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Integrating Sustainability into Construction Project Portfolio Management

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Abstract

Construction project portfolio management has a large impact on many companies as they are often confronted with having more projects to select from than the resources available to execute them. Selecting the wrong projects will lead to wasted resources and loss of benefits which may have been gained by focussing on other projects. While there have been many discussions surrounding portfolio theory, there is currently a lack of framework which integrates sustainability into construction project portfolio management. This paper departs from existing frameworks (which focus more on monetary gains in projects) by proposing robust methods to account for sustainability across two critical stages: I. Screening; II. Optimal portfolio selection. Under the screening stage, sustainability project criteria are proposed followed by the use of second order moment thinking to account for uncertainty in sustainability measurements. The outputs from the screening stage are then used for developing an efficient frontier which facilitates the selection of an optimal portfolio from a sustainability perspective. The originality of this paper is that it aims to integrate sustainability thinking into construction project portfolio management which has not been attempted.

Keywords: *construction project portfolio management, sustainability, screening, optimal, efficient frontier*

1. Introduction

According to Archer and Ghasemzadeh (2000), project portfolio management is defined as the process of selecting projects which do not violate constraints or exceed resources. While there are studies that have demonstrated the positive influence of project portfolio management on business results (see Meskendahl, 2010; Reyck *et al.*, 2005), in reality, implementing such a framework can be very challenging. Le and Nguyen (2007) outline three reasons for this. Firstly, projects may have conflicting objectives, some tangible others intangible hence making comparability and selection difficult. Secondly, uncertainties exist in the criteria used to gauge project suitability. Thirdly, interdependency may exist between a set of projects to the others which is difficult to quantify. A review of the literature reveals that much of the discussion in this area has taken a narrow focus on company's financial objectives (Meskendahl, 2010), resource constraints (Gutjahr *et al.*, 2008; Gutjahr *et al.*, 2010; Stummer *et al.*, 2009) and refinement of portfolio analysis methods (see Doerner *et al.*, 2006; Carlsson *et al.*, 2007; Hu *et al.*, 2008; Carazo *et al.*, 2010) with little or no consideration for sustainability issues. There are myriad of definitions available for sustainability or sustainable development. Sustainable development is defined by the Brundtland Report (1987) as 'meeting the needs of the present generation without compromising the ability of future generations to meet their own needs'. In the context of the construction industry, the term sustainable construction is commonly used. Kibert (2005) defines sustainable construction as the responsible development and management of a healthy built environment, based on the efficient use of resources and on ecological principles.

Accounting for sustainability is important especially for construction based projects due to its high impact - energy consumed in constructing, occupying and operating buildings/infrastructure is exorbitant and is known to contribute to more than half of UK's carbon emissions while waste is estimated to contribute to more than 90 Mega tonnes annually from this sector (Constructing Excellence, 2007). According to the Australian Bureau of Statistics (2003), construction projects have a significant impact on the environment in terms of the massive use of land, materials and energy. Against this background, it is necessary for construction companies to adopt a strategy for managing the sustainability impacts from the projects adopted. If the portfolio of projects selected have significant environmental, social and economic implications, there is a possibility that a construction company may face future litigation and reputational risk.

Yet, existing literature relating to construction portfolio management all neglect the need to focus on sustainability issues. For example, Hernández *et al.* (2011) introduce a new metric known as the 'Project Value to Portfolio Value (PV2PV)' to assess added value (from a financial perspective) of a new construction project to the value of the company's actual portfolio of construction projects. Kangari and Riggs (1988) compare and document differ-

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ences between portfolio management of construction projects and portfolio management of securities. Tong *et al.* (2001) recommend the use of genetic algorithm optimisation in the building and construction portfolio management. They argue that the models proposed can be used to forecast long term asset management strategies and help minimise total maintenance and replacement costs. Guo and Yu (2013) highlight the current situation of the Chinese construction industry and argue for the adoption of project portfolio management. Few have considered how sustainability can be measured in construction project portfolio management.

To address sustainability issues, it is vital that equal consideration is given to it as much as the current emphasis is on the traditional focus of cost, time and money. This paper aims to fill the gap in research by proposing robust methods to account for sustainability in construction project portfolio management. The second order moment method is proposed for measuring the sustainability score. This departs from the mostly deterministic manner of measuring sustainability based on a checklist (see Siew, 2014a; Siew *et al.*, 2013; Siew, 2014c) and instead allows for the accounting of uncertainty which is inherent in measuring sustainability performance.

2. Background-Framework

This paper builds upon Archer and Ghasemzadeh's (1999) integrated framework for project portfolio management. Fig. 1 presents an adaptation of the original framework which captures different stages such as pre-screening, individual project analysis, screening, optimal portfolio selection, portfolio adjustment, project development and phase/gate evaluation.

The first stage is pre-screening which involves a qualitative selection of potential project proposals that are preferably in line with the overall vision of the company. If the project management team sees potential in any of the projects, more in depth analysis of individual projects are conducted at the second stage. Various methods have been suggested for individual project analysis such as the calculation of present worth, project risk, return on investment, risk analysis and market research. The main outcome from individual project analysis is an agreement of a common set of criteria. The third stage is screening where the agreed criteria (from the second stage) is applied across all projects to filter out only the best projects. Archer and Ghasemzadeh (1999) caution that at this stage the threshold set should not be too arbitrary to prevent the elimination of promising projects.

At the optimal portfolio selection stage, Archer and Ghasemzadeh (1999) suggest the use of a two-step process. The first step involves quantifying the relative total benefit for each project using either Q-Sort or pairwise comparison tools such as the Analytic Hierarchy Process (AHP). The second step should account for all project interdependencies, resource limitations and other constraints in deriving an optimised portfolio.

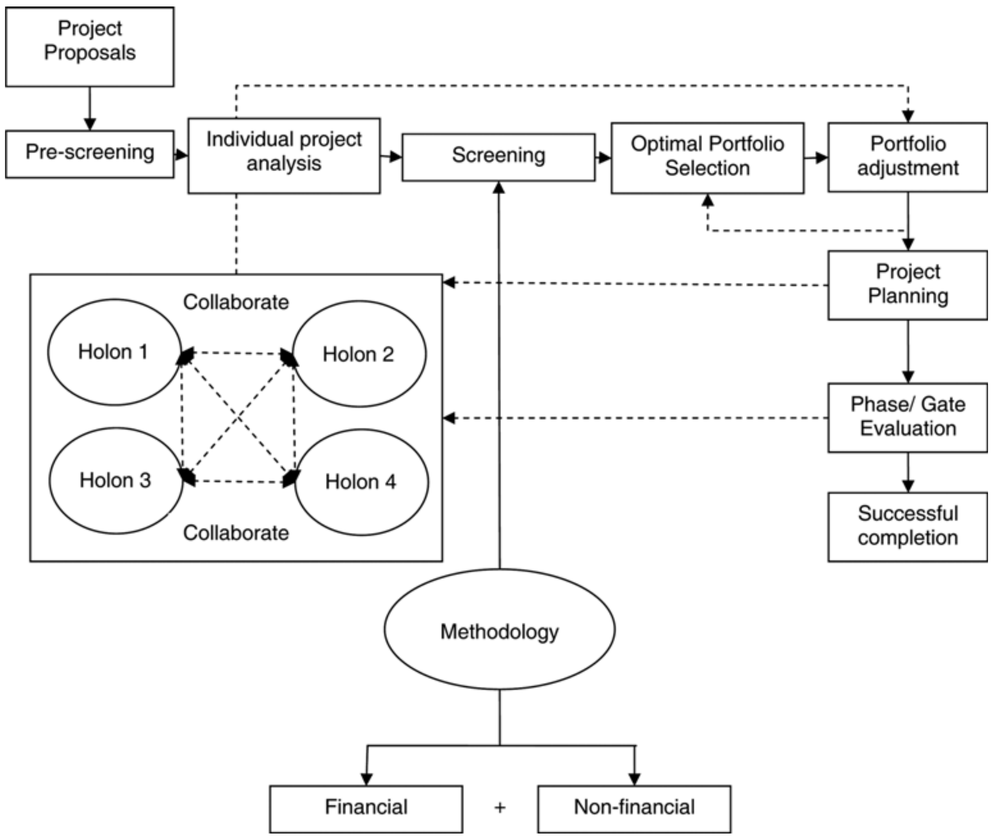

Fig. 1. Framework for Project Portfolio Management Accounting for Sustainability (adapted from Archer and Ghasemzadeh, 1999)

Next is project planning which involves the participation of multiple-agents (i.e., contractors, subcontractors etc). Each project can be viewed as a system. The most important attribute of the systems concept is to view things as a whole instead of separate and independent components. Systems can exist in many forms be it biological or sociological, technical or non-technical, simple or complex. Each system has smaller components (which could be treated as systems themselves) that are interdependent and can be integrated into a larger whole. The components of a system are referred to as 'holons' (Karapetrovic and Willborn, 1999). Every holon is part of a bigger system known as a holarchy. Holons by themselves are considered to be autonomous. That is to say that they have the capability of creating and controlling their own plans and strategies (Karapetrovic and Willborn, 1999). Together, holons can work towards achieving a common goal or objective. Applying this concept in project management, contractors or subcontractors can also be viewed as interacting holons working towards a common objective. Depending on available resources and due to the dynamic nature of projects, there should be some flexibility to adjust the weights placed on each portfolio.

For the purpose of this paper, attention is shifted to two critical stages namely: screening and optimal portfolio selection. These two critical stages correspond to the framework proposed by Archer and Ghasemzadeh (1999) as shown in Fig. 1. Ways to incorporate sustainability thinking in these stages are each discussed in turn.

3. Critical Stages

This section discusses the relevant concepts and proposals relating to the two critical stages:

i) **Screening** – deals with the pre-assessment of sustainability for projects. A list of project criteria is proposed followed by the use of second order moment to measure sustainability

ii) **Optimal Portfolio Selection** – The means and variances derived from the screening stage is used to find the efficient portfolio frontier

3.1 Screening

Mainstream Sustainability Reporting Tools (SRTs) for buildings/ infrastructure such as BREEAM, LEED and Green Star among others are predominantly focussed on environmental criteria (Siew *et al.*, 2013) with little consideration for social and economic criteria. Environmental criteria that are consistently proposed in these mainstream SRTs include water usage, energy consumption, Greenhouse Gas (GHG) emission and waste management among others. Fernandez-Sanchez and Rodrýguez-Lopez (2010) recommend a list of criteria for infrastructure projects in Spain. Some of the important criteria in their list to measure sustainability include health and safety, economical cost/economical benefit, control on the project, project governance and strategic management.

Given the scarcity of research addressing social and economic criteria in construction projects, a list of criteria across three sustainability domains (economic, environmental and social) is

Table 1. Economic Criteria

Primary Criteria	Secondary Criteria	Tertiary Criteria
Economic	Profit	Project revenue
		Operating cash flow
	Expenditure risk or debt	Depreciation or maintenance cost
		Cost surplus
		Disaster risk (Replacement Cost/ Revenue)
	Aid from government/ organisation	Significant financial assistance received from government (proportion of project cost funded)

Table 2. Environmental Criteria

Primary Criteria	Secondary Criteria	Tertiary Criteria
Environmental	Energy consumption	Estimated direct energy consumption per project
		Estimated indirect energy consumption per project
	Waste production	Estimated total waste produced per project
	Water consumption	Estimated total water consumption per project
	Water savings	Estimated total amount of water reuse per project
		Estimated amount of water saved per project
	GHG emissions	Estimated total direct greenhouse gas emissions per project
		Estimated total indirect greenhouse gas emissions per project
	Emission of ozone depleting substances/ other emissions	Estimated emissions of ozone-depleting substances by weight per project
		NO, SO and other significant air emissions by weight per project
	Environmental incidents	Estimated total environmental incidents based on scale of project
	Environmental design criteria	Quality of design
	Land productivity	Estimated land area affected by human activity
	Usage of recycled materials/products	Estimated life cycle cost
		Weight of recycled materials used
	Compliance	Monetary value of significant fines

Table 3. Social Criteria

Primary Criteria	Secondary Criteria	Tertiary Criteria
Social	Leadership/ Knowledge management	Ratio of accredited professionals
		Proportion of sustainability related clauses in project contracts
	Supply chain	Number of significant suppliers, contractors and other business partners that have undergone human rights screening
	Health and Safety	Estimated total injuries
		Estimated total fatalities
	Training	Total training hours for project members in sustainability

proposed to aid in the assessment of sustainability (see Tables 1 to 3). Relevant criteria that were proposed by other frameworks (Siew *et al.*, 2013) are also incorporated in this list. This list has been validated with a working group of 20 construction project managers with at least 5 years of experience. The criteria proposed here are deemed to be appropriate to assess the sustainability of construction projects.

In the screening process, it is important that project owners have an estimate or target for each of the respective criterion. This can be derived through either use of a project database (differentiated by scale and geographical location) or consultation with the project management team.

Each of the criteria can be measured on any scale as deemed fit (i.e. 1 to 10 point interval scale where 1 represents worst performance to 10 representing best performance). Any other interval scale may be used by the project management team. As pre-assessment deals with the potential of attaining sustainability, uncertainty must be acknowledged. One way of acknowledging this is through the use of second order moment thinking described in section 3.1.1.

3.1.1 Second Order Moment

This paper suggests that one suitable way to obtain expected values and variances for each criterion, denoted X, is to ask scorers to first estimate optimistic (a), most likely (b) and pessimistic (c) values in line with PERT thinking leading to an expected value or mean, $E[X] = (a + 4b + c)/6$, and a variance, $\mathrm{Var}[X] = [(c - a)/6]^2$ (Carmichael, 2006; Carmichael and Balatbat, 2008; Siew, 2014a; Siew, 2014b).

Essentially, this characterises each criterion by a measure of central tendency and a measure of dispersion. Criteria can now be combined to give an overall sustainability score characterised similarly. The mean or expected value is adopted as the measure of central tendency, and variance (standard deviation squared) as the measure of dispersion.

Consider a criterion X_i, $i = 1, 2, \ldots, n$, composed of subcriteria $[Y_{ik}]$, $k = 1, 2, \ldots, m$, with mean $E[Y_{ik}]$ and variance $\mathrm{Var}[Y_{ik}]$, obtained through first estimating optimistic, most likely and pessimistic values, as outlined above. Then,

$$X_i = v_{il}Y_{il} + v_{i2}Y_{i2} + \cdots + v_{im}Y_{im} \tag{1}$$

where v_{ik}, $i = 0, 1, 2, \ldots, n$; $k = 1, 2, \ldots, m$, are the subcriteria weightings obtained, for example, through Analytic Hierarchy Process (AHP) (see Saaty, 1980).

The expected value and variance of X_i become,

$$E[X_i] = \sum_{k=1}^{m} v_{ik}E[Y_{ik}] \tag{2}$$

$$\mathrm{Var}[X_i] = \sum_{k=1}^{m} v_{ik}^2\mathrm{Var}[Y_{ik}] + 2\sum_{k=1}^{m-1}\sum_{l=k+1}^{m} v_{ik}v_{il}\mathrm{Cov}[Y_{ik}, Y_{il}] \tag{3}$$

Equation (3) allows for possible correlation between the subcriteria, acknowledged through covariances $\mathrm{Cov}[Y_{ik}, Y_{il}]$. The variance expression can be written alternatively in terms of the subcriteria correlation coefficients, ρ_{kl}, between Y_{ik} and Y_{il}, $k, l = 1, 2, \ldots, m$,

$$\mathrm{Var}[X_i] = \sum_{k=1}^{m} v_{ik}^2\mathrm{Var}[Y_{ik}] + 2\sum_{k=1}^{m-1}\sum_{l=k+1}^{m} v_{ik}v_{il}\rho_{kl}\sqrt{\mathrm{Var}[Y_{ik}]}\sqrt{\mathrm{Var}[Y_{il}]} \tag{4}$$

The total sustainability score, denoted SS here, is the average weighted sum of the criteria X_i, $i = 0, 1, 2, \ldots, n$,

$$SS = \sum_{i=1}^{n} w_iX_i \tag{5}$$

where w_i, $i = 0, 1, 2, \ldots, n$ are the criteria weightings obtained, for example, through AHP. The expected value and variance of SS become,

$$E[SS] = \sum_{i=0}^{n} w_iE[X_i] \tag{6}$$

$$\mathrm{Var}[SS] = \sum_{i=0}^{n} w_i^2\mathrm{Var}[X_i]\frac{\mathrm{Var}[X_i]}{(1+r)^{2i}} + 2\sum_{i=0}^{n-1}\sum_{j=i+1}^{n} w_iw_j\mathrm{Cov}[X_i, X_j] \tag{7}$$

Equation (7) allows for possible correlation between the criteria, acknowledged through covariances $\mathrm{Cov}[X_i, X_j]$. The variance expression can be alternatively written in terms of the criteria correlation coefficients between X_i and X_j, namely ρ_{ij},

$$\mathrm{Var}[SS] = \sum_{i=0}^{n} w_i^2\mathrm{Var}[X_i] + 2\sum_{i=0}^{n-1}\sum_{j=i+1}^{n} w_iw_j\rho_{ij}\sqrt{\mathrm{Var}[X_i]}\sqrt{\mathrm{Var}[X_j]} \tag{8}$$

For independent criteria X_i,

$$\mathrm{Var}[SS] = \sum_{i=0}^{n} w_i^2 \mathrm{Var}[X_i] \quad (9)$$

For perfect correlation of the criteria X_i,

$$\mathrm{Var}[SS] = \left(\sum_{i=0}^{n} w_i \sqrt{\mathrm{Var}[X_i]} \right)^2 \quad (10)$$

Var[*SS*] is smaller for the assumption of independence compared with the assumption of correlation.

Where the variance terms are zero, the expressions reduce to a conventional deterministic treatment. It is suggested that a project's sustainability score be expressed as the pair {*E*[*SS*], Var[*SS*]}, that is in terms of a measure of central tendency and a measure of dispersion. Standard deviation could be used alternatively to variance. Where necessary, especially if SS values are large, they can also be taken as the average total score (*SS′*) given as:

$$SS' = \frac{\sum_{i=1}^{n} w_i X_i}{n} \quad (11)$$

3.2 Optimal Portfolio Selection

The outputs from the screening stage (means and variances) are then used for developing an efficient frontier which facilitates the selection of an optimal portfolio from a sustainability perspective. Traditionally, the concept of the portfolio efficient frontier refers to a set of feasible portfolio return and risk level that offers the lowest risk for any given return or the highest return at any level of risk. Portfolios that lie on this line are known as efficient or optimal portfolios. These portfolios are optimised by varying the weights of individual assets within the portfolio universe; see Eqs. (11) and (12). A range of literature spanning three decades have covered extensively the concept of optimal portfolios (Merton, 1972; Markowitz, 1952; Fama and French, 2005; Vörös, 1986) and will not be covered in this paper. Readers are also referred to the work by Roychoudhury (2007) which provides a detailed explanation and derivation of an optimal portfolio. For the purpose of this paper, it is sufficient to understand that the mean and standard deviations obtained from stage 1 (screening) can be extended to the development of an optimal portfolio. Portfolios below the efficient frontier are considered to be 'suboptimal' or 'inefficient'.

The portfolio can be constructed by using Eqs. (11) and (12)

$$R_p = \sum_{i=1}^{n} w_i r_i \quad (11)$$

$$\sigma_p^2 = \sum_{i=1}^{n} w_i^2 \sigma_i^2 + \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} w_i w_j \rho_{ij} \sigma_i \sigma_j \quad (12)$$

where R_p is the return of the portfolio, σ_p^2 is the portfolio variance, σ_i is the standard deviation on asset *i*, w_i is the weight of each asset, r_i is the return of an asset, ρ_{ij} refers to the coefficient of correlation between assets *i* and *j*. *n* simply refers to the number of assets in a portfolio (Markowitz, 1952; Muller, 1988 for more detailed mathematical modelling).

Meanwhile, the efficient frontier curve can be constructed by using Eqs. (13) and (14). x^* is considered efficient when there exists no portfolio *x* with (Muller, 1988):

$$E[E(x)] \geq E[R(x^*)] \quad (13)$$

$$\mathrm{Var}[R(x)] \leq \mathrm{Var}[R(x^*)] \quad (14)$$

where *E*[*R*(*x*)] is the expected return of portfolio *x* and Var[*R*(*x*)] is the variance of portfolio *x*.

For the purpose of this analysis, expected return is substituted with expected sustainability score *E*[*SS*] of projects while variance of return with the dispersion of sustainability score Var [*SS*].

4. Construction Projects

The framework proposed in this paper is tested on three actual construction projects. Details of these projects are highlighted as follows:

- Project A-Large road construction
  This project involved a major road infrastructure with a total value of approximately $150M. The project involved extensive earthworks, drainage, pavements, roads, furniture and management of traffic.
- Project B-Construction of a single two-way grade bypass road
  The project involved the construction of a 7 km single two way grade separated bypass road.
- Project C-Bridge construction
  A contractor was engaged to undertake the formation and

Table 4. Sustainability Scores for Project A

Secondary Criteria	Optimistic	Most likely	Pessimistic
Profit	5	3	1
Expenditure	5	3	1
Aid from government	5	4	1
Energy consumption	5	3	1
Waste production	5	3	1
Water consumption	5	3	1
Water savings	5	3	1
GHG emissions	7	4	1
Emission of ozone depleting substances/ other emissions	3	2	1
Environmental incidents	5	4	1
Environmental design criteria	6	4	1
Land productivity	6	4	1
Usage of recycled materials/products	6	4	1
Compliance	6	4	2
Leadership	6	4	3
Supply chain	6	3	1
Health and safety	5	3	2
Training	5	3	2
Total sustainability score	96	53	23
Adjusted sustainability score (*SS′*)	5.33	2.94	1.28

Table 5. Average Sustainability Scores for 3 Projects

Project	$E[SS']$	Std$[SS']$
A	8.59	0.67
B	8.6	0.67
C	9.5	0.67

bridge construction for a 30 km new rail freight line.

5. Application of Framework

5.1 Screening

Project A is used as an example to illustrate the proposed framework. A 10-point scale is used where 1 represents worst performance and 10 represents best performance. For ease of calculation, the secondary criteria is adopted (see Tables 1 to 3). Optimistic, most likely and pessimistic values are estimated by the construction manager for each criterion. Then, the average SS is calculated. Tertiary criteria can be used to ensure a more robust sustainability assessment.

Optimistic = 5.33, most likely = 2.94, pessimistic = 1.28. Let SS = average sustainability score. Then,

$$E[SS'] = (5.33 = 4 \times 2.94 + 1.28)/4 = 8.59 \quad (15)$$

$$\text{Var}[SS'] = [(5.33 - 1.28)/6]^2 = 0.45 \text{ (or standard deviation} = 0.67)$$

Scenarios	Portfolio weight			Portfolio	
	Project A	Project B	Project C	Stdev$[SS']$	$E[SS']$
1	0	0	1	0.67	9.5
2	0	0.2	0.8	0.5525	9.32
3	0	0.4	0.6	0.48314	9.14
4	0	0.6	0.4	0.48314	8.96
5	0	0.8	0.2	0.5525	8.78
6	0	1	0	0.67	8.6
7	0	0	1	0.67	9.5
8	0.2	0	0.8	0.5525	9.318
9	0.4	0	0.6	0.48314	9.136
10	0.6	0	0.4	0.48314	8.954
11	0.8	0	0.2	0.5525	8.772
12	1	0	0	0.67	8.59
13	0	1	0	0.67	8.6
14	0.2	0.8	0	0.5525	8.598
15	0.4	0.6	0	0.48314	8.596
16	0.6	0.4	0	0.48314	8.594
17	0.8	0.2	0	0.5525	8.592
18	1	0	0	0.67	8.59
19	0.2	0.2	0.6	0.44443	9.138
20	0.2	0.4	0.4	0.402	8.958
21	0.2	0.6	0.2	0.44443	8.778
22	0.4	0.2	0.4	0.402	8.956
23	0.4	0.4	0.2	0.402	8.776
24	0.6	0.2	0.2	0.44443	8.774

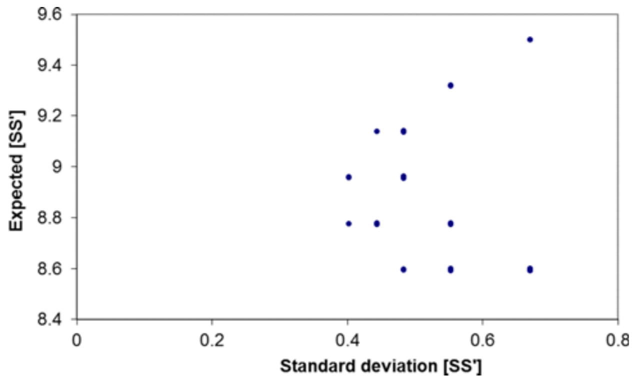

Fig. 2. $E[SS']$ – VAR$[SS']$ Efficient Frontier Curve

5.2 Optimal Portfolio Selection

In a similar fashion, $E[SS']$ and Var$[SS']$ are also derived for Projects B, C, D and E as shown in Table 5. Assume that criteria are not correlated to each other.

By varying the weights on Projects A, B and C through an iterative process, $E[SS']$ and Std$[SS']$ are determined by applying Eqs. (6) and (7). The $E[SS']$ and Std$[SS']$ for each of these scenarios are then plotted as shown in Fig. 2 (horizontal axis represents Std$[SS']$ while vertical axis represents $E[SS']$). The efficient frontier curve is determined as the outer most curve. Portfolios that fall on this outer most curve (highlighted scenarios) is known as optimal portfolios.

The optimal project portfolio lies on the efficient frontier curve. There is no other combination of project portfolios (apart from that on the efficient frontier curve) that would give better sustainability performance without increasing the variance.

6. Conclusions

Ignoring sustainability in construction projects could potentially lead to reputational or litigation risk as explained in earlier sections. Therefore, it is crucial for construction project managers to be able to measure the sustainability of their project portfolio. This paper makes an original contribution by proposing a way to measure sustainability across project portfolio. This has not been attempted based on the review of existing literature. As a summary, the main steps of the proposed methodology are:

6.1 Screening

- Determine optimistic, most likely and pessimistic estimates for each criterion listed in Tables 1 to 3.
- Compute expected means and variances using second order moment

6.2 Optimal Portfolio Selection

- Use outputs from screening stage to develop efficient frontier curve
- Portfolio may be adjusted taking into account resource constraints

There are a few limitations with this proposed study. Firstly, only 20 construction practitioners were asked to validate the proposed list of sustainability criteria. Future studies could look into expanding on this sample size. Secondly, in order to select the most viable portfolio option, adjustments would need to be made taking into account existing projects, interactions among them or even 'direct resource competition' (Archer and Ghasemzadeh, 1999). According to Archer and Ghasemzadeh (1999, p. 210), in reality, projects compete for limited resources. Therefore scheduling would need to be done and accounted for to ensure that use of resources is optimised. This implies that even though based on the efficient frontier curve, suggestions of 'the most sustainable' combination of portfolios is available, these may not necessarily be the options selected by the project management team due to resource constraints.

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