International Journal of Scientific Advances
ISSN: 2708-7972
Volume: 7 | Issue: 5 | Sep – Oct 2026 Available Online: www.ijscia.com
DOI: 10.51542/ijscia.v7i5.1

Business Process Improvement Portfolio Selection Under Resource Constraints: An Integrated Multi-Criteria Decision and Optimization Approach

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ABSTRACT

This study examines business process improvement portfolio selection in a resource-constrained industrial case by integrating group Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), criterion-weight sensitivity analysis, and binary mixed-integer linear programming (MILP). Five decision makers assessed ten improvement initiatives across six benefit-oriented criteria. Group AHP generated criterion weights, SAW converted initiative performance into comparable utility values, Monte Carlo simulation examined sensitivity to ±20% perturbations in criterion weights over 10,000 iterations, and MILP selected feasible initiative combinations under investment, implementation-effort, technical-capacity, and dependency constraints. Four normalized what-if resource scenarios were evaluated. The results show that the highest-valued individual initiative is not necessarily included in the best feasible portfolio under severe resource scarcity. Across the investigated scenarios, MILP portfolios produced 10.94–36.68% higher aggregate SAW utility than sequential rank-based selection. Individual rankings showed limited preference sensitivity among the leading initiatives, while portfolio composition remained unchanged when the optimization was repeated using the 10th-percentile simulated utilities. These findings are case-specific and demonstrate the practical distinction between initiative ranking and resource-constrained implementation planning rather than general validation of a new optimization method.

Keywords: business process improvement; multi-criteria decision making; portfolio optimization; preference sensitivity; resource allocation

INTRODUCTION

Organizations commonly face more business process improvement opportunities than can be implemented simultaneously. Financial limits, implementation effort, technical capacity, and prerequisite relationships force managers to choose not only which initiatives are attractive, but also which combinations can be implemented together. This distinction is especially important for small industrial contractors, where several operational and administrative improvements compete for the same scarce resources.

Multi-Criteria Decision-Making (MCDM) provides a structured way to evaluate improvement alternatives that differ across operational, technical, organizational, and risk-related dimensions [1]. Business-process prioritization studies have used structured decision methods to identify attractive processes and support automation or improvement choices [2], [3], [4]. However, a priority ranking is not equivalent to an implementation plan. A high-ranked initiative may be infeasible under current resource limits or may require enabling initiatives to be implemented first.

Project-portfolio research shows that MCDM can be combined with mathematical programming to translate preference-based values into feasible combinations under explicit resource constraints [5], [6]. At the same time, criterion weights in MCDM are judgment-based and may change when managerial preferences vary. Sensitivity analysis is therefore useful for examining whether individual priorities or selected portfolios depend strongly on a single baseline weight structure [7], [8], [9].

This study applies an integrated decision-support architecture to a small-scale contractor supporting the oil and gas industry. Group AHP is used to elicit criterion weights, SAW to estimate initiative-level utility, Monte Carlo simulation to examine sensitivity to criterion-weight perturbation, and binary MILP to identify feasible portfolios under resource and dependency constraints. The contribution is case-based: the study demonstrates how a ranking-oriented MCDM result can be used as an input to an implementation-allocation decision, while explicitly separating value, preference sensitivity, and feasibility.

The study addresses four questions: (1) which initiatives have the highest multi-criteria value; (2) how sensitive are those priorities to criterion-weight changes; (3) which initiative combinations maximize aggregate utility under progressively relaxed resource scenarios; and (4) how does optimization compare with sequential implementation based on ranking alone?

LITERATURE REVIEW

Business Process Improvement Prioritization

Process prioritization is needed when organizations face more improvement opportunities than available managerial and implementation capacity. Process-portfolio research emphasizes systematic identification of candidate processes and the need to account for interdependencies between improvement initiatives [2], [3]. Savić et al. [4] further showed that AHP can support business-process automation prioritization and that ranking stability should be examined rather than assumed.

Multi-criteria evaluation of improvement initiatives

Group AHP is appropriate when several functional perspectives must be combined into a common criterion-weight structure. Geometric aggregation of reciprocal pairwise-comparison matrices allows multiple judgments to be combined while preserving the ratio-scale logic of AHP [10], [11]. SAW can then aggregate normalized initiative performance across benefit-oriented criteria into comparable utility values. In this study, the SAW score is interpreted as an initiative-value coefficient rather than a final implementation sequence.

Preference sensitivity in multi-criteria decisions

Deterministic criterion weights can imply more precision than is warranted when weights are based on managerial judgment. Sensitivity and robustness analysis therefore examine how rankings or utility values change under alternative weight configurations [7]. Monte Carlo perturbation is useful for estimating rank frequencies, top-rank probabilities, and conservative utility estimates across repeated plausible weight vectors. The present analysis is limited to criterion-weight uncertainty; it does not model uncertainty in costs, implementation effort, dependencies, or realized benefits.

Resource-constrained portfolio selection

A high individual utility does not guarantee inclusion in the best feasible combination once resource limits and prerequisites are considered. Portfolio-selection research combines multi-criteria value assessment with explicit optimization to account for scarce resources and interdependencies [5], [6], [12], [13], [16]. This distinction is directly relevant to business process improvement because ranking identifies relative attractiveness, whereas portfolio optimization determines an implementable combination.

Research positioning

The study does not introduce a new AHP, SAW, Monte Carlo, or MILP algorithm. Its research positioning lies in the decision logic connecting four analytical layers: group preference elicitation, initiative-level utility estimation, criterion-weight sensitivity analysis, and resource-constrained portfolio selection. This architecture is evaluated in one organizational case and is therefore interpreted as an application-oriented decision-support study rather than evidence of general applicability across industrial organizations.

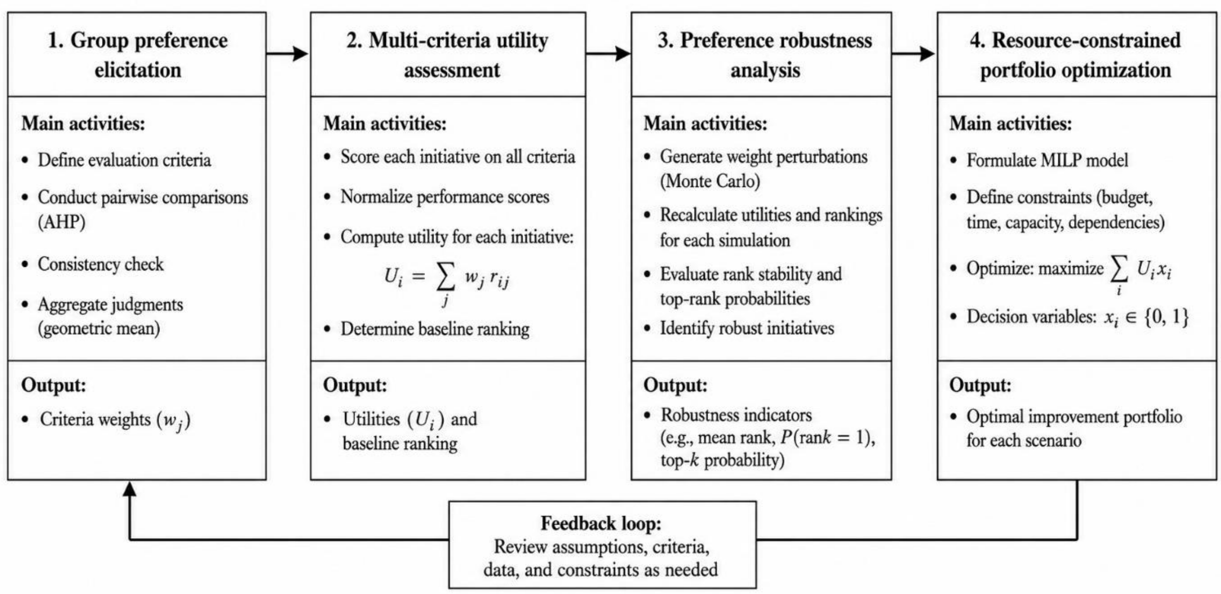

FIGURE 1: Integrated Decision-Support Architecture Used in The Case Study.

METHODS

Research design and case context

A quantitative decision-analytic case study was conducted in a small-scale contractor supporting the oil and gas industry. The organization faced multiple operational and administrative improvement needs while financial, implementation, and technical resources were constrained.

Five decision makers represented operations management, project management, warehouse/logistics, information technology, and finance/administration. Ten candidate initiatives covering warehouse, logistics, administration, and finance formed the decision set.

Candidate improvement initiatives

TABLE 1: Candidate Business Process Improvement Initiatives.

Code	Domain	Improvement initiative
I1	Warehouse	Real-Time Inventory Visibility System
I2	Warehouse	Barcode/QR-Based Material Receiving and Issuing
I3	Warehouse	Critical Spare-Part Reorder and Stock Alert System
I4	Logistics	Integrated Material Delivery Scheduling
I5	Logistics	Shipment Tracking and Vendor Expediting Dashboard
I6	Logistics	Digital Material Request and Delivery Coordination
I7	Administration	Digital Document Approval Workflow
I8	Administration	Centralized Project Document Control System
I9	Finance	Automated Invoice Verification and Three-Way Matching
I10	Finance	Project Cost Monitoring and Cash-Flow Dashboard

Criteria and expert assessment

Six benefit-oriented criteria were used to represent improvement in value. Major implementation burdens were modeled separately as constraints so that initiative attractiveness would not be conflated with resource feasibility. Initiative performance on the six criteria was assessed by the decision makers and aggregated by arithmetic means.

TABLE 2: Improvement-Value Criteria.

Code	Criterion	Operational definition
C1	Operational Performance Impact	Expected effect on efficiency, accuracy, responsiveness, or productivity
C2	Process Criticality	Importance of the affected process to operational/project continuity
C3	Risk Reduction Potential	Ability to reduce errors, delays, shortages, or disruptions
C4	Cross-Process Integration Potential	Ability to improve information or workflow integration across functions
C5	Implementation Feasibility	Technical and organizational feasibility of the proposed improvement
C6	User Acceptance Readiness	Expected employee readiness and willingness to adopt the improvement

Group AHP weighting and SAW utility

Each decision maker completed a reciprocal pairwise-comparison matrix using the 1–9 AHP judgment scale. Individual matrices were checked for consistency and aggregated using the element-wise geometric mean. The resulting group matrix produced the criterion-weight vector, with judgments accepted when the consistency ratio (CR) was below 0.10. For SAW, all six criteria were treated as benefits. Normalized performance was calculated as $r_{ij} = x_{ij} / \max_i(x_{ij})$, and baseline utility as $U_i = \Sigma_j w_j r_{ij}$. The resulting U_i values were used as coefficients in the subsequent portfolio model rather than as an automatic implementation sequence.

Criterion-weight sensitivity analysis

Sensitivity to managerial preferences was examined by independently perturbing each baseline criterion weight within ±20%, renormalizing the resulting vector, and recalculating initiative utilities over 10,000

Monte Carlo iterations. The analysis reports mean rank, probability of Rank 1, probability of remaining in the top three, and a conservative utility defined as the 10th percentile of each simulated utility distribution. The test therefore evaluates robustness only to criterion-weight uncertainty under the specified perturbation range.

Portfolio optimization and dependency constraints

For each initiative i, binary variable x_i equals 1 when the initiative is selected and 0 otherwise. The nominal MILP maximizes total portfolio utility, max $\Sigma_i U_i x_i$, subject to investment, implementation-effort, and technical-capacity ceilings. Two precedence constraints were included: $x_3 \leq x_1$ and $x_6 \leq x_1$, reflecting the requirement for reliable inventory visibility before the spare-part reorder system and digital material coordination are implemented. A second optimization used the 10th-percentile simulated utilities with the same constraints to examine whether criterion-weight sensitivity changed portfolio composition.

What-if resource scenarios and benchmark

Four normalized what-if scenarios were used to examine portfolio behavior as resource availability increased: S1 = 25%, S2 = 40%, S3 = 60%, and S4 = 80% of the aggregate requirements for implementing all ten initiatives. These scenarios are analytical planning envelopes rather than observed annual organizational budgets. The complete initiative requires IDR 895 million, 2,270 implementation hours, and 1,410 technical hours. Accordingly, the scenario ceilings shown in Table 3 were derived directly from these totals. Each MILP result was compared with a greedy benchmark that sequentially selected initiatives according to baseline SAW rank while respecting the same resource and dependency constraints.

TABLE 3: Derived Resource Ceilings for Normalized What-If Scenarios.

Scenario	Share	Investment ceiling (IDR million)	Implementation effort (h)	Technical capacity (h)
S1	25%	223.75	567.5	352.5
S2	40%	358.00	908.0	564.0
S3	60%	537.00	1,362.0	846.0
S4	80%	716.00	1,816.0	1,128.0

RESULTS

Group preference structure

The group AHP result was internally consistent (CR = 0.0152). Operational Performance Impact received the largest weight (0.2670), followed by Process Criticality (0.1974), Risk Reduction Potential (0.1755), Cross-Process Integration Potential (0.1572), Implementation Feasibility (0.1116), and User Acceptance Readiness (0.0914). The first three criteria account for approximately 64% of the total decision weight, indicating that the expert group emphasized operational contribution, continuity, and risk reduction.

TABLE 4: Group AHP Criterion Weights.

Rank	Code	Criterion	Weight
1	C1	Operational Performance Impact	0.2670
2	C2	Process Criticality	0.1974
3	C3	Risk Reduction Potential	0.1755
4	C4	Cross-Process Integration Potential	0.1572
5	C5	Implementation Feasibility	0.1116
6	C6	User Acceptance Readiness	0.0914

Initiative utility and criterion-weight sensitivity

Baseline SAW results identify I6 as the highest-valued individual initiative (0.8714), followed by I3 (0.8620) and I1 (0.8608). The difference between Rank 1 and Rank 3 is approximately 0.011, so the upper ranking should not be interpreted as strongly separated. Monte Carlo analysis shows that I6 occupies Rank 1 in 78.97% of simulations and I3 in 21.03%, while I1 remains in the top three in 99.54% of simulations. The evidence therefore suggests limited preference and sensitivity among the leading alternatives rather than complete invariance of the ranking

TABLE 5: Baseline SAW and Criterion-Weight Sensitivity Results.

Initiative	SAW utility	Baseline rank	P(Rank=1)	P (Top 3)	10th-percentile utility
I6	0.8714	1	78.97%	100.00%	0.8635
I3	0.8620	2	21.03%	100.00%	0.8540
I1	0.8608	3	0.00%	99.54%	0.8521
I2	0.8403	4	0.00%	0.46%	0.8370
I5	0.8225	5	0.00%	0.00%	0.8176
I4	0.8162	6	0.00%	0.00%	0.8145
I10	0.7878	7	0.00%	0.00%	0.7854
I9	0.7701	8	0.00%	0.00%	0.7660
I8	0.7658	9	0.00%	0.00%	0.7608
I7	0.6982	10	0.00%	0.00%	0.6901

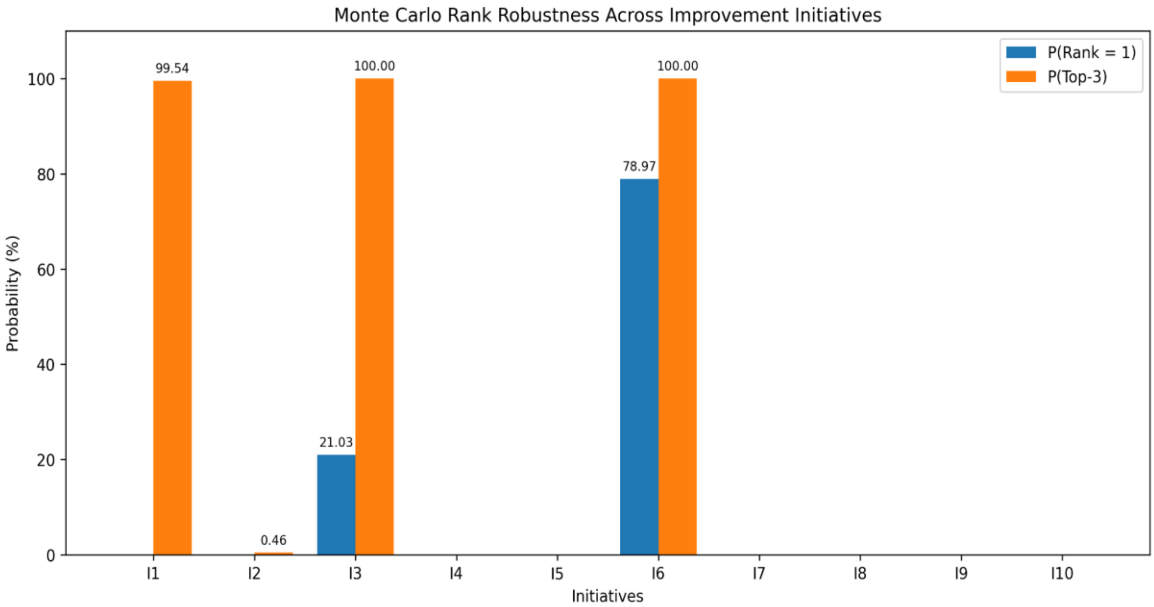

FIGURE 2: Rank-Acceptability Results Under ±20% Criterion-Weight Perturbation.

Resource-constrained portfolio results

Portfolio composition changes as the scenario resource envelope expands. Under S1, the optimal portfolio is I2, I4, and I7. Although I6 has the highest individual SAW utility, it is excluded because it requires I1 as a prerequisite, and the combined package is too resource-intensive under severe scarcity. Under S2, I1 becomes feasible and enables I3, producing I1, I3, I4, and I8. Under S3, all three highest-valued initiatives can be accommodated, while S4 expands the selected portfolio to eight initiatives. These results illustrate that high individual value and portfolio inclusion are distinct decisions.

TABLE 6: Optimized Portfolios Across What-If Resource Scenarios.

Scenario	Availability	Selected initiatives	MILP utility
S1	25%	I2, I4, I7	2.3547
S2	40%	I1, I3, I4, I8	3.3049
S3	60%	I1, I2, I3, I4, I6, I7	4.9489
S4	80%	I1, I2, I3, I4, I6, I7, I8, I10	6.5025

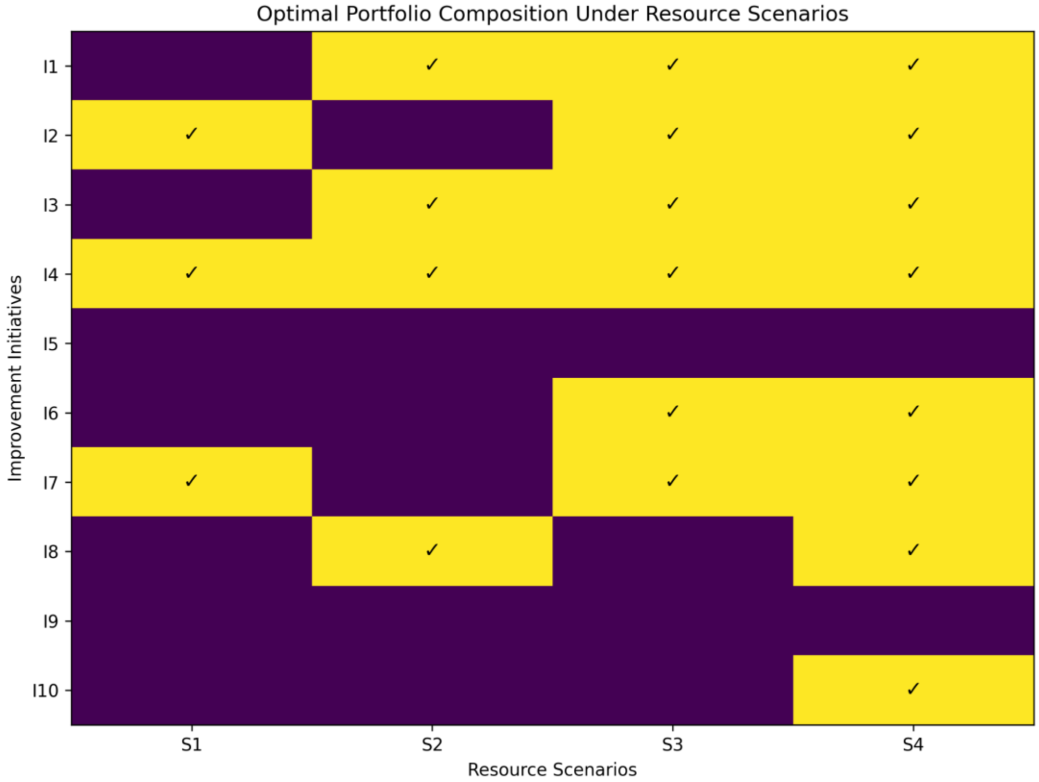

FIGURE 3: Portfolio Composition Across Normalized Resource Scenarios.

Ranking-based selection versus optimization

Sequentially following the SAW ranking produced lower aggregate utility than MILP optimization in all four investigated scenarios. The difference was largest under severe scarcity and decreased as the resource envelope expanded: 36.68% in S1, 27.39% in S2, 16.25% in S3, and 10.94% in S4. These percentages are specific to the investigated case, utilities, dependencies, and scenario assumptions, but they provide direct within-case evidence that a priority ranking should not automatically be interpreted as an implementation sequence.

TABLE 7: Rank-Based Versus Optimized Portfolio Utility.

Scenario	Rank-based utility	MILP utility	Utility gain
S1	1.7228	2.3547	36.68%
S2	2.5942	3.3049	27.39%
S3	4.2570	4.9489	16.25%
S4	5.8611	6.5025	10.94%

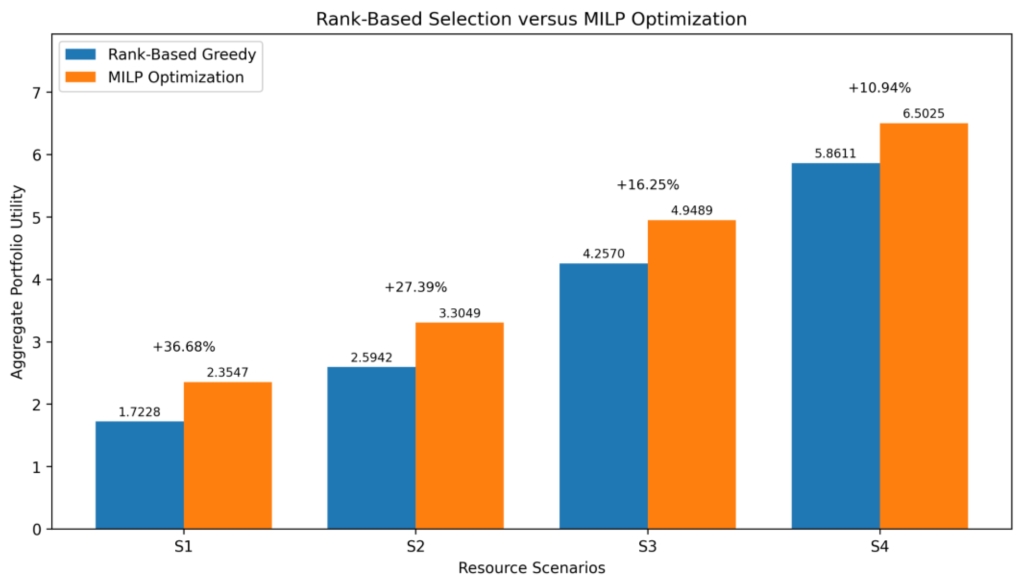

FIGURE 4: Aggregate Utility of Rank-Based and Optimized Portfolios.

Portfolio stability under criterion-weight uncertainty

Repeating the optimization with the 10th-percentile simulated utilities produced the same portfolio composition in S1–S4, with Jaccard similarity equal to 1.000 in every scenario. This result should be interpreted narrowly: within the ±20% criterion-weight perturbation examined; the selected portfolios were insensitive to the resulting utility changes. It does not establish robustness to uncertainty in resource requirements, dependencies, initiative performance scores, or realized implementation benefits.

DISCUSSION

The case results highlight four decision implications. First, multi-criteria ranking and implementation allocation answer different questions. SAW provides a comparable indication of initiative value, whereas MILP accounts for the opportunity cost created by scarce resources. Second, precedence relationships can change the attractiveness of a high-ranked initiative when its enabling requirement consumes substantial resources. Third, resource scarcity increases the value of explicit portfolio optimization because the penalty for inefficient allocation is greatest when the feasible envelope is tight. Fourth, sensitivity at the level of individual ranking does not necessarily translate into a different portfolio when the optimization problem is constrained by the same resource and dependency structure.

These findings are consistent with the portfolio perspective in which resource constraints and interdependencies can make lower-ranked alternatives part of a better overall combination [5], [6], [13]. The enabling role of inventory visibility in the case is also consistent with digital warehousing studies emphasizing integrated material information and inventory visibility in oil-and-gas and manufacturing settings [14], [15]. The analysis also complements process-prioritization studies by showing why a prioritized list should be treated as an input too, rather than a substitute for implementation planning. Importantly, the present evidence is bound by one organizational case and four normalized resource scenarios. The study therefore supports the internal decision logic of the case rather than a universal claim that the same portfolios or performance gains will occur elsewhere.

MANAGERIAL IMPLICATIONS

Managers should avoid treating priority ranking as a fixed implementation sequence. Initiative value, resource consumption, and prerequisite relationships should be evaluated separately before commitments are made. In the investigation case, the portfolio perspective made it possible to identify combinations that delivered greater aggregate utility than sequential rank-based selection under the same constraints. The normalized scenarios can also be used as a planning exercise to explore staged implementation as resource availability changes. Because the scenarios are not observed annual budgets, they are best interpreted as decision-support envelopes for comparative planning rather than direct budget recommendations.

LIMITATIONS AND FUTURE RESEARCH

The study is limited to one organizational context, ten candidate initiatives, five decision makers, expert-based initiative assessments, case-specific resource requirements, and normalized what-if resource scenarios. The Monte Carlo analysis varies criterion weights only, while initiative performance scores, resource requirements, dependency relationships, and benefit realization remain fixed. The study also does not include post-implementation validation of realized benefits. Future research should evaluate the decision architecture with observed organizational resource limits, larger or multiple organizational cases, expanded expert panels, uncertainty in resource and performance parameters, and post-implementation outcome data.

CONCLUSIONS

This study applied an integrated multi-criteria decision and optimization approach to business process improvement portfolio selection in a resource-constrained industrial case. Group AHP represented organizational preferences, SAW translated initiative performance into comparable utility values, Monte Carlo simulation examined sensitivity to criterion-weight changes, and MILP selected feasible initiative combinations under resource and dependency constraints.

Three conclusions emerge from the case. First, the highest-valued individual initiative is not necessarily included in the best feasible portfolio when resources are severely constrained. Second, under the four investigated scenarios, optimized portfolios produced 10.94–36.68% higher aggregate SAW utility than sequential rank-based selection. Third, the selected portfolios remained unchanged when the optimization was repeated using 10th-percentile utilities derived from the specified criterion-weight perturbation. These findings demonstrate the practical distinction between ranking and implementation allocation within the investigated case. They should not be interpreted as evidence of general applicability or robustness beyond the organizational setting, initiative set, resource assumptions, and uncertainty dimensions examined here.

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