to the number of employees assigned to the project, i.e., $a_h = x_h$.

5.2 Interactive evaluation of alternatives

Let's assume the following baseline path to achieve the goal is given as a reference:

$$\chi_0^{(0)} = (s_0, a_0, s_1, a_1, s_2, a_2, s_3), \quad (53)$$

Where:

$$s_0 = (0.8, 0.3, 0.1, 0) \rightarrow a_0 = (4, 1, 0, 0) \rightarrow \quad (54)$$

$$s_1 = (1, 0.35, 0.1, 0) \rightarrow a_1 = (0, 3, 2, 0) \rightarrow \quad (55)$$

$$s_2 = (1, 0.5, 0.2, 0) \rightarrow a_2 = (0, 0, 0, 2) \rightarrow \quad (56)$$

$$s_3 = (1, 0.5, 0.2, 0.1) \quad (57)$$

The following vectors will be presented to experts for evaluation:

$$\tau(\chi_0^{(0)}) = (1, 2, 2, 3) \quad (58)$$

$$b(\chi_0^{(0)}) = (0, 0, 3) \quad (59)$$

which must be assessed from the point of view of flexibility and risk.

The decision maker does not accept the initial proposal. The decision maker requires the resource buffer in stage $h = 1$ to increase from 0 to at least 2, permits the target-attainment time of project P_2 to increase from 2 to 3, and permits the resource buffer in stage $h = 2$ to decrease from 3 to 1. New proposal χ is generated (which results from solving the equation (45) for which $D = 4$):

$$s_0 = (0.8, 0.3, 0.1, 0) \rightarrow a_0 = (4, 1, 0, 0) \rightarrow \quad (60)$$

$$s_1 = (1, 0.35, 0.1, 0) \rightarrow a_1 = (0, 1, 2, 0) \rightarrow \quad (61)$$

$$s_2 = (1, 0.4, 0.2, 0) \rightarrow a_2 = (0, 2, 0, 2) \rightarrow \quad (62)$$

$$s_3 = (1, 0.5, 0.2, 0.1) \quad (63)$$

The following vectors are presented to decision maker for evaluation:

$$\tau(\chi_0^{(1)}) = (1, 3, 2, 3) \quad (64)$$

$$b(\chi_0^{(1)}) = (0, 2, 1) \quad (65)$$

This plan was accepted by the decision-maker. After implementing $a_0 = (4, 1, 0, 0)$, the expected successor state is $s_1 = (1, 0.35, 0.1, 0)$. The observed state is instead

$$\tilde{s}_1 = (1, 0.3, 0.1, 0). \quad (66)$$

The difference results from the fact that the employee assigned to project P_2 did not produce the expected progress during stage $h = 0$. This observed deviation does not change the criterion weights, VIKOR indices, or project hierarchy. It only changes the initial state from which the feasibility of the remaining plan is evaluated.

New allocation of resources is proposed:

$$\tilde{s}_1 = (1, 0.3, 0.1, 0) \rightarrow a_1 = (0, 2, 2, 0) \rightarrow \quad (67)$$

$$s_2 = (1, 0.4, 0.2, 0) \rightarrow a_2 = (0, 2, 0, 2) \rightarrow \quad (68)$$

$$s_3 = (1, 0.5, 0.2, 0.1) \quad (69)$$

This is a solution that results in minimal change in the allocation of workers in terms of distance D ($D = 1$). This approach preserves the decision maker's previously defined preferences. The following vectors are presented to decision maker for evaluation:

$$\tau(\chi_1^{(0)}) = (1, 3, 2, 3) \quad (70)$$

$$b(\chi_1^{(0)}) = (1, 1) \quad (71)$$

This plan was accepted by the decision-maker. After the next period, the following project implementation status was achieved:

$$\tilde{s}_2 = (1, 0.4, 0.2, 0). \quad (72)$$

The observed state is consistent with the expected state at this decision stage. The unimplemented part of the accepted plan remains feasible, and project activities are therefore continued according to the current reference continuation.

$$\tilde{s}_2 = (1, 0.4, 0.2, 0) \rightarrow a_2 = (0, 2, 0, 2) \rightarrow \quad (73)$$

$$s_3 = (1, 0.5, 0.2, 0.1) \quad (74)$$

The following vectors are presented to decision maker for evaluation:

$$\tau(\chi_2^{(0)}) = (1, 3, 2, 3) \quad (75)$$

$$b(\chi_2^{(0)}) = (1) \quad (76)$$

This plan was accepted by the decision-maker, which allowed the final state to be achieved:

$$\tilde{s}_3 = (1, 0.5, 0.2, 0.1). \quad (77)$$

6 Discussion

6.1 From project ranking to periodic portfolio-plan revision

The central methodological distinction is between establishing project priorities once and revising resource allocations repeatedly. The procedure does not generate the baseline plan and does not recalculate project priorities after each observation. It accepts a given feasible plan as its initial reference, verifies the feasibility of the remaining continuation after every state update, and produces a minimum-distance revision only when the current continuation cannot or should not be retained.

The proposed approach is dynamic in the sense of repeated state observation, feasibility verification, and plan revision, not in the sense of changing project priorities or applying dynamic programming. It does not derive an optimal policy for every possible state. Instead, it maintains a feasible plan for the remaining horizon and allows that plan to be revised when observed project progress or resource availability differs from the assumptions underlying its previous version.

6.2 Interpretation of dependent weights

The weighting architecture recognizes that criterion relevance can arise from a network of effects. A resource bottleneck can affect time to market, financial return, operational exposure, and flexibility. DANP transfers these dependencies into the limiting weights. Nevertheless, the weights remain conditional on expert selection, elicitation scales, matrix orientation, normalization, and the system boundary. They must not be presented as objective measurements.

6.3 Interactive decision support

Expert intervention is compatible with periodic portfolio revision only when its role is transparent. Experts receive the fixed project ranking, the proposed continuation of the allocation plan, the resulting resource-buffer vector, and the expected project target-attainment times. They may retain the existing continuation or request a modification in response to information that is not fully represented by the formal criteria or constraints.

An expert modification does not automatically constitute a feasible plan. The revised allocations must again satisfy the resource, activity, competency, and terminal requirements. The reason for the modification, the resulting changes in resource allocations, and their consequences for the resource buffer and target-attainment times should be recorded. This creates an auditable distinction between the analytical recommendation and the final managerial decision.

6.4 Managerial implications

The model separates project attractiveness from implementability, identifies future resource bottlenecks, protects contractual or milestone obligations, and

exposes the opportunity cost of reallocating scarce employees. It can support monthly or quarterly portfolio reviews while retaining a longer planning horizon.

6.5 Limitations

The model depends on subjective judgments and is sensitive to panel composition, expert weights, scale interpretation, normalization, criterion direction, and the VIKOR parameter (v). The fixed criterion structure improves case fidelity but limits transferability. Four projects, five employees, and three stages provide an illustrative rather than general validation. Larger portfolios increase the number of feasible allocations and candidate plan revisions, which may require heuristic plan-generation and screening procedures.

Further limitations concern the representation of plan revisions. The procedure does not guarantee a globally optimal allocation plan and does not evaluate a policy for every possible future state. It reacts to information after that information has been observed. Configuration-level assessments may also be nonlinear in project intensity and project interactions. The fixed global weight vector improves comparability between review stages, but it cannot represent a genuine change in organizational preferences during the planning horizon. The deterministic example addresses uncertainty through state observation and subsequent plan revision rather than through probability distributions or stochastic transitions.

7 Conclusions

RQ1 asks how a fixed project hierarchy derived from interdependent evaluation criteria can be incorporated into periodic revisions of the unimplemented part of a resource-feasible project portfolio plan. The proposed procedure addresses this question through four connected components. The WINGS-inspired DEMATEL procedure represents the intrinsic importance of criteria and their direct and indirect relations. DANP transforms this structure into a global criterion-weight vector. VIKOR uses this fixed vector and the initial project evaluations to determine one project hierarchy before the first decision stage. The planning component treats a given feasible baseline plan as its input and uses the fixed hierarchy together with resource, activity, competency, and terminal constraints to verify and, when necessary, revise the plan's unimplemented part after an observed state update.

The key contribution of the proposed method is an interactive plan-revision procedure. Each continuation is described by two operational characteristics: the project target-attainment-time vector and the resource-buffer vector. Target-attainment times show the timing consequences of the proposed allocation, whereas resource buffers indicate the capacity retained for unplanned work and therefore represent operational flexibility. The buffer may also support an interpretation of exposure to operational disruption, but risk is not introduced as a separate optimization criterion in the formal model.

The approach is dynamic because the portfolio state, feasibility conditions, and remaining resource allocations may change between review stages. The criterion weights, project evaluations used for prioritization, VIKOR indices, and project hierarchy remain unchanged. The procedure does not employ dynamic programming and does not generate a state-contingent optimal policy. Its purpose is to maintain a feasible and managerially interpretable plan while allowing controlled revisions in response to observed deviations from the previous plan.

The resource-buffer vector and project target-attainment times complement the project ranking by showing the operational consequences of a planned trajectory. They allow experts to identify periods with limited resource flexibility and projects whose targets are concentrated near the end of the planning horizon. Expert judgment remains part of the final decision, but every modification must be checked for resource feasibility and continued attainability of the terminal requirements.

The proposed procedure offers opportunities for further development. Employee competencies can be incorporated into subsequent versions of the procedure. Project rankings can also be changed. Finally, further work is required to more realistically reflect projects progress.

The principal contribution is therefore the separation and integration of four functions: preference modelling, fixed project prioritization, feasible portfolio planning, and interactive revision of the remaining plan. Further research should examine larger portfolios, alternative rules for translating project rankings into resource allocations, costs of changing an existing plan, and the performance of the revision procedure under different patterns of observed disruption.

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Appendix A1. DEMATEL

Let M experts, with individual validity marked with the λ_m , assess the direct influence of element i on element j . In conventional DEMATEL, the aggregated direct-relation matrix is

$$A = [a_{ij}]_{n \times n} = \sum_{m=1}^M \lambda_m A^{(m)}, \quad \lambda_m \geq 0, \quad \sum_m \lambda_m = 1, \quad (78)$$

where $a_{ii} = 0$ and the orientation $i \rightarrow j$ is used throughout. In the WINGS-inspired hybrid input used in the computational example, the supplied diagonal values encode intrinsic strengths rather than self-influences. These diagonal strengths are therefore retained as a separate importance vector. The normalized matrix is $X = sA_D$, with

$$s = \min \left\{ \frac{1}{\max_i \sum_j (a_D)_{ij}}, \frac{1}{\max_j \sum_i (a_D)_{ij}} \right\}. \quad (79)$$

Provided that $\lim X^g_{g \rightarrow \inf} = [0]_{n \times n}$, the total-influence matrix is

$$T = X + X^2 + \dots = X(I - X)^{-1}. \quad (80)$$

For every element,

$$r_i = \sum_j t_{ij}, \quad c_i = \sum_j t_{ji}. \quad (81)$$

The sum $r_i + c_i$ represents prominence, while $r_i - c_i$ distinguishes net influencing elements from net influenced elements. The procedure is applied at group level to obtain T_D and at criterion level to obtain T_C . Thresholds may simplify influence maps but must not remove numerical relations used by DANP unless a separate justification and sensitivity test are provided.

Appendix A2. DANP

Partition the criterion total-influence matrix according to n groups:

$$T_C = \begin{bmatrix} T_C^{11} & \dots & T_C^{1n} \\ \vdots & \ddots & \vdots \\ T_C^{n1} & \dots & T_C^{nn} \end{bmatrix}. \quad (82)$$

Each nonzero block is row-normalized. For block (i, j) ,

$$d_p^{ij} = \sum_q t_{C,pq}^{ij}, \quad T_C^{\alpha ij} = [t_{C,pq}^{ij} / d_p^{ij}]. \quad (83)$$

The unweighted supermatrix is constructed by transposing the normalized influence structure,

$$W_u = (T_C^\alpha)^T. \quad (84)$$

The group total-influence matrix is similarly normalized:

$$T_D^\alpha = \left[t_D^{ij} / \sum_j t_D^{ij} \right]. \quad (85)$$

Its entries weight the corresponding blocks of W_u to obtain a column-stochastic weighted supermatrix W_w . Because the influence matrix uses rows as sources while the ANP supermatrix uses columns as sources, the required transpose and block orientation must be verified explicitly. The limit supermatrix is

$$W^\infty = \lim_{z \rightarrow \infty} (W_w)^z. \quad (86)$$

When the matrix is irreducible and aperiodic, the columns converge to a common vector. After normalization, its entries form ω . The implementation reports stochasticity checks, tolerance, iterations, and any remedial treatment required for reducibility or periodicity.

Appendix A3. VIKOR

For feasible alternatives $i = 1, \dots, m$ and criteria $k = 1, \dots, K$, define best and worst values. For a benefit criterion,

$$f_k^* = \max_i z_{ik}, \quad f_k^- = \min_i z_{ik}, \quad (87)$$

and reverse the extrema for a cost criterion. The normalized distance from the ideal is

$$d_{ik} = \frac{f_k^* - z_{ik}}{f_k^* - f_k^-} \quad (88)$$

for benefit criteria, with the direction adjusted for cost criteria. A criterion with $f_k^* = f_k^-$ provides no discrimination and its gap is set to zero for the current choice set.

Compute

$$S_i = \sum_{k=1}^K \omega_k d_{ik}, \quad (89)$$

$$R_i = \max_k \{\omega_k d_{ik}\}, \quad (90)$$

$$Q_i = v \frac{S_i - S^*}{S^- - S^*} + (1 - v) \frac{R_i - R^*}{R^- - R^*}, \quad (91)$$

where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, and $R^- = \max_i R_i$. The parameter $v \in [0, 1]$ balances aggregate utility and maximum regret. Alternatives are ranked increasingly by Q , S and R .

Let $i^{(1)}$ and $i^{(2)}$ be the first and second alternative in the Q ranking. Acceptable advantage holds when

$$Q(i^{(2)}) - Q(i^{(1)}) \geq \frac{1}{m - 1}, \quad (92)$$

for $m > 1$. Acceptable stability holds when $i^{(1)}$ is also first by S or R . If both conditions hold, $i^{(1)}$ is the compromise solution. Otherwise, VIKOR reports a compromise set under its standard decision rules.