Multicriteria Programming Approach to Development Project Design with an Output Goal and a Sustainability Goal*

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Abstract Especially intended for managers faced with development project design, this paper proposes a multicriteria decision making (MCDM) model with two objectives, output maximization and sustainability to be attained as much as possible. This proposal is motivated because: (a) aggressive managers seek to optimize the project output by using deterministic methods such as capital budgeting techniques and mathematical programming models; (b) conservative managers seek sustainability by using replicas of running development projects, which have proven reliable in practice; (c) few managers use stochastic models to ensure sustainability as these models require unavailable information on random variables and complex feedback. Then, this proposal is to articulate the aggressive output standpoint and the conservative replica standpoint into a two-objective programming model looking for a compromise solution between both goals. A numerical example on farm project design is developed in detail and discussed.

1 Introduction

Development projects are often designed as replicas of currently running projects which inspire confidence concerning sustainability. This is viewed as a practical way of sustainable design easier and less cumbersome than the design attempts based on stochastic models such as classical expected utility maximization (Von Neumann and Morgenstern 1947; Arrow 1965). Consequently, the proposition in this paper does not deal with risk and stochastic aspects at all. In contrast, the proposition establishes an objective of safety and sustainability, this objective being articulated into a multiobjective model by considering replicas of a reliable pattern.

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First, project managers have often difficulties in finding statistical data to measure risk by variance and covariance matrices (see Ballestero 2006). In other decision making scenarios such as for example portfolio choice, the analyst can use time series of prices and returns from daily observations on the markets, these data being precise and reliable. In contrast, time series are not generally available for development project design. Managers can analyze some real world cases (either historical or current in nature) related to their projects but nothing else. Available case studies on development projects hardly provide time series concerning all critical variables involved in each project. On the other hand, many project managers are not used to handling stochastic models in the framework of design.

This paper proposes an approach to development project design relying on multiobjective programming. Objectives in this model are as follows:

1. To maximize the project's output when potential impacts on sustainability are ignored, namely, when adverse consequences resulting from risk/uncertainty inherent in the development project are overlooked. This maximization objective is often considered by aggressive managers who use capital budgeting techniques and deterministic programming models in the certainty context.
2. To achieve sustainability/safety as much as possible by designing the project as a replica of a running development project which has proven reliable. This objective is often considered by conservative managers who devise a development project as a replica of another existing project, because the existing pattern is viewed as a high standard of sustainability/safety.

Indeed, sustainability of the project means that the investment can be maintained at a satisfactory operational level now and in the future up to a reasonable time horizon.

Potential users of the paper are development project managers and financial consultants especially interested in design.

Our proposal is relevant as development project design is relevant. Also, the replica-based statement is new. In fact, no similar approaches where replicas of development projects play a critical role combined with deterministic optimization are currently found in the decision making literature. Therefore, references to pave the way for reading the paper should be few. Concerning multiobjective programming in general, suitable references are Caballero et al. (1997) and Steuer (2001). Regarding sustainable clean development projects to be selected by multiple criteria approaches, see Lenzen et al. (2007). Concerning trust in construction projects, an empirical analysis is Khalfan et al. (2007).

2 Methodology

This chapter deals with development project design by multiobjective programming. Consider a development project P to be drawn up. Let $(q_1, q_2, \ldots, q_i, \ldots, q_n)$ be the vector describing the characteristics of this project. These characteristics are viewed as investments of particular resources in the project. Therefore, q_i is quantity of the ith resource to be invested. Let $(q_1^*, q_2^*, \ldots, q_i^*, \ldots, q_n^*)$ be the vector describing the characteristics of the running development project P^*, which is taken by the project manager as a pattern of sustainable design. Then, the decision variables are defined as follows:

$$x_i = q_i / q_i^*; i = 1, 2, \ldots, n \quad (1)$$

Decision variables (1) define a replica of pattern P^*.

For technical reasons, some characteristics can be excluded from the vector as they require values fixed a priori by the project manager.

2.1 First Objective: Output Maximization

In Chap. 1, Sect. 1, this objective is stated by maximizing a capital budgeting measure (for example, Net Present Value) as output achievement. This maximization is often formulated by linear programming (LP) or another mathematical programming model. This means that risk/uncertainty is not considered. In other words, all the data are then viewed as nonrandom variables although they were random in nature. An advantage of LP is simplicity; however, the random negative impacts on the project's safety/sustainability are disregarded. Accepting this limitation, the project manager states the following LP model:

$$\max \sum_{i=1}^{n} r_i q_i = \max \sum_{i=1}^{n} r_i q_i^* x_i \quad (2)$$

subject to

$$\sum_{i=1}^{n} a_{ij} q_i^* x_i \le c_j; j = 1, 2, \ldots, m \quad (3)$$

together with the non-negativity conditions. As the characteristics have the meaning of particular resources to be invested in the project, each $r_i q_i$ in (2) represents a capital budgeting measure such as Net Present Value. Sometimes, the project manager can estimate these measures in terms of relative importance by using indexes r_i of benefit. In economics and management science, benefits are defined as the positive contribution to an economic value from an entrepreneurial activity or project. In any case, the r_i benefit indexes should be expressed in appropriate units for aggregation.

Constraints (3) are referred to limited resources (physical, financial, environmental, etc.). Thus, they are classified in technical constraints and budget constraints. Each coefficient a_{ij} measures a cost per unit associated with the ith characteristic in the context of the jth constraint. Parameter c_j also means a cost in the jth context.

Solution to deterministic linear program (2) to (3) is denoted as: $x_a = (x_{1a}, x_{2a}, \ldots, x_{ia}, \ldots, x_{na})$.

2.2 Second Objective: Sustainability

In Chap. 1, Sect. 2, this objective involves designing development project P as an exact or scale replica of an existing reliable (sustainable) development project, namely, the P^* pattern. This pattern is regarded by the project manager as a real world model of sustainability. Therefore, the project manager's second goal is to produce a counterpart of development project P^* that resembles the pattern as closely as possible. Accordingly, the second objective is stated as follows: to achieve either an exact or scale replica $x_b = (x_{1b}, x_{2b}, \ldots, x_{ib}, \ldots, x_{nb})$ on a scale smaller, equal or larger than the P^* original, namely,

$$x_{1b} = x_{2b} = \ldots = x_{ib} = \ldots = x_{nb} = \chi \tag{4}$$

where χ is a positive parameter. In the special case $\chi = 1$, we would have an exact replica.

Once the pattern has been chosen, the constraint system (3) together with the scale replica condition (4) is solved leading to the x_b replica vector. Notice that this vector solution lies on the frontier given by the constraint system (3).

2.3 Compromise Solution

The next purpose is to obtain a 'satisficing' compromise solution to the two-objective problem formulated from the first and the second objectives. In other words, the project manager looks for a compromise between output maximization (unrelated to the pattern) and the replica design, so that both play their role in the development project design. This suggests the following:

Assumption 1. *Compromise solution. This is the frontier point where the line defined by the following vector:*

$$x_c = \alpha x_a + \beta x_b; \alpha, \beta \geq 0, \alpha + \beta = 1 \tag{5}$$

intercepts frontier (3).

Meaning. Equation (5) means a compromise between x_a and x_b, namely, between solutions to the first and the second objective, respectively. Weights α and β of the convex combination are decided by the project manager to reflect preferences for output maximization (unrelated to the pattern) and for the replica design, respectively.

From (3) to (4), we get:

$$\chi \leq c_j \Big/ \sum_{i=1}^{n} a_{ij} q_i^*; \; j = 1, 2, \ldots, m \tag{6}$$

To determine vector x_b by (4), we specify χ as the lowest right hand side value in the set of constraints (6). By introducing this χ value into (4), vector x_b is determined as a frontier point. On the other hand, the x_a vector is the standard solution to the LP problem (2) to (3). Now, vectors x_a and x_b just obtained are introduced into (5), together with weights α and β previously established from the manager's preferences. Thus, vector x_c is determined.

Finally, we should determine the frontier point $x_f = (x_{1f}, x_{2f}, \ldots, x_{if}, \ldots, x_{nf})$, where vector x_c intercepts frontier (3). This final solution is given by:

$$x_f = \lambda x_c \tag{7}$$

where parameter λ is obtained by:

$$\max \lambda \tag{8}$$

subject to

$$\lambda \sum_{i=1}^{n} a_{ij} q_i^* (\alpha x_{ia} + \beta x_{ib}) \leq c_j; \, j = 1, 2, \ldots, m; \lambda \geq 0. \tag{9}$$

2.4 Feedback

Weights α and β in (5) can be modified from their initial values, thus obtaining new solutions to be evaluated in terms of output achievement and resemblance to the pattern. Suppose α and β change to $\alpha' = (1 + \varepsilon)\alpha$ and $\beta' = (1 - \alpha - \varepsilon\alpha)$, respectively, other things being equal. This change in weights leads to a new vector x_c', the difference between both the old and the new vector being:

$$x_c{}' - x_c = \varepsilon\alpha \, (x_a - x_b)$$

Therefore, the difference between both vectors tends to zero either if ε tends to zero, or if $(x_a - x_b)$ tends to zero, other things being equal. Usually in sensitivity analysis, ε is small, and $\varepsilon\alpha$ is still smaller than ε since $\alpha < 1$. In Sect. 4, further research on this issue from empirical information is foreseen.

3 An Illustrative Example

A fictitious case of development project design in agriculture is here presented, with numerical values taken from unpublished discussion notes used by the author. This is to decide farm areas of meadows, dry farming and orchards. To make their decision, the project managers attempt to imitate to a certain extent an already running agricultural project which has proven reliable and sustainable. In other words, this pattern is technically, economically and environmentally considered as an example of sustainability. Pattern P^* has the following characteristics: $q_1^* = 255.57$ ha of meadows; $q_2^* = 125.35$ ha of dry farming; and $q_3^* = 273.83$ ha of orchards.

Objectives (as defined in Chap. 1) are as follows.

3.1 First Objective: Output Maximization (Unrelated to the Pattern)

This is the solution to deterministic LP (2) to (3). Benefit indexes $r_1 = 8.30$, $r_2 = 5.93$, and $r_3 = 9.49$ in objective function (2) are estimated by the project managers from a capital budgeting perspective. Each index is expressed in monetary units per hectare. Therefore, the following LP model is formulated.

$$\max(8.30 * 255.57 * x_1 + 5.93 * 125.35 * x_2 + 9.49 * 273.83 * x_3)$$

subject to [see (3)]

- Land constraint:
  $255.57 * x_1 + 125.35 * x_2 + 273.83 * x_3 \leq 772.80$ size units.
- Investment costs:
  $67.05 * 255.57 * x_1 + 53.18 * 125.35 * x_2 + 35.84 * 273.83 * x_3 \leq 41924.19$ monetary units.
- Environmental constraint:
  $273.83 * x_3 \leq 282.34$ size units.

Non-negativity conditions: $x_1 \geq 0$, $x_2 \geq 0$, $x_3 \geq 0$.

By solving this LP model, we obtain:

$$x_a = (1.856,\ 0,\ 1.031)$$

Hence, output maximization (first objective) yields the following solution.

- Meadows: 1.856*255.57 = 474.34 ha
- Dry farming: 0*125.35 = 0 ha
- Orchards: 1.031*273.83 = 282.32 ha

3.2 Second Objective: Sustainability (Related to the Pattern)

By applying (6) to the numerical data, we get:

$$\chi \leq 772.80/(255.57 + 125.35 + 273.83) = 772.80/654.75 = 1.18$$

$$\chi \leq 41924.19/(67.05 * 255.57 + 53.18 * 125.35 + 35.84 * 273.83)$$
$$= 41924.19/33616.15 = 1.25$$
$$\chi \leq 282.34/273.83 = 1.031$$

Therefore, $\chi = 1.031$. From chain (4), we have:

$$x_b = (1.031, 1.031, 1.031).$$

Hence, the second objective yields the following sizes:

- Meadows: $1.031 * 255.57 = 263.49$ ha
- Dry farming: $1.031 * 125.35 = 129.24$ ha
- Orchards: $1.031 * 273.83 = 282.32$ ha

3.3 Compromise Solution and Final Solution on the Frontier

They require the following tasks.

First step. Establish weights α and β according to the project manager's preferences for output maximization (first objective) and for replica (second objective). In our example, $\alpha = 0.45$ and $\beta = 0.55$, namely, the project manager slightly prefers the sustainability objective to the output maximization objective.

Second step. Compute the x_c compromise vector. From (5) with the numerical expressions of x_a and x_b obtained in Sects. 3.1 and 3.2, respectively, we get:

$$x_c = 0.45*(1.856, 0, 1.031)+0.55*(1.031, 1.031, 1.031) = (1.402, 0.567, 1.031)$$

Third step. Compute parameter λ by the auxiliary LP model (8) to (9), namely:

$\max \lambda$

subject to

$$\lambda * (255.57 * 1.402 + 125.35 * 0.567 + 273.83 * 1.031) = 711.70\lambda \leq 772.80$$
$$\lambda * (67.05 * 255.57 * 1.402 + 53.18 * 125.35 * 0.567 + 35.84 * 273.83 * 1.031)$$
$$\leq 41924.19$$
$$\lambda * 273.83 * 1.031 \leq 282.34$$

together with the non-negativity condition $\lambda \geq 0$. By solving this auxiliary model, we get $\lambda = 1.000086 \approx 1$.

Fourth step. Determine the final solution x_f from (7) on the frontier, namely:

$$x_f = (1 * 1.402, 1 * 0.567, 1 * 1.031) = (1.402, 0.567, 1.031)$$

Therefore, development project P is sized as follows:

- Meadows: $1.402 * 255.57 = 358.31$ ha
- Dry farming: 0.567*125.35 = 71.07 ha
- Orchards: 1.031*273.83 = 282.32 ha

3.4 Comparison of Results

Let us compare the sizes given by the final x_f solution to the sizes given by the x_a and x_b solutions.

- Meadows: 24.45% smaller than the respective x_a result. Moreover, 26.47% larger than the respective x_b result.
- Dry farming: This increases from zero (in vector x_a) to 0.567 (in vector x_f). Moreover, 45% smaller than the respective x_b result.
- Orchards: here, all three solutions coincide. This is because: (a) the sizes given by the x_a and x_b solutions are both equal to 231.99; then, the compromise value between LP and the replica is also 231.99; and (b) the compromise point is brought to the frontier by the factor $\lambda = 1.000086 \approx 1$, so that the compromise value does not increase.

In short, we have:

(a) With the x_f solution, the extremely unbalanced results given by LP are avoided. This occurs with dry farming. While the LP solution was no dry farming, this abrupt result is substantially mitigated in the x_f solution. Also, meadows is reduced by around 25% over the LP result, thus correcting the too large size resulting from LP.
(b) However, the x_f solution allows the project manager to propose an original design to a certain extent. Indeed, project P has turned out to be far from being an exact replica of the pattern.

4 Concluding Remarks

A major result has been to articulate aggressiveness and conservatism in development project design. Aggressiveness involves maximizing the project's output, while conservatism involves replica projects from the axiom: "if the pattern has proven sustainable, then its replica will be probably sustainable". Solutions obtained from the two-objective programming model depend on the α/β preference ratio. Preference weights α and β have a clear meaning to the manager and they are straightforwardly elicited as occurs in decision making approaches whenever the number of weights does not exceed two. Moreover, the initial solution can be evaluated and modified by feedback –an appealing procedure to managers. By moving parameters α and β in (5), the project manager can analyze tradeoffs between output achievement and resemblance to the pattern. This allows the project manager to adjust the solution to convenient output levels or resemblance. In any case, the final solution (vector x_f) lies on the frontier of constraints (3). Certainly, the two-objective programming model developed above is not the only possible way of addressing the aggressiveness versus conservatism dilemma in development project design. A goal programming model with similar scope and purpose can be also proposed. In short, the paper has shown how development project design can be deterministically addressed (without difficult stochastic treatment) in terms of output optimization and sustainability by the replica-based approach.

Further research can be conducted on the following issues:

(a) To develop real world case studies, where managers really proposes different (α, β) weights leading to different results, which are discussed through sensitivity analysis.
(b) To introduce utility functions related to compromise programming (CP). For this purpose, a theorem connecting bi-attribute utility and CP could be applied in the above two-criterion framework (Ballestero and Romero 1998, Chap. 6).
(c) To extend the proposition in such a way, that instead of existing object, a fictitious reference object created on the basis of some existing (or fictitious) objects could be taken into consideration. This extension is suggested to the author by an anonymous referee.

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